

Report of the Meeting of the WOAHA Biological Standards Commission

Original: English (EN)

4 to 8 September 2023

Paris

Introduction and Member contribution

A meeting of the WOAHA Biological Standards Commission (hereafter called 'the Commission') was held from 4 to 8 September 2023 at the WOAHA Headquarters in Paris, France. During the meeting, 15 chapters from the WOAHA *Manual of Diagnostic Tests and Vaccines for Terrestrial Animals (Terrestrial Manual)* were approved for circulation for first-round Member comment, six Reference Centre applications and eight nominations for replacement experts were also evaluated.

Annexes

Texts in [Annexes 4 to 18](#) are presented for first-round comment.

How to submit comments

Members are reminded that they should submit the rationale for all their proposed changes to the texts, and include references where relevant for the Commission to consult. Your participation in the WOAHA Standard-setting process is valued. Thank you for your engagement in the process!

The guidance should be followed when submitting comments:

1. Comments may be general or specific, but specific comments are more valuable. General comments should be such that some conclusion and action can be taken in response to them. For example, instead of stating "This test is no longer used in our laboratory", indicate the reasons the test is no longer used and what test is used instead.
2. Specific comments should be identified by indicating the line number in the text, to facilitate the editorial process.
3. Highlighting typing or technical errors is welcome, but the correct word or figure should be indicated in its place. For example, instead of indicating simply "0.8 M is too high", the preferred value should also be indicated.
4. Bear in mind that the introductory chapters (Part 1 of the *Terrestrial Manual*) set general standards for the management of veterinary diagnostic laboratories and vaccine facilities and are not intended to be exhaustive, and indeed none of the chapters can give a completely comprehensive cover of the subject, otherwise the *Terrestrial Manual* would be too long. However, assistance in indicating priorities is always helpful.
5. The *Terrestrial Manual* is intended for world-wide use. The chapters need to reflect the development of new technology, while maintaining the established methods, usually requiring less sophisticated apparatus. New technology should not be described in detail until it has gained wide acceptance as a reliable method.
6. We recommend that if you have no specific comments, please respond to the WOAHA to that effect.
7. Any comments, proposed changes or revisions should be supported by clear evidence (the scientific rationale) such that some conclusion and action can be taken in response to them.

Deadline to comment

Comments on relevant texts in this report must reach the Headquarters by [7 December 2023](#) to be considered at the February 2023 meeting of the Commission.

Where to send comments

All comments should be sent to the Science Department at: BSC.Secretariat@woah.org

Date of the next meeting

The Commission noted the dates for its next meeting: [5 to 9 February 2024](#)



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1. Welcome from the directors

1.1. Director General

Dr Monique Eloit, the WOAHA Director General, met the Biological Standards Commission on 5 September and thanked its members for their support and commitment to achieving WOAHA objectives.

Dr Eloit remarked on the positive outcomes of the 90th General Session, highlighting the favourable response to the change in the Session's format, which included an Animal Health Forum on Avian Influenza. Dr Eloit emphasised that the forum facilitated interactive discussions and encouraged exchanges from both a policy and technical perspective.

Dr Eloit informed the Commission that WOAHA is currently undergoing a consultancy to evaluate the Organisation's *Basic Texts* from both a technical and legal viewpoint. The importance of this consultancy is to introduce a more robust and transparent approach to the organisation's procedures, supported by a solid legal basis. Dr Eloit pointed out the need to determine which fundamental documents or SOPs¹ necessitate revision and subsequent endorsement by the Assembly. The revision of the *Basic Texts* is essential to maintaining WOAHA's credibility among stakeholders, and Members. This assessment will be completed in time for the celebrations of WOAHA's 100th anniversary in May 2024.

Finally, Dr Eloit reminded the Commission that the deadline for submission of nominations for election to WOAHA Specialist Commissions was 8 September 2023, and that the elections will take place during the General Session in May 2024.

The Commission thanked Dr Eloit for these updates.

1.2. Deputy Director General, International Standards and Science

Dr Montserrat Arroyo, WOAHA Deputy Director General, International Standards and Science, welcomed members of the Biological Standards Commission and thanked them for their ongoing contributions to the work of WOAHA.

Dr Arroyo informed the Commission that the Organisation is currently dedicating efforts to various IT projects with the aim of creating tools that will facilitate access to WOAHA services and practices as detailed in the organisation's *Basic Texts*. Among these tools are the evolution of the system for collecting annual reports from Reference Centres, a digitised system for navigating the Code and Manuals, an improved system for self-declaration of disease status, and a repository of PVS reports, all with the goal of improving and simplifying access to these tools, ensuring transparency, and enhancing the traceability of WOAHA's work, while also interconnecting all the tools.

Dr Arroyo also expressed her satisfaction with the past General Session and highlighted that the Organisation will celebrate its 100th anniversary in the coming year. She congratulated the Commission on its interactions with the other Specialist Commissions, emphasising the importance of harmonising and adopting a consistent approach to common work themes.

Finally, Dr Arroyo asked the Commission to discuss the rationale behind the maintenance of chapters in the *Terrestrial Manual* on unlisted diseases, underscoring the challenges and resources required for this effort, both for the Secretariat and the experts, and for the Commission itself (see agenda item 5.11).

The members of the Commission thanked Dr Arroyo for the excellent support provided by the WOAHA Secretariat.

1.3. Updates from the WOAHA Headquarters

1.3.1. Transparency of the WOAHA process for the elaboration of Standards

The Secretariat informed the Commission that the WOAHA Director General had agreed to implement a step-wise approach to improve the transparency of the WOAHA process for the elaboration of Standards that will include the publication of comments considered, responses, and an evolution of the reports of the Aquatic Animals Commission, the Code Commission and the Biological Standards Commission. This is also to align with the 7th Strategic Plan. The Secretariat also noted that this proposal had been discussed with the Presidents of the three Commissions (Aquatic Animals, Biological Standards and Code Commissions) at a meeting after the 90th General Session in May 2023 and that they supported this approach.

¹ SOPs: Standard operating procedures

The Secretariat explained that this process also aims to ensure that Members can gain a better understanding of the complexity and range of opinions, as well as of Commission decisions, and that this will result in a better understanding of Members concerns and should also improve the quality of the comments received.

The Secretariat explained that this would be a progressive process, that will start in March/April 2024 with the publication of comments considered on new and revised standards during the February 2024 meetings of the respective Commissions on the Delegates only website at the same time as the respective February 2024 report. This process will include an evolution of the Commission reports towards full transparency of comments considered and Commissions responses, which will result in better documentation and traceability of the WOAHA process for the elaboration of Standards. The Secretariat noted that Delegates will be kept well informed throughout this process, including a detailed communication that will be sent after the publication of this report.

2. Adoption of the agenda

The proposed agenda was presented and adopted. Dr Emmanuel Couacy-Hymann chaired the meeting and the WOAHA Secretariat acted as rapporteur. The agenda and the list of participants can be found at [Annexes 1](#) and [2](#) respectively.

3. Collaboration with other Specialist Commissions

3.1. Horizontal issues among the Specialist Commissions

3.1.1. Case definitions: infection New World (*Cochliomyia hominivorax*) and Old World (*Chrysomya bezziana*) screwworms, and Crimean–Congo haemorrhagic fever (revisited)

The Biological Standards Commission discussed the case definitions for New World (*Cochliomyia hominivorax*) and Old World (*Chrysomya bezziana*) screwworms and gave its recommendations to the Scientific Commission for Animal Diseases (see agenda item 9.3.2.1 of the report of the meeting of the Scientific Commission for Animal Diseases, 11–15 September 2023).

Regarding the case definition for Crimean–Congo haemorrhagic fever that the Biological Standards Commission had reviewed at the February 2023 meeting, the Scientific Commission submitted technical questions on the demonstration of active infection by ELISA² (IgG, competitive and IgM). The Biological Standards Commission agreed with the recommendation of the lead expert on the diagnostic protocols to establish serological evidence of active infection, including using two different serological tests each based on a different antigen for the detection of IgM antibodies given the potential for cross-reactivity, or by seroconversion based on a rise in total or IgG antibody titres on samples taken at 2–4 weeks apart. The lead expert added two footnotes to the purpose *Confirmation of clinical cases in animals* in Table 1 *Diagnostic test formats for Crimean–Congo haemorrhagic fever virus infections in animals*, of *Terrestrial Manual* Chapter 3.1.5 to capture this information. The amended chapter is included in the batch of chapters that will be sent for first-round comment in October 2023 (see agenda item 5.1).

For details of the case definition, refer to the September 2023 report of the Scientific Commission.

3.2. Scientific Commission for Animal Diseases

Nothing for this meeting.

3.3. Terrestrial Animal Health Standards Commission

Matters between the Terrestrial Animal Health Standards Commission and the Biological Standards Commission.

3.3.1. Updates from the February 2023 Code Commission meeting

The Biological Standards Commission was updated by the Secretariat of the Code Commission on the current topics under review by the Code Commission to ensure complementarity and alignment of the two Commission's respective work programmes.

2 ELISA: enzyme-linked immunosorbent assay

3.3.2. Biological Standards Commission's recommendations to the Terrestrial Animal Health Standards Commission

At the February 2023 meeting, the Code Commission had referred a Member request to define the latent period for FMD³ virus to the Biological Standards Commission, noting that such detail should be in the *Terrestrial Manual* and not the *Terrestrial Code*. The Biological Standards Commission asked the network of Reference Laboratory experts if a definition of latent period was a useful and necessary addition to the *Terrestrial Manual* chapter, and if it was, to develop a definition. The experts responded that the latent period for FMD is usually defined as the time between infection and the point when an animal is infectious as opposed to the incubation period, which is defined in the *Terrestrial Code* as the time from infection to the first clinical signs. The latent period is usually considered to be shorter than the incubation period (by 0–4 days), but the experts felt that it would be difficult to define in terms of days with a high degree of precision. Although the latent period is an important epidemiological parameter, the experts could not see how it would be useful to include this term in either the *Terrestrial Code* or *Terrestrial Manual* chapter. The Biological Standards Commission therefore would not recommend its addition to the *Terrestrial Manual*, and would inform the Code Commission of its position (see also agenda item 5.5).

3.3.3. Meeting of the Bureaus (7 September 2023)

See agenda item 3.2. of the report of the meeting of the Terrestrial Animal Health Standards Commission, 5–14 September 2023

3.3.4. Comments on Chapter 5.8. International transfer and laboratory containment of animal pathogenic agents

The advice of the Biological Standards Commission was sought regarding the need to revise *Terrestrial Code* Chapter 5.8. *International transfer and laboratory containment of animal pathogenic agents*. The Biological Standards Commission agreed with a Member comment that *Terrestrial Manual* Chapter 1.1.4. *Biosafety and biosecurity: Standard for managing biological risk in the veterinary laboratory and animal facilities* (last adopted in 2015) no longer refers to classification of pathogens into risk categories, but rather recommends a risk analysis approach to the management of biological risks for biosafety and biosecurity in veterinary laboratories and animal facilities. The *Terrestrial Code* chapter therefore is not harmonised with the *Terrestrial Manual* and should be updated.

3.3.5. Questions on Chapter 6.10. Responsible and prudent use of antimicrobial agents in veterinary medicine

Regarding Chapter 6.10. *Responsible and prudent use of antimicrobial agents in veterinary medicine*, the Code Commission had received comments referring to the establishment of clinical breakpoints. The Code Commission considered that clinical breakpoints should be established in accordance with *Terrestrial Manual* Chapter 2.1.1. *Laboratory methodologies for bacterial antimicrobial susceptibility testing*. The Biological Standards Commission agreed to liaise with the Working Group on Antimicrobial Resistance and other WOAH experts to update chapter 2.1.1, ensure it aligns with Codex Alimentarius Committee guidelines, and that the issue of the establishment of clinical breakpoints is fully addressed. The chapter would be added to the 2024/2025 review cycle, and thus could be proposed for adoption at the same time as *Terrestrial Code* chapter 6.10.

3.4. Aquatic Animal Health Standards Commission

Nothing for this meeting.

4. Work Programme

The updated work programme was agreed and can be found at [Annex 3](#).

5. Manual of Diagnostic Tests and Vaccines for Terrestrial Animals

For this Agenda Item, the Commission was joined by Dr Steven Edwards, Consultant Editor of the WOAH *Terrestrial Manual*.

3 FMD: foot and mouth disease

5.1. Review of draft chapters received for endorsement for circulation for first round Member comment

The Commission reviewed 16 draft chapters and approved 14 for circulation, some subject to clarification of certain points by the experts, for first-round Member comment and eventual proposal for adoption by the Assembly in May 2024. The 14 chapters and a brief summary of the main amendments are provided below:

- 1.1.5. *Quality management in veterinary testing laboratories*: updated the references and URLs; clarified that limited availability of suitable material may render validation difficult; included substantial technical updates to the sections on: accreditation; determination of the scope of the quality management system or of the laboratory's accreditation; quality assurance, quality control and proficiency testing; validation of the test method; and estimation of measurement uncertainty; updated the section on strategic planning.

The revised Chapter 1.1.5. *Quality management in veterinary testing laboratories* is presented as [Annex 4](#) for first-round comments.

- 1.1.9. *Tests for sterility and freedom from contamination of biological materials intended for veterinary use*: given the importance of the laboratory perspective, the chapter has been updated to give the reader an example-based overview of tests and their regulatory background included brief illustrative examples of vaccine contamination in the introduction and in more detail in Section G. *Protocol examples* – these examples are a strong motivator for extraneous agent testing; updated Section A. *An overview of testing approaches* with more recent opportunities and challenges; merged sections on living and inactivated viruses and bacteria, e.g. B & C, D & F, to simplify and streamline the chapter; the examples given in Section G. *Protocol examples* are clearly marked as non-prescriptive and non-exhaustive examples; updated references and weblinks.

The revised Chapter 1.1.9. *Tests for sterility and freedom from contamination of biological materials intended for veterinary use* is presented as [Annex 5](#) for first-round comments.

- 2.2.4. *Measurement uncertainty*: removed reference to the “WOAH Validation Standard” because the newly adopted validation chapter in the *Terrestrial Manual* will differ from the future one in the *Aquatic Manual* so there is no longer one Standard that applies to both Manuals: the title of chapter 1.1.6 has thus been changed to “*Validation of diagnostic assays for infectious diseases of terrestrial animals* – this change will be made to all chapters in *Terrestrial Manual* Section 2.2. *Validation of diagnostic tests*; clarified that the method described in the chapter is known as the “top-down” approach, and included information of its requirements along with a section on the scope and limitations of the top-down approach; added an example of a measurement uncertainty calculation in molecular tests.

The revised Chapter 2.2.4. *Measurement uncertainty* is presented as [Annex 6](#) for first-round comments.

- 2.2.6. *Selection and use of reference samples and panels*: updated cross references to Chapter 1.1.6 *Validation of diagnostic assays for infectious diseases of terrestrial animals*; added a figure on the documentation that is required of reference materials; added a list of references for further reading.

The revised Chapter 2.2.6. *Selection and use of reference samples and panels* is presented as [Annex 7](#) for first-round comments.

- 3.3.6. *Avian tuberculosis*: updated the nomenclature and classification of species in the genus *Mycobacterium*; reviewed the ratings of some of the tests in Table 1 *Test methods available for the diagnosis of avian tuberculosis and their purpose*; updated the section on nucleic acid recognition methods; added a section on the stained antigen test; updated the section on the production and minimum requirements for tuberculin production, and the list of references. **NB**: the Commission agreed to include the information on avian tuberculin production given in Section C *Requirements for diagnostic biologicals* in chapter 3.1.13 *Mammalian tuberculosis (infection with Mycobacterium tuberculosis complex)*.

The revised Chapter 3.3.6. *Avian tuberculosis* is presented as [Annex 9](#) for first-round comments.

- 3.4.1. *Bovine anaplasmosis*: updated the information in the introduction to the chapter; added an illustration of a stained blood smear showing *Anaplasma marginale* initial bodies; the thoroughly updated the section on the PCR⁴, including adding a table of primer sequences, and the section on the ELISAs including adding a displacement double-antigen sandwich ELISA that has been developed to differentiate between *A. marginale* and *A. centrale* antibodies; emphasised that the complement fixation test has variable sensitivity and removed it from Table 1; reviewed the ratings of some of the tests in Table 1 *Test methods available for the diagnosis*

4 PCR: polymerase chain reaction

of bovine anaplasmosis and their purpose – the experts also developed justification tables for the ratings of the tests in Table 1 for each purpose: these tables can be accessed by clicking on the individual purpose. The Commission believes that the information in these justification tables will be extremely useful to users of the *Terrestrial Manual* when deciding which test to use for a given purpose.

The revised Chapter 3.4.1. *Bovine anaplasmosis* is presented as [Annex 10](#) for first-round comments.

- 3.4.7. *Bovine viral diarrhoea*: updated the taxonomy; reviewed the ratings of some of the tests in Table 1 *Test methods available for the diagnosis of bovine viral diarrhoea and their purpose* and developed justification tables for the ratings of the tests in Table 1 for each purpose.

The revised Chapter 3.4.7. *Bovine viral diarrhoea* is presented as [Annex 11](#) for first-round comments.

- 3.4.12. *Lumpy skin disease* (vaccine section only): added text on the scarcity of information on the role of wildlife in lumpy skin disease (LSD) epidemiology; thoroughly updated Section C *Requirements for vaccines*.

The revised Chapter 3.4.12. *Lumpy skin disease* (vaccine section only) is presented as [Annex 12](#) for first-round comments.

- 3.6.9. *Equine rhinopneumonitis (infection with equid herpesvirus-1)*: clarified that the chapter covers infection with equid herpesvirus-1: most of the information on equid herpesvirus-4 has been removed as EHV4 is not listed; thoroughly updated Section B *Diagnostic techniques* in particular the section on virus detection by PCR, which now has a table on primer and probe sequences for a number of real-time PCRs and subsections on POC⁵ molecular tests and molecular characterisation, and the sections on virus isolation and on virus neutralisation, and added a section on the complement fixation test; developed justification tables for the ratings of the tests in Table 1 for each purpose.

The revised Chapter 3.6.9. *Equine rhinopneumonitis (infection with equid herpesvirus-1)* is presented as [Annex 13](#) for first-round comments.

- 3.8.1. *Border disease*: minor update, mainly of the taxonomy.

The revised Chapter 3.8.1. *Border disease* is presented as [Annex 14](#) for first-round comments.

- 3.8.12. *Sheep pox and goat pox*: included fluorescent antibody testing and histopathology in Table 1 *Test methods available for diagnosis of sheep pox and goat pox and their purpose*; thoroughly updated the section on nucleic acid recognition methods, in particular the conventional and real-time PCR methods; clarified that ELISAs cannot discriminate between antibodies to different capripoxviruses.

The revised Chapter 3.8.12. *Sheep pox and goat pox* is presented as [Annex 15](#) for first-round comments.

- 3.9.1. *African swine fever* (infection with African swine fever virus) (vaccine section only): a consultant working with vaccine developers, subject matter experts, representatives from the scientific community, regulatory authorities and WOA Reference Laboratories had thoroughly updated Section C *Requirements for vaccines* on the manufacture of pure, potent, safe and efficacious vaccines for ASF⁶ including key vaccine performance and quality criteria.

The newly drafted section of Chapter 3.9.1. *African swine fever* (infection with African swine fever virus) (vaccine section only) is presented as [Annex 16](#) for first-round comments. An appendix to the draft chapter is also included for information comprising the results of the consultation, the key parameters, summaries of discussions, etc.

- 3.10.4. *Infection with Campylobacter jejuni and C. coli*: updated the taxonomy and the references and emphasised that *C. jejuni* and *C. coli* are of interest mainly from the point of view of food safety; reviewed the ratings of some of the tests in Table 1 *Test methods available for the diagnosis of Campylobacter jejuni and C. coli and their purpose* and developed justification tables for the ratings of the tests in Table 1 for each purpose. Updated the details in the methods for isolation and identification of the agent.

5 POC: point of care (tests)

6 ASF: African swine fever

The revised Chapter 3.10.4. *Infection with Campylobacter jejuni and C. coli* is presented as [Annex 17](#) for first-round comments.

3.10.8. *Toxoplasmosis*: thoroughly updated since last adopted in 2017. In the interest of clarity, the text has not been marked up.

The revised Chapter 3.10.8. *Toxoplasmosis* is presented as [Annex 18](#) for first-round comments.

The batch of draft chapters also includes revised Chapter 3.1.5 *Crimean–Congo haemorrhagic fever* presented as [Annex 8](#) for first-round comments (see agenda item 3.1.1).

	Appendix	Chapter	
1.	4	1.1.5.	Quality management in veterinary testing laboratories
2.	5	1.1.9.	Tests for sterility and freedom from contamination of biological materials intended for veterinary use
3.	6	2.2.4.	Measurement uncertainty
4.	7	2.2.6.	Selection and use of reference samples and panels
5.	8	3.1.5.	Crimean–Congo haemorrhagic fever
6.	9	3.3.6.	Avian tuberculosis
7.	10	3.4.1.	Bovine anaplasmosis
8.	11	3.4.7.	Bovine viral diarrhoea
9.	12	3.4.12.	Lumpy skin disease (vaccine section only)
10.	13	3.6.9.	Equine rhinopneumonitis (infection with equid herpesvirus-1)
11.	14	3.8.1.	Border disease
12.	15	3.8.12.	Sheep pox and goat pox
13.	16	3.9.1.	African swine fever (vaccine section only)
14.	17	3.10.4.	Infection with <i>Campylobacter jejuni</i> and <i>C. coli</i>
15.	18	3.10.8.	Toxoplasmosis

5.2. Follow-up from September 2022: conclusions and recommendations from the WOAHS Scientific and Technical Review issue on diagnostic test validation science

5.2.1. Progress on development of a validation report form for tests recommended in the *Terrestrial Manual*

At the meeting in February 2023, the Commission simplified and streamlined the validation report template for tests recommended in the *Terrestrial Manual* in the light of comments submitted by experts participating in a pilot scheme to test the template's suitability and usability. The new version of the document was shared again with those WOAHS Reference Laboratories in the pilot scheme for further feedback on its utility.

At this meeting, the Commission agreed to make some final adjustments to the template, mainly to improve the introductory paragraph to better clarify the template's scope and purpose. It is important to emphasise that what is important is not how much data can be inserted under each heading in the template but rather are there data to demonstrate that the performance of the assay has been evaluated and that it is proven fit for the chosen purpose in Table 1.

Once the final version has been approved by all members of the Commission, the template will be made available on the WOAHS website, and Reference Laboratory experts contributing to *Terrestrial Manual* chapters will be invited to use it to post their validation data online. In this way a repository of validation reports for recommended tests will be created for anyone seeking the validation data available for a given test. The Commission believes that this is an important advance, particularly for new technologies.

As stated in the September 2022 report, the template will also be used for experts requesting to add tests to the *Terrestrial Manual*.

5.2.2. Progress on development of a template for a new *Terrestrial Manual* section on the rationale behind the selection of tests included in Table 1. *Test methods available and their purpose*

At the meeting in February 2023, the Commission agreed to give the template developed to justify the selection of tests considered to be fit for purpose in Table 1, along with their rating, to all experts in the 2023/2024 review cycle when they were invited to update or draft a *Terrestrial Manual* chapter. Experts contributing to four disease chapters had used the template when updating their chapters. The Commission reviewed the submissions and found that this new section is an excellent addition to chapters in the *Terrestrial Manual* providing users with extremely useful information when they are deciding on tests to use for the various purposes while ensuring that the selection process is evidence-based. The new tables provide information on the type of sample, the test's accuracy, the test population, validation report if available, the advantages and disadvantages, and references. The Commission agreed that a link to the justification table would be added to each purpose in Table 1 so that users could click on the purpose for direct access to this information. It is hoped that more contributors to the *Terrestrial Manual* disease chapters will fill in the justification table template in the future.

5.3. Inclusion of videos on diagnostic techniques on the WOAHP website disease portals: review of submitted videos

In February 2023, the Commission requested the Secretariat to contact the Reference Laboratories to ask if they have videos of diagnostic techniques they would like added to their chapter. At this meeting, the Commission reviewed the videos submitted. The Commission proposed that a repository of videos could be made available on the WOAHP website. For the present, the videos would be from WOAHP Reference Laboratories only and linked to diagnostic techniques for tests in the *Terrestrial Manual*. Each video would need to be accompanied by information on its contents, the publication associated with the technique, the software and equipment needed to perform the test and the language of the video. For a video to be added to the repository, the following criteria need to be met:

- i) Clarity: quality of the visual and audio aspects of the video should be high and the technique clearly explained for users;
- ii) Relevant to the *Terrestrial Manual* chapter;
- iii) Should not contain culturally inappropriate content;
- iv) The technique should be carried out in accordance with the *Terrestrial Manual* standards for quality technical proficiency, quality assurance and biosafety;
- v) Should not contain trade names or advertise certain kits or platform;
- vi) Should have a disclaimer stating that WOAHP is not endorsing the contents of the video.

It should also be stressed that the videos are not WOAHP standards. Any videos received would be first vetted by the Secretariat to ensure they fulfil the criteria. They will then be sent to the other Reference Laboratories for the disease in question before being submitted to members of the Commission for final approval to be added to the repository.

5.4. Further review of Chapter 1.1.6 Validation of diagnostic assays for infectious diseases of terrestrial animals

The Commission had received some last-minute changes to Chapter 1.1.6 *Validation of diagnostic assays for infectious diseases of terrestrial animals* after it was adopted in May 2023, expanding the information in the chapter on validation of POC tests. For this meeting, the Commission had also reviewed a first draft of a new chapter on the diagnostic validation of POC tests for WOAHP-listed viral diseases using field samples and agreed that the chapter needed further development with input from the Reference Laboratory networks. The Commission decided to wait until the new chapter is finalised and adopted before addressing the proposed amendments to chapter 1.1.6.

5.5. Follow-up from February: need for a definition of latent period in the chapter on foot and mouth disease

See agenda item 3.3.2.

5.6. Review and alignment of the validity criteria of the PD₅₀ and PPG tests for foot and mouth disease between the *Terrestrial Manual* and the European Pharmacopoeia

The Commission was informed of the need to harmonise methods used for FMD vaccine potency assessment in the *Terrestrial Manual* and the European Pharmacopoeia (EuPh) to ensure that there is no variability in the interpretation of the methods in both texts. A WOAHP Reference Laboratory expert is working with the EuPh to resolve this issue.

5.7. Purpose of the list of contributors and addresses in the *Terrestrial Manual*

The *Terrestrial Manual* includes a list of contributors to individual chapters with their professional addresses at the time of writing. The Commission believes the list gives credibility to the *Terrestrial Manual* and its inclusion contributes to the transparency of the standard-setting process. However, some of the experts on the current list have retired since contributing to chapters and their former employers do not allow them to use their former professional affiliation in the list. The Commission decided that in such cases to avoid including personal addresses, the name of the expert and their country of residence alone would be included. Experts who had changed employer but not retired, would be asked if the new employer would allow them to use that affiliation in the list.

5.8. Publication of Member comments and need to review the Commission's practice

As a result of the decision to publish Member comments (see agenda item 1.3.1), the Commission will need to change its current working practices. The first implemented change is to annex the chapters for comment to the reports.

5.9. *Terrestrial Manual* status: update on chapters selected for the 2024/2025 review cycle

The Commission examined the status of chapters that had previously been identified for update in the 2023/2024 review cycle but had not been received. The Commission decided to add to the list the remaining chapters that had last been updated in 2018, and to ask the contributors to chapters last adopted in 2019 if their chapters required an update. The Commission encouraged those Reference Laboratories with outstanding chapters to deliver by the deadline. The following chapters have been identified for update in 2024/2025 (year last adopted in brackets after the title).

- 1.1.2. Collection, submission and storage of diagnostic specimens (2013)
- 1.1.3. Transport of biological materials (2018)
- 1.1.4. Biosafety and biosecurity: Standard for managing biological risk in the veterinary laboratory and animal facilities (2015)
- 1.1.7. Standards for high throughput sequencing, bioinformatics and computational genomics (2016)
- 2.1.3. Managing biorisk: examples of aligning risk management strategies with assessed biorisks (2014)
- 2.1.1. Laboratory methodologies for bacterial antimicrobial susceptibility testing (2019)
- 2.2.1. Development and optimisation of antibody detection assays (2014)
- 2.2.2. Development and optimisation of antigen detection assays (2014)
- 2.2.3. Development and optimisation of nucleic acid detection assays (2014)
- 2.2.5. Statistical approaches to validation (2014)
- 2.2.7. Principles and methods for the validation of diagnostic tests for infectious diseases applicable to wildlife (2014)
- 2.2.8. Comparability of assays after minor changes in a validated test method (2016)
- 2.3.2. The role of official bodies in the international regulation of veterinary biologicals (2018)
- 2.3.3. Minimum requirements for the organisation and management of a vaccine manufacturing facility (2016)
- 2.3.5. Minimum requirements for aseptic production in vaccine manufacture (2016)
- 3.1.2. Aujeszky's disease (infection with Aujeszky's disease virus) (2018)
- 3.1.8. Foot and mouth disease (infection with foot and mouth disease virus) (2021)
- 3.1.9. Heartwater (2018)
- 3.1.14. New World screwworm (*Cochliomyia hominivorax*) and Old World screwworm (*Chrysomya bezziana*) (2019)
- 3.1.17. Q fever (2018)
- 3.1.20. Rinderpest (infection with rinderpest virus) (2018)
- 3.1.25. West Nile fever (2018)
- Introductory note on bee diseases (2013)
- 3.2.4. Nosemosis of honey bees (2013)

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- 3.2.5. Infestation of honey bees with *Aethina tumida* (small hive beetle) (2018)
 - 3.2.6. Infestation of honey bees with *Tropilaelaps* spp. (2018)
 - 3.3.1. Avian chlamydiosis (2018)
 - 3.3.2. Avian infectious bronchitis (2018)
 - 3.3.4. Avian influenza (including infection with high pathogenicity avian influenza viruses) (2021)
 - 3.3.7. Duck virus enteritis (2018)
 - 3.3.8. Duck virus hepatitis (2017)
 - 3.3.11. Fowl typhoid and Pullorum disease (2018)
 - 3.3.12. Infectious bursal disease (Gumboro disease) (2016)
 - 3.4.9. Enzootic bovine leukosis (2018)
 - 3.4.11. Infectious bovine rhinotracheitis/infectious pustular vulvovaginitis (2017)
 - 3.4.13. Malignant catarrhal fever (2018)
 - 3.4.15. Theileriosis in cattle (infection with *Theileria annulata*, *T. orientalis* and *T. parva*) (2018)
 - 3.4.16. Trichomonosis (2018)
 - 3.6.1. African horse sickness (infection with African horse sickness virus) (2019)
 - 3.6.4. Epizootic lymphangitis (2018)
 - 3.6.6. Equine infectious anaemia (2019)
 - 3.6.7. Equine influenza (infection with equine influenza virus) (2019)
 - 3.6.10. Equine viral arteritis (2013)
 - 3.6.11. Glanders and melioidosis (2018)
 - 3.8.2. Caprine arthritis/encephalitis and Maedi-visna (2017)
 - 3.8.3. Contagious agalactia (2018)
 - 3.8.5. Enzootic abortion of ewes (ovine chlamydiosis) (infection with *Chlamydia abortus*) (2018)
 - 3.8.7. Ovine epididymitis (*Brucella ovis*) (2015)
 - 3.8.11. Scrapie (2022)
 - 3.8.12. Sheep pox and goat pox (2017) (vaccine section)
 - 3.9.2. Atrophic rhinitis of swine (2018)
 - 3.9.3. Classical swine fever (infection with classical swine fever virus) (2022: diagnostic tests section)
 - 3.9.8. Swine vesicular disease (2018)
 - 3.9.9. Teschovirus encephalomyelitis (2017)
 - 3.9.10. Transmissible gastroenteritis (2008)
 - 3.10.9. Verocytotoxigenic *Escherichia coli* (2008)

5.10. Update on WOAHS Standards Online Navigation Tool Project

The WOAHS Standards Department informed the Commission of a project to develop a new WOAHS Standards Online Navigation Tool. This project is an initiative to change how WOAHS Standards are displayed and made available to Members and other users. The project will enhance the display of the *Aquatic Code*, *Terrestrial Code*, *Aquatic Manual*, and *Terrestrial Manual* on the WOAHS website. The project will also comprise a specific tool aimed at providing specific search functions for the visualisation of sanitary measures recommended for the international trade of commodities for terrestrial Animals. Also, the new tool is expected to simplify the annual updating process of the content of the Standards.

The project is aligned with the goals of the 7th Strategic Plan and will provide significant benefits to WOAHS and its Members, including enhanced accessibility to WOAHS Standards, efficiency in information retrieval, all the while supporting the implementation of WOAHS Standards. The project will also bring gains to the Organisation itself, by

improving the efficiency of internal processes and the interoperability across various datasets related to WOAH Standards.

The Commission expressed interest and support for the project and recognised the importance of facilitating Members' access to achieve better understanding and use of WOAH Standards.

5.11. Terrestrial *Manual* chapters on non-listed diseases

At the meeting of the Bureaus of the Code and Biological Standards Commissions it was noted that some of the *Terrestrial Manual* chapters being updated were on non-listed or delisted diseases. The bureaus discussed the value of keeping and updating such chapters and whether they belong in a WOAH standard. It was noted that the Aquatic Animals Commission decided some time ago to maintain only chapters on listed diseases in the *Aquatic Manual*. The issue was also raised by Dr Arroyo in her welcome presentation. There are a total of 29 such chapters in the *Terrestrial Manual*. The Commission agreed that maintaining these chapters may not be the best use of resources. The Commission agreed to develop evidence-based criteria for keeping or deleting these chapters and to apply them at the meeting in February 2024. As Members could still need assistance with diagnosing and controlling these diseases, the Reference Laboratories and experts could be maintained if desired.

6. WOAH Reference Centres

6.1. Improving and automating the performance review for annual reports of Reference Laboratories using a risk-based approach

Every year, each Reference Laboratory submits an annual report of its activities. The questionnaire comprises 29 questions based on the ToR⁷ of the Reference Laboratories. Currently, each Commission member is tasked with evaluating approximately 40 laboratory reports annually, representing a heavy workload. During the Commission meeting in September 2022, the Members expressed the need to increase the efficiency of the evaluation process while reducing the workload.

At this meeting, the Secretariat proposed for the Commission's review a semi-automated system aimed at creating an effective method of performance assessment able to detect underperforming Reference Laboratories with a high level of sensitivity. Currently, all the annual reports are saved in a database; the system will use this database to generate an Excel file, reflecting an initial quantitative review of the reports. Using a risk-based approach and "weighting" the responses, the initial analysis can be further reviewed. The system will thereby categorise the Reference Laboratories as low risk or high risk of under-performance. This approach ensures that every report is screened uniformly to identify Reference Laboratories that need a more in-depth assessment by a Commission member by directing focus on potentially poor performers. In this way, the number of reports each BSC member evaluates could be reduced by 50 per cent while optimising the effort entailed. The system also ensures that each Reference Laboratory is evaluated at least once every 3 years.

The Commission recognised that some of the activities listed in the ToR for Reference Laboratories were more fundamental to the functioning of the laboratory than others and agreed to weight the responses in three categories: 'essential', 'core' and 'non-core' tasks. In this context, 'essential' signifies an activity that is mandatory to the functioning of the Reference Laboratory, 'core' denotes an activity that is optimal but its undertaking might depend on the Reference Laboratory's situation, and 'non-core' refers to activities that are of benefit to Members but not essential to the overall performance evaluation of the laboratory. The Commission also discussed the existing 'watch list' and the criteria for inclusion on it, such as those Reference Laboratories that did not submit a report or that had previously received a letter requesting clarification of aspects of their performance, as well as Reference Laboratories identified by the Commission based on professional judgement.

The Commission agreed to implement the system for the first time for the review of 2022 reports. The Secretariat will be responsible for distributing the reports identified by the system equally to each Commission member. An extraordinary meeting will be held in October 2023 to finalise the evaluations of the 2022 annual reports, assess the performance of the new system and communicate the findings with the network.

6.2. Applications for WOAH Reference Centre status

The Commission recommended acceptance of the following applications for WOAH Reference Centre status:

WOAH Reference Laboratory *Tularemia*
Institute for Bacterial Infections and Zoonoses, Friedrich-Loeffler-Institut (FLI)

⁷ ToR: Terms of Reference

Federal Research Institute for Animal Health
Naumburger Str. 96a – 07743 Jena,
GERMANY
Tel.: (49-3641) 804.2243; E-mail: herbert.tomaso@fli.de
Website: [Institute of Bacterial Infections and Zoonoses \(IBIZ\); Friedrich-Loeffler-Institut \(fli.de\)](https://www.fli.de)
Designated expert: Dr Herbert Tomaso

WOAH Reference Laboratory for Rabies
Laboratory for Emerging Viral Zoonoses, Research and Innovation Department
Istituto Zooprofilattico Sperimentale Delle Venezie
Viale dell'Università 10, 35020 Legnaro (PD)
ITALY
Tel.: (+39 049) 808.4385
E-mail: pdebenedictis@izsvenezie.it
Website: <https://www.izsvenezie.it/>
Designated expert: Dr Paola De Benedictis

WOAH Reference Laboratory for Theileriosis
Epidemiology, Parasites and Vectors, Agricultural Research Council –
Onderstepoort Veterinary Research, Onderstepoort 0110
SOUTH AFRICA
Website: [Epidemiology, Parasites and Vectors \(arc.agric.za\)](https://www.arc.agric.za)
Designated expert: Dr Barend Johannes Mans

WOAH Collaborating Center for Genome Monitoring of Swine Viral Disease
National Bio and Agro-Defense Facility (NBAF)
1980 Denison Ave. Manhattan, KS 66502
UNITED STATES OF AMERICA
Tel.: +1-785 477.9006
E-mail: Alfonso.Clavijo@usda.gov; Douglas.Gladue@usda.gov; Manuel.Borca@Usda.gov
Website: [National Bio and Agro-Defense Facility | USDA](https://www.usda.gov/nbaaf)
Contact Point: Douglas Gladue

Two applications had been received from the same institute in a Member in the Africa Region for Collaborating Centres, one for field epidemiology and one for risk assessment for animal health. Though the applicant is active and collaborates with institutes both within and outside the region, the Commission found that neither application provided sufficient details of the activities they propose to undertake and the services that they will provide to Members in the region. Neither did either application include a 5-year work plan. The Commission also noted that both applications chose Animal health management as the main focus area, with overlapping specialties in epidemiology, surveillance and risk assessment. The applicant will be requested to merge the two applications into one application for Collaborating Centre status and at the same time to strengthen the application by including details of proposed activities and outputs, and a 5-year work plan.

6.3. Changes of experts at WOA Reference Centres

The Delegates of the Members concerned had submitted to WOA the following nominations for changes of expert at WOA Reference Laboratories. The Commission recommended their acceptance:

Rabbit haemorrhagic disease:
Dr Patrizia Cavadini to replace Dr Lorenzo Capucci at the Istituto Zooprofilattico Sperimentale della Lombardia e dell'Emilia Romagna, Brescia, ITALY

Lumpy skin disease and sheep pox and goat pox:
Dr Georgina Limon-Vega to replace Dr Pip Beard at the Pirbright Institute, UNITED KINGDOM

Salmonellosis (Salmonella spp.):
Dr Francesca Martelli to replace Dr Rob Davies at the Animal and Plant Health Agency, UNITED KINGDOM

Foot and mouth disease:
Dr Vivian O'Donnell to replace Dr Consuelo Carrillo at the APHIS National Veterinary Services Laboratories, UNITED STATES

6.4. Review of new and pending applications for laboratory twinning

As of September 2023, 85 projects have been completed and 19 projects are underway. Of the completed projects, 15 Reference Laboratories and four Collaborating Centres have achieved WOAHA designation status.

Two Laboratory Twinning project proposals were presented for the Commission's review:

1. **South Africa – China (People's Rep. of)** for lumpy skin disease: the Commission supported the technical contents of this project proposal.
2. **South Africa - Ghana** for African swine fever: the Commission supported the technical contents of this project proposal.

6.5. Analysis of the questionnaire sent to all Reference Laboratories

The questionnaire developed by the Commission was sent to all experts in charge of Reference Laboratories. Of 180 experts, 126 responses were received (70% response rate), representing all five WOAHA regions. The survey was focused on the Reference Laboratory system and processes, covering topics not included in the annual report template. It placed particular emphasis on the point of contact between Reference Laboratories and WOAHA, as well as the Commission. The survey provided an opportunity for experts to suggest changes and improvements to the system. It was divided into seven sections addressing various aspects of the Reference Laboratory system.

The survey results indicated overall satisfaction among Reference Laboratories. Multiple responses highlighted the need to simplify and make the application process, annual reports, and *Terrestrial Manual* chapter reviews more transparent. The Reference Laboratory experts also expressed a desire for closer contact with the Commission and WOAHA staff, preferably in-person, to strengthen networking, align and harmonise efforts, and set joint goals.

The Commission discussed the benefits that accrue from face-to-face meetings of the designated experts responsible for the Reference Laboratories and noted that almost a decade had elapsed since the most recent global conference of WOAHA Reference Centres in Incheon, Korea (Rep. of).

The survey will serve as a fundamental information source for enhancing processes related to Reference Laboratories. The questionnaire results will be shared with all Reference Laboratories as informational feedback as well as attached as [Annex 19](#) in this report.

6.6. Feedback from Laboratories that are not complying with the key ToR

The Commission was made aware of two Reference Laboratories that are not accredited to ISO 17025 or equivalent quality management system despite this being an essential requirement of all WOAHA Reference Laboratories. The laboratories would be given 2 years to achieve accreditation and provide certificates or proof of equivalency.

6.7. Develop a plan of how to evaluate the progress made since the Collaborating Centres submitted their 5-years work plans

Collaborating Centres are designated for a period of 5 years, during which they adhere to a 5-year work plan, which was submitted at the beginning of the designation period. At the end of this period, the Director General sends a letter requesting a report of the achievements of the 5 years as outlined in the work plan. The Commission evaluates this report and decides if the Collaborating Centre's designation should be renewed or not based on their performance and the need to maintain a Centre for the specific topic.

This system of designating Collaborating Centres for a 5-year period was introduced in 2020 with the adoption of the SOPs ([Collaborating Centre - Procedures for Designation](#)). The first Centres to reach the end of their 5-year designation will do so at the end of 2024.

The Commission discussed the best approach to obtaining information on the activities of the Centres during their 5-year designation period. The Commission agreed that a letter requesting a final report of their activities over the past 5-years in relation to the 5-year work plan originally submitted should be sent in the last quarter of the fifth year of the designation (September). At the February 2024 meeting, the Commission will develop a template for this final report along with performance criteria: it should include evidence of the Centre's impacts and achievements, benefits to the region, etc. The Centres will also be requested to submit the regular annual report, and both will be assessed by the Commission.

The Commission will conduct an initial evaluation of the final reports, with the first results announced in the relevant February meeting. Those Collaborating Centres with an accepted final report will be notified after the February meeting that their designation can be renewed and will be asked to submit a new 5-year plan. Those Centres whose level of performance was not accepted will have a 6-month appeal period until the next Commission meeting in September at which their designation will be further evaluated and could lead to their withdrawal from the list.

6.8. Update on the three Reference Laboratory network (ASF, PPR⁸ and rabies)

African swine fever

The WOAHA ASF Reference Laboratory network held regular virtual meetings to exchange scientific and technical expertise, including recent developments on ASF vaccines, and discussed activities in developing training programmes to assist at-risk countries, including the organisation of proficiency tests. The network is finalising a laboratory manual, including diagnostic algorithms to detect low virulent and novel emergent ASFV variants, and to explore user requirements on an open access information sharing platform for ASF virus genome sequence data. In the upcoming year, the Network plans to review its [overview](#) of ASF diagnostic tests for field application (POC tests).

Peste des petits ruminants

The WOAHA PPR Reference Laboratory network continues to regularly update its [website](#) and organise activities in support of its members. Its second annual newsletter was circulated in July 2023 and published on its website. The newsletter provides an update on recent and forthcoming activities of the network as well as updates on activities of its members including other relevant networks (FAO/IAEA⁹ VETLAB Network). The main activities planned for 2023 include the organisation of a webinar in September 2023 on the harmonisation of PPR diagnostic methods through proficiency tests and the third workshop of the network, which will be held virtually in December 2023.

Rabies

The WOAHA Reference Laboratory Network for Rabies (RABLAB) increased meetings to bimonthly in order to improve information sharing and alignment of activities between reference laboratories. Following recommendations from the RABLAB meeting in December 2022, *Istituto Zooprofilattico Sperimentale delle Venezie* (IZSVe), the FAO¹⁰ Reference Centre for Rabies, has joined RABLAB as an affiliate member, helping improve coordination of international efforts for rabies control.

Following recommendations from the Commission February 2023 meeting, the [WOAHA website](#) has been updated to better highlight the role of RABLAB in supporting WOAHA Members. RABLAB recommendations, including the '[Procedure for production of in-house \(internal\) positive control serum for rabies antibody testing](#)' and the '[RABLAB statement on the use of commercial rapid immunochromatographic tests](#)' can also be found online. To improve support for WOAHA Members in their rabies control efforts, the RABLAB network has also developed [a guidance document to assist WOAHA Members in compiling information to support applications for WOAHA endorsement of official control programmes for dog-mediated rabies](#) and the network continues to participate in several Twinning projects to build laboratory capacity for rabies diagnosis. RABLAB members continue to support international initiatives, in particular the United Against Rabies Forum activities, and have contributed to guidance on the role of oral rabies vaccination for dogs, and the development of a United Against Rabies Country Partnership programme.

There are ongoing discussions about the use of lateral flow devices (LFDs) for rabies virus detection. The RABLAB network has [developed guidance](#) for WOAHA Members regarding this. The RABLAB network is continuing discussions with relevant manufacturers to explore how protocols and tests can be improved to support rabies surveillance.

6.9. Review of the current list of Main Focus Areas and Specialties

The Commission reconsidered the recommendation made at its February 2023 meeting to change the title of one of the Main Focus Areas for WOAHA Collaborating Centres from "Wildlife Health and Biodiversity" to "Climate Change and Environment". The Commission noted the importance of maintaining the original title, Wildlife Health and Biodiversity, to reflect WOAHA's commitment to the implementation of WOAHA's Wildlife Health Framework, which included an objective to develop the network of Collaborating Centres specialising in wildlife health.

8 PPR: Peste des petits ruminants

9 IAEA: International Atomic Energy Agency

10 FAO: Food and Agriculture Organization of the United Nations

However, the Commission also identified that the text describing the Main Focus Area did not currently reflect a wildlife theme. The Commission therefore suggested that the descriptive text be amended.

The Commission also suggested integrating climate change and its impacts as specialties in three of the Main Focus Areas, namely Animal Health Management, Animal Production, and Wildlife Health and Biodiversity.

Following the meeting, the list was also reviewed and further amended by the Aquatic Animal Health Standards Commission. The updated document with the changes shown is available at [Annex 20](#).

6.10. Clarify the role of the Contact Point in providing advice and services to WOAAH Members

Each WOAAH Collaborating Centre has one designated Contact Point to supervise the Centre's activities and act as the liaison between WOAAH, the Commission, and WOAAH Members. The Contact Point is often the Director of the institute that hosts the Centre, though in reality, other members of the Centre's personnel often take responsibility for responding to administrative issues or requests for assistance from Members on behalf of the official Contact Point. The Commission highlighted the need for a reliable and available point of contact. This was deemed essential for situations that required seamless communication and immediate assistance from a Reference Centre.

The official Contact Point will be asked if they are willing to continue to receive and re-direct requests or if they would prefer to nominate another staff member to be this first point of contact for their Centre for administrative purposes. This member will not replace the official Contact Point of the Centre but will facilitate all contact between the Centre and WOAAH. This approach would enhance collaboration and also ensure timely response to the demands of those who depend on the services of the Reference Centre. The continual availability of a point of contact is considered essential for the success of these centres by the Commission.

7. Ad hoc Groups: Update on activities of past ad hoc Groups

7.1. Ad hoc Group on Replacement of the International Standard Bovine Tuberculin (ISBT) and Avian Tuberculin (ISAT)

In April 2023, the *ad hoc* Group on Replacement of the International Standard Bovine Tuberculin (ISBT) met virtually to continue discussions on the ISBT replacement process. Led by the UK Health Security Agency (UK HSA), a series of experiments were conducted to assess the potency of a newly manufactured PPD diagnostic reagent for *Mycobacterium bovis* in sensitised guinea-pigs. The goal was to establish the best method for evaluating the reagent's potency compared with standard PPD reagents in guinea-pigs sensitised with *M. bovis*. The experiments are currently in a new phase of testing with the aim of obtaining standardised results that will enable the assessment of the validity of the potential tuberculin replacement. The results are expected by the last quarter of the year.

The *ad hoc* Group also addressed the depletion of avian PPD reserves, providing comments on the technical criteria specifications and identifying potential manufacturers to launch the process of identifying a suitable replacement.

Following the update, the Commission noted the substantial commitment of time and resources being dedicated to the project to develop replacement tuberculin.

8. International Standardisation/Harmonisation

8.1. WOAAH Register of diagnostic kits – update and review of new or renewed applications

The Secretariat for Registration of Diagnostic Kits (SRDK) informed the Commission of the status of ongoing applications. At present, there are 16 diagnostic test kits in the WOAAH Register of Diagnostic Kits.

8.1.1. Ongoing application for Genelix™ ASFV real-time PCR detection kit

The assessment of the application for *Genelix™ ASFV real-time PCR detection* kit (Sanigen) is under evaluation. No major issues have been identified in the 3rd Assessment Report. The applicant has submitted the revised dossier with the answers to the Panel of Experts (PoE). The review is under evaluation by PoE. The endorsement of the Review Panel Final Report and Validation Studies Abstract is planned to take place during the next Commission meeting (February 2024) and preparation of a new Resolution in May 2024 is underway.

8.1.2. Renewal of Avian Influenza Antibody test kit (registration number 20080203)

The applicant (BioChek [UK]) has provided the notification letter and declared that the test is still viable and that no changes have been introduced since the last renewal. The renewal procedure was initiated via the Reference Laboratories on 9 August 2023 according to the current Renewal Procedure. In expectation of a 5-year renewal of the Avian Influenza Antibody test kit, a new Resolution is being prepared for presentation in 2024.

8.1.3. Renewal of Newcastle Disease Antibody test kit (registration number 20140109)

The applicant (BioChek [UK]) has provided the notification letter and declared that the test is still viable and no that changes have been introduced since the last renewal. The renewal procedure was initiated via the Reference Laboratories on 9 August 2023. In expectation of a 5-year renewal of the Newcastle Disease Antibody test kit, a new Resolution is being prepared for presentation in 2024.

8.1.4. Update on WOAHP SOP and application form

The SRDK updated the WOAHP webpage on the registration of diagnostic kits to reflect the new WOAHP logo and brand in the SOPs and application form.

8.2. Standardisation programme

8.2.1. Association française de normalisation: follow-up from February 2023

Following the February 2023 meeting, the Commission had informed AFNOR¹¹, on behalf of CEN/TC¹² 469, that proposals for amendments to the *Terrestrial Manual* should be submitted through the European Union representative and that CEN could not be involved directly in the work and discussions of the Commission. In response, the Chair of CEN/TC 469 clarified that CEN is not a European Union institution but a private international non-profit organisation recognised as the European standard-setting organisation. The Commission was informed that CEN/TC 469 does not hold the status of an international organisation having signed an agreement with WOAHP, and therefore cannot submit proposals directly on WOAHP standards. WOAHP has signed an agreement to be a liaison organisation to participate in CEN/TC work. CEN/TC would need to investigate other means for submitting its proposals on introductory chapters of the *Terrestrial Manual*, through national Delegates or the European Commission.

8.2.2. Project to extend the list of WOAHP-approved reference reagents: review of guidelines

The project to extend the list of WOAHP-approved reference reagents is not progressing, with no WOAHP Reference Laboratory submitting candidate reagents in the past few years. The main barrier is that the guidelines for antibody standards¹³, antigen standards¹⁴ and PCR assays¹⁵, are too demanding and thus costly to be an incentive for Reference Laboratories. As the Commission would like to maintain and extend the list, it was agreed to ask the disease-specific networks, namely ASF, FMD, rabies and PPR, to establish minimum criteria for the development of reference reagents so that the guidelines could be made more achievable while maintaining the quality of the reagents produced. At the next meeting in February 2024, the Commission will review the advice received, amend the guidelines and develop a list of priority reagents.

9. Follow-up from the General Session

9.1. Excerpt from the Final Report: comments from Members

At the General Session, a Member had informed the Assembly that a new vaccine for *Paenibacillus larvae* had been authorised for use in the country and requested that the vaccine be included in Chapter 3.2.2. *American foulbrood of honey bees (infection of honey bees with Paenibacillus larvae)*. As this is a new diagnostic advance for this disease, the Commission would request more information from the Member in question and from the WOAHP Reference Laboratories before proceeding with the request.

11 AFNOR: Association française de normalisation

12 CEN/TC: European Committee for Standardization/Technical Committee

13 <https://www.woah.org/app/uploads/2021/03/a-guideline-antibody-standards.pdf>

14 <https://www.woah.org/app/uploads/2021/03/a-guideline-antigen-standards.pdf>

15 <https://www.woah.org/app/uploads/2021/03/a-guideline-pcr-standards.pdf>

Another Member drew the Commission's attention to the WOAH website, where previous amendments to the *Terrestrial Code* chapters are available in chronological order and can be accessed. The Delegate proposed that the same service be provided for the *Terrestrial Manual*.

The Commission discussed the value of this project and concluded that the Secretariat make available the chapters amended each year since 2013, based on the documents circulated with the February reports, i.e. the versions of the chapters proposed for adoption with all the amendments marked up. A table similar to the one for the *Terrestrial Code* would be created and updated on an annual basis, indicating the year (edition), revised chapter, Resolution, and the published chapter. Until 2012, the *Terrestrial Manual* was published every 4 years and no marked up chapters were circulated. These editions are available on the WOAH document portal.

9.2. The Animal Health Forum and the adopted Resolution on avian influenza

In light of the ongoing global avian influenza crisis, WOAH hosted its first [Animal Health Forum](#) (AHF), fully dedicated to the disease. The AHF served as a platform for international experts, the private sector and government representatives to engage in meaningful discussions about the current challenges and perspectives for combatting avian influenza. The AHF, held during 90th General Session, convened key stakeholders and WOAH Members to discuss how to minimise the impacts of avian influenza across sectors. Based on the Technical Item entitled [Strategic Challenges in the Global Control of High Pathogenicity Avian Influenza](#) presented at the event, participants discussed the impact of the disease, the fitness for purpose of existing prevention and control tools, international trade impact, and the necessity to enhance global coordination. WOAH Members adopted a [Resolution](#) that will serve as a basis for shaping future avian influenza control activities, while protecting wildlife, supporting the poultry industry and the continuity of trade. The Resolution notably underscores the importance of Members respecting and implementing WOAH international standards to effectively combat avian influenza.

The Commission was updated on the WOAH avian influenza resolution implementation framework that defines the activities, outputs and expected outcomes for the next 2 years to address the strategic challenges in the global control of HPAI that were discussed during the 90th WOAH General Session. This framework has been developed in consultation with the WOAH scientific network, the technical departments at headquarters and regional and subregional offices.

The Commission was briefed on the meeting of the WOAH Working Group on Wildlife which was held in June 2023 at the WOAH Headquarters. Given the global level of concern regarding avian influenza and its potential impact on wildlife, the Working Group prepared a brief statement on considerations associated with emergency vaccination of high conservation value species against avian influenza. The Working Group noted that the current *Terrestrial Code* chapter on avian influenza does not include information relevant to surveillance and reporting of highly pathogenic avian influenza (HPAI) in wild mammals, and to address this, the group submitted comments on the *Terrestrial Code* chapter for consideration. The Working Group discussed the available guidance on response to HPAI outbreaks in marine mammals and proposed next steps to draft a practical guide for field response to HPAI outbreaks in marine mammals, with a focus on biosecurity and sample collection and carcass disposal with the assistance of the WOAH Collaborating Centre Health of Marine Mammals.

The Commission was briefed on the update of the GF-TADs¹⁶ avian influenza strategy. which was last updated in 2008. The strategy is expected to be a short high-level document presenting the background, objectives, theory of change and the governance that rely on strong involvement at regional level. The strategy's purpose is to guide and create a global coordination framework to support regional and country action plans dedicated to the prevention and control of HPAI. The final version of the strategy is expected to be available by the end of the year.

The Commission commended the various activities presented to address the current global avian influenza crisis. In accordance with the [adopted Resolution](#), the Commission agreed on the need to review the *Terrestrial Manual* chapter on avian influenza by Reference Centre experts to ensure the information is up to date with the latest science and fit for purpose. The Commission decided to pay special attention to new developments in diseases causing significant global impacts (e.g. avian influenza, African swine fever) and to prioritise those chapters in the work plan. To this end, the WOAH Reference Laboratories will be asked to review the current *Terrestrial Manual* chapter on avian influenza for important amendments as needed on an immediate basis. The amended chapter will go for one review round and be annexed to the February 2024 report for Member comments with the aim of proposing it for adoption in May 2024. The Commission emphasised the importance for Members to respect and implement of WOAH international standards to effectively combat the disease.

16 GF-TADs: Global Framework for the Progressive Control of Transboundary Animal Diseases

10. Conferences, Workshops, Meetings

10.1. Update on the WAVLD seminar in Lyon, France in 2023 and Commission involvement in future seminars

The 1-day WOAHSeminar had been held on 30 June 2023 during the ISWAVLD (International Symposium of the World Association of Veterinary Laboratory diagnosticians) in Lyon, France. ISWAVLD is an essential biennial meeting for all veterinarians, biologists, scientists and students who are involved to different degrees in research and laboratory diagnosis. The theme of the WOAHSeminar was “Towards the Veterinary Diagnostics of the Future”; the One Health concept was a major theme throughout the agenda of the WAVLD symposium. The WOAHSeminar, a parallel daylong session, promoted the work of laboratory diagnostics, One Health in the laboratory setting, and capacity building and attracted a global audience of veterinary laboratory diagnosticians to advocate the needs of WOAHSeminar Members; the private sector was also present.

The WOAHSeminar had presentations on sustainable laboratory biosafety and biosecurity from recognised experts. Other topics included the challenges of sustainability of veterinary laboratory networks, supporting laboratory leadership in investment case development, countries perspectives of the benefits of the sustainable laboratories approach for national veterinary laboratory networks, update on the global laboratory leadership programme using a One Health approach, outcomes of the WOAHSeminar biosafety research roadmap, grand challenge for sustainable laboratories, safe and cost-effective protocols for shipment of suspected FMD samples for laboratory diagnostics, experience of the laboratory twinning project in ensuring high quality FMD vaccines, the Nagoya protocol and animal health, diagnostic kits and challenges to detection in wildlife. The WOAHSeminar ended with a panel discussion on laboratory equipment management solutions.

The response to the Seminar, as well as WOAHSeminar’s engagement and involvement throughout the Symposium was positive from both the WAVLD Executive Board and the Symposium participants. The next ISWAVLD will occur in Calgary, Canada in June 2025. The Commission agreed to be fully involved by providing technical inputs for the theme and agenda of the WOAHSeminar. The Commission discussed topics that could be of interest for the next Seminar, including emerging transboundary animal diseases that are of importance to WOAHSeminar, novel technologies for animal disease diagnosis, updates on established successful networks such as ASF, FMD, rabies, PPR and avian influenza and the road to eradication of these diseases, how to integrate pen-side tests for disease diagnosis and information on validation techniques.

11. Matters of interest for consideration or information

11.1. Update on OFFLU

In response to the global surge in avian influenza outbreaks, the OFFLU ¹⁷ experts participated in various teleconferences and tripartite risk assessments and shared important data with the scientific community and policy makers. The network released scientific statements to address emerging animal influenza threats which include [statement on high pathogenicity avian influenza caused by viruses of the H5N1 subtype](#), [avian influenza events in mammals](#) and [cats](#).

The Commission was briefed on OFFLU’s contribution to the [February 2023 WHO¹⁸ Consultation on the Genetic and antigenic characteristics of zoonotic influenza A viruses and development of candidate vaccine viruses for pandemic preparedness](#). The network provided sequence data gathered from laboratories in Europe, Asia, Africa, Oceania, and the Americas. For the [avian influenza report](#), they collected 795 avian influenza virus sequences of H5, 34 of H7, and 305 of H9 subtypes. Additionally, for the [swine influenza report](#) they gathered 69 swine influenza virus sequences of H1 and 7 of H3 from WOAHSeminar Reference Centres, national veterinary laboratories, and research networks via the OFFLU network.

An [OFFLU avian influenza matching \(AIM\) initiative](#) to provide information on the real-time antigenic characteristics of contemporary avian influenza viruses is underway. This information will facilitate selection of appropriate vaccines for poultry and updating of poultry vaccine antigens in places where vaccines are being used. A report presenting the results of the pilot project will be made available to stakeholders in October 2023 and networking and expanding the geographical reach of this project with select partners is ongoing.

The OFFLU wildlife technical activity has been sharing data and offering support to countries and working closely with their local public health counterparts to track and monitor risk in response to the H5 mammalian spillovers experienced throughout 2022 and 2023. OFFLU experts released [statements to update the H5N1 events in wild birds](#)

17 OFFLU: Joint WOAHSeminar-FAO Network of Expertise on Animal Influenza

18 WHO: World Health Organization

[in the Americas](#) and the [Europe](#) and also contributed to the [Scientific task force on avian influenza and wild birds statement](#).

The swine influenza virus expert group contributed invaluable information to the WHO vaccine composition meeting for influenza prepandemic preparedness.

The Expert Surveillance Panel of Equine Influenza comprising OFFLU and WHO influenza experts reviewed the recent equine Influenza virus activity in various countries, characteristics of the viruses isolated and provided vaccine recommendations.

11.2. Update on rinderpest

The Commission was updated on the rinderpest post-eradication activities. WOAAH continues to work in partnership with FAO to reduce the RVCM¹⁹ holdings around the world, with the exception of diagnostic materials and vaccines. All seven FAO-WOAAH designated RHF²⁰ had their designations extended as a result of the site inspections of five of these facilities, conducted in 2022. The two remaining facilities will be inspected in 2024. WOAAH will host a meeting on the 25th October 2023 to review inspection SOPs together with representatives of the Smallpox and Polio secretariats and the EuFMD²¹.

The third meeting of the RHF Network will take place at the WOAAH HQ on the 6 and 7 December 2023. The Pirbright Institute will develop a competitive ELISA that only uses non-infectious material in 2024–2025, and this test will be validated by the members of the RHF Network. Currently, two members of the RHF Network are undertaking 'sequence and destroy' projects.

After the site inspection done by independent inspectors in October 2022, and a review of corrective actions by the FAO-WOAAH Rinderpest Joint Advisory Committee (JAC) in September 2023, the Ethiopian National Veterinary Institute has been authorised to start rinderpest (RBOK) vaccine production to replenish the reserve at AU-PANVAC. There has not been any progress in sequestration or destruction of RVCM in the five Members that hold these materials outside of FAO-WOAAH designated RHF²⁰, in spite of several in-person and virtual discussions having been held.

Finally, the GF-TADs Management Committee is overseeing the review of the size and membership of the JAC done by the FAO-WOAAH Rinderpest Secretariat. The JAC will have five members instead of seven and the new membership will be announced during the last trimester of 2023.

11.3. Update on VICH²² activities

The next VICH Steering Committee and Outreach Forum meeting will take place in Tokyo from 13 November to 16 November 2023. There are no vaccine- or biologicals-related VICH Guidelines or Concept Paper for comment at this time. VICH is undergoing a structural reorganisation to better address the needs of the Members who may have diverse expectations of the VICH Forum. This pre-meeting will be the second meeting to discuss the expectations for the future of the VICH Forum and the impact of past 5 years of being a member of the Forum. The agenda for this pre-meeting is being prepared by WOAAH.

11.4. Update on the Grand Challenge for sustainable laboratories

The Commission was updated on plans to launch a Grand Challenge to identify solutions to improve the sustainability of laboratories. A short motion picture was shown that had been premiered at the Biologic Weapons Convention in August 2023. The Commission was also updated on a study to assess the feasibility of running such a Grand Challenge, and informed that a high level meeting would take place in the UK in November 2023 with the aim of convening investment partners to take forward the initiative.

A member of the Commission had been part of the advisory board that reviewed the outcomes of the feasibility study. The member highlighted the importance of engaging local communities and experts in the development of solutions, and pointed out that technological leaps in diagnostic technology could reshape the current laboratory model.

19 RVCM: Rinderpest virus-containing materials

20 Rinderpest holding facilities

21 EuFMD: European Commission for the Control of Foot-and-Mouth Disease

22 VICH is a trilateral (EU-Japan-USA) programme aimed at harmonising technical requirements for veterinary product registration. Its full title is the International Cooperation on Harmonisation of Technical Requirements for Registration of Veterinary Medicinal Products

11.5. Biosafety Research Roadmap

The Commission was updated on the Biosafety Research Roadmap announcing that it had delivered results in two areas: 1. A series of papers had been published in *Applied Biosafety* identifying gaps in the current evidence base for biosafety and biosecurity for 8 selected pathogens, and 2: a review of laboratory acquired infections and laboratory escapes over the past 20 years had been submitted for publication in *Lancet Microbe*. The outcomes of this work would be synthesised into a Chatham House policy paper calling for greater transparency in reporting laboratory accidents and for greater investment in the evidence base for biological risk management.

11.6. Collaboration with WOAAH in the implementation of non-animal testing for veterinary vaccines batch release testing

The WOAAH Antimicrobial Resistance and Veterinary Products Department requested the Commission to provide analysis and comments on WOAAH's assessment on the future collaboration with the Animal Free Safety Assessment Collaboration (AFSA), HealthforAnimals and the International Alliance for Biological Standardization (IABS). The aim is to continue to collaborate on the implementation of non-animal testing for veterinary vaccines batch release testing in the *Terrestrial Manual*: "Implement 3Rs (*Replace, Reduce and Refine*) in Veterinary Vaccines Batch Release Testing". More specifically, the collaboration searches to:

- 1) Review relevant chapters of the *Terrestrial Manual*, add information on all available non-animal testing methodologies, and consider including additional guidance on these methodologies in the disease-specific chapters. The objective of this work is to support industry and regulatory stakeholders to use such new approaches.
- 2) Explore further collaboration on training and scientific education on consistency and non-animal safety and potency tests. The objective of this work is to improve access to and use of alternatives globally.

The collaboration started on 9 May 2022: two webinars, for the Americas and Asia-Pacific regions, and a face-to-face workshop were organised to determine what was needed to facilitate alternative methods validation, implementation and regulatory acceptance, including global harmonisation, of non-animal-based batch release testing for veterinary vaccines. The [report](#) from the webinars and workshop was published in the journal *Biologicals* in July 2023.

The Commission agreed on the value of continuing this collaboration, and requested further information on the 3Rs process to define and select alternative methods to ensure quality, validation and equivalency with existing methods.

11.7. Update on the development of guidelines for alternative strategies for the control of *Mycobacterium tuberculosis* complex infection in livestock

The Commission was informed of the development of Guidelines for Alternative Strategies for the Control of *Mycobacterium tuberculosis* complex infection in livestock. The guidelines are being developed by two consultants who began their work in May 2023. The objective is to illustrate selected tuberculosis control strategies that are flexible and adaptable to the changing conditions of real-world scenarios, taking into account socioeconomic and cultural settings.

The consultancy will identify existing science-based strategies for the control of *M. tuberculosis* complex infection in livestock other than slaughter and testing. The methodology will involve a literature review and the elicitation of expert opinion through surveys, interviews, and focus group discussions. This document will be reviewed upon an *ad hoc* Group expected to convene in January 2024.

The Commission emphasised the importance of presenting this document during the General Session in 2024.

11.8. Composition of the WOAAH editorial board for the *Scientific and Technical Review*

The Head of the Publications Unit explained why a new Editorial Board was being established for WOAAH's peer reviewed journal, the *Scientific and Technical Review*. Although the content is of high quality and robust editorial and reviewing processes are in place, the publication lacks governance to ensure its scientific credibility.

The Editorial Board will monitor and foster the quality and impact of the *Scientific and Technical Review* and will also advise on WOAAH's overall publications strategy on request. The role of the Board will be mainly advisory but they will also participate occasionally in reviewing content and will attend two meetings per year.

WOAH would ask the Commission members if anybody would be willing to join the Editorial Board. Given that the mandate of the current Commission will end in May 2024, the term of the first nominated candidate will run until

September 2024. If no member of the Commission could commit to the role, then WOAAH could ask other experts outside the Commission if they would like join the board.

The Commission agreed that the creation of a new Editorial Board would be a positive step forward for WOAAH's publications.

11.9. Update on activities under the IHSC²³-WOAH collaboration agreement and consultancy project in Asia

The Commission was updated on the activities carried out between 2022 and 2023 under the collaboration agreement between WOAAH and the IHSC. These activities include:

- The collaboration of the horse industry to improve WOAAH Standards with regard to equine-related diseases;
- The development of diagnostic capabilities (i.e. glanders) and vaccines for horses (i.e. African horse sickness inactive vaccine and vaccine banks);
- The implementation of tools to facilitate the safe movements of competition horses.

The Commission was also briefed on the state of play and activities of two consultancy projects in South America and in Asia and the Pacific Region, particularly in terms of the assessment of laboratory capacity to diagnose equine diseases and the organisation several webinars on equine-related diseases to enhance preparedness.

The Commission commended the work conducted under this collaboration agreement and emphasised the importance of enhancing the diagnostic capabilities for equine encephalitides in the Americas.

11.10. Update on the virtual biobank project

The Commission was briefed on the reactivation of the Virtual Biobank project in April 2023, with the WOAAH Collaborating Centre for Veterinary Biologicals Biobank, host by Istituto Zooprofilattico Sperimentale della Lombardia e dell'Emilia Romagna (IZSLER), Italy, taking the lead. The project was on hold due to the SARS-CoV-2 pandemic; the new timeline aims at completing the development of the web platform in 2024.

The project is currently in the development phase, with ongoing efforts to create the design a prototype. IZSLER's IT technical team is working in collaboration with the WOAAH IT and Communication teams to build the project's website. Discussions are currently taking place between both IT teams regarding the web page server, where the architecture and design of the website will be stored.

To ensure that the project progresses, monthly meetings are being convened to deliberate on the project's advancement.

.../Annexes

23 IHSC: International Horse Sports Confederation

Annex 1. Adopted Agenda

MEETING OF THE WOAHP BIOLOGICAL STANDARDS COMMISSION

Paris, 4–8 September 2023

1. Welcome

- 1.1. Director General
- 1.2. Deputy Director General, International Standards and Science
- 1.3. Updates from the WOAHP Headquarters

2. Adoption of Agenda

3. Collaboration with other Commissions

- 3.1. Horizontal issues among the Specialist Commissions
 - 3.1.1. Infection New World (*Cochliomyia hominivorax*) and Old World (*Chrysomya bezziana*) screwworms, and Crimean–Congo haemorrhagic fever (revisited)
- 3.2. Scientific Commission for Animal Diseases
 - 3.2.1. Nothing for this meeting.
- 3.3. Terrestrial Animal Health Standards Commission
 - 3.3.1. Updates from the February 2023 Code Commission meeting
 - 3.3.2. Biological Standards Commission's recommendations to the Terrestrial Animal Health Standards Commission
 - 3.3.3. Meeting of the Bureaus (7 September)
 - 3.3.4. Questions on Chapter 12.6 *Infection with equine influenza virus*
 - 3.3.5. Comments on Chapter 5.8. *International transfer and laboratory containment of animal pathogenic agents*
 - 3.3.6. Questions on Chapter 6.10. *Responsible and prudent use of antimicrobial agents in veterinary medicine*
- 3.4. Aquatic Animal Health Standards Commission
 - 3.4.1. Nothing for this meeting.

4. Work Programme

5. Manual of Diagnostic Tests and Vaccines for Terrestrial Animals

- 5.1. Review of draft chapters received for endorsement for circulation for first round Member comment
- 5.2. Follow-up from September 2022: conclusions and recommendations from the WOAHP *Scientific and Technical Review* issue on diagnostic test validation science
 - 5.2.1. Progress on development of a validation report form for tests recommended in the *Terrestrial Manual*
 - 5.2.2. Progress on development of a template for a new *Terrestrial Manual* section on the rationale behind the selection of tests included in Table 1. *Test methods available and their purpose*
- 5.3. Inclusion of videos on diagnostic techniques on the WOAHP website disease portals: review of submitted videos
- 5.4. Further review of Chapter 1.1.6 *Validation of diagnostic assays for infectious diseases of terrestrial animals*
- 5.5. Follow-up from February 2023: need for a definition of latent period in the chapter on foot and mouth disease
- 5.6. Review and alignment of the validity criteria of the PD₅₀ and PPG tests for foot and mouth disease between the *Terrestrial Manual* and the European Pharmacopoeia
- 5.7. Purpose of the list of contributors and addresses in the *Terrestrial Manual*
- 5.8. Publication of Member comments and need to review the Commission's practice
- 5.9. *Terrestrial Manual* status: update on chapters selected for the 2024/2025 review cycle
- 5.10. Update on WOAHP Standards Online Navigation Tool Project
- 5.11. *Terrestrial Manual* chapters on non-listed diseases

6. WOAH Reference Centres

- 6.1. Improving and automating the performance review for annual reports of Reference Laboratories using a risk-based approach
- 6.2. Applications for WOAH Reference Centre status
- 6.3. Changes of experts at WOAH Reference Centres
- 6.4. Review of new and pending applications for laboratory twinning
- 6.5. Analysis of the questionnaire sent to all Reference Laboratories
Reference Laboratories – Implementation of the SOPs
- 6.6. Feedback from Laboratories that are not complying with the key ToRs:
Collaborating Centres – Implementation of the SOPs
- 6.7. Develop a plan of how to evaluate the progress made since Centres submitted their 5-year work plans
Reference Centre networks
- 6.8. Update on the three Reference Laboratory networks (African swine fever, peste des petits ruminants and rabies)
- 6.9. Review of the current list of Main Focus Areas and Specialties
- 6.10. Clarify the role of the Contact Point in providing advice and services to WOAH Members

7. Ad hoc Groups: Update on activities of past ad hoc Groups

- 7.1. Ad hoc Group on Replacement of the International Standard Bovine Tuberculin (ISBT) and Avian Tuberculin (ISAT)

8. International Standardisation/Harmonisation

- 8.1. WOAH Register of diagnostic kits: update and review of new or renewed applications
 - 8.1.1. Ongoing application for Genelix™ ASFV real-time PCR detection kit
 - 8.1.2. Renewal of Avian Influenza Antibody test kit (registration number 20080203)
 - 8.1.3. Renewal of Newcastle Disease Antibody test kit (registration number 20140109)
 - 8.1.4. Update on WOAH SOP and application form
- 8.2. Standardisation programme
 - 8.2.1. Association française de normalisation: follow-up from February 2023
 - 8.2.2. Project to extend the list of WOAH approved reference reagents: review of guidelines

9. Follow-up from the General Session

- 9.1. Excerpt from the Final Report: comments from Members
- 9.2. The Animal Health Forum and the adopted Resolution on avian influenza

10. Conferences, Workshops, Meetings

- 10.1. Update on the WAVLD seminar in Lyon, France in 2023 and Commission involvement in future seminars

11. Matters of interest for consideration or information

- 11.1. Update on OFFLU
- 11.2. Update on rinderpest
- 11.3. Update on VICH activities
- 11.4. Update on the Grand Challenge for sustainable laboratories
- 11.5. Biosafety Research Roadmap
- 11.6. Collaboration with WOAH in the implementation of non-animal testing for veterinary vaccines batch release testing
- 11.7. Update on the development of guidelines for alternative strategies for the control of *Mycobacterium tuberculosis* complex infection in livestock
- 11.8. Composition of the WOAH editorial board for the *Scientific and Technical Review*
- 11.9. Update on activities under the IHSC²⁴-WOAH collaboration agreement and consultancy project in Asia
- 11.10. Update on the virtual biobank project

24 IHSC: International Horse Sports Confederation

Annex 2. List of Participants

MEETING OF THE BIOLOGICAL STANDARDS COMMISSION

Paris, 4–8 September 2023

MEMBERS OF THE COMMISSION

Prof. Emmanuel Couacy-Hymann
(President)
Professor of Virology
CNRA/LIRED
Abidjan
CÔTE D'IVOIRE

Prof. Ann Cullinane
(Vice-President)
Head of Virology Unit
Irish Equine Centre
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Dr John Pasick
(Vice-President)
Formerly National Centre for
Foreign Animal Disease
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Dr Joseph S. O'Keefe
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Prof. Chris Oura
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Dr Gregorio Torres
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Science Department

Dr Charmaine Chng
Deputy Head
Science Department

Dr Mariana Delgado
Scientific Secretariat Officer
Science Department

Annex 3. Work Programme for the WOAHA Biological Standards Commission

MEETING OF THE BIOLOGICAL STANDARDS COMMISSION

Paris, 4–8 September 2023

Subject	Issue	Status and Action
Updating the <i>Terrestrial Manual</i>	1) Circulate the chapters approved by the BSC to Members for first-round comment	October 2023
	2) Remind authors of the chapters identified previously for update but not yet received and invite authors of chapters newly identified for update	On-going
	3) Create a database of validation reports to be published on the WOAHA Website for tests recommended in the <i>Terrestrial Manual</i>	On-going
	a) Finalise the template for the validation report for current and future tests recommended in the <i>Terrestrial Manual</i> and make available to Reference Laboratory experts for submission for new or existing tests	December 2023
	4) Add a new section to the disease-specific chapters to describe the rationale behind the selection of tests for different purposes given in Table 1 <i>Test methods available and their purpose</i> and an explanation for their score. Subsequently, add links to the validation reports (point 3 above)	Accomplished
	a) Send the template for this new section to the experts updating Manual chapters asking they use it or provide a justification in an alternative format of their choice	Accomplished
	5) Ask Reference Centres to provide links to suitable instructional videos to be added to the end of the disease-specific chapters. Videos to be reviewed by the BSC when the chapter is up for review	On-going
	6) Develop criteria for removing chapters for nonlisted diseases and assess those chapters against the criteria	For February
	7) Review new developments in diseases causing significant global impacts (e.g. avian influenza, African swine fever) and prioritise those chapters	On-going
Collaborating Centres	1) Implementation of the adopted SOPs:	
	a) Develop a template for the Collaborating Centres for the report of their assessment of their performance in the past 5-years to be compared with the 5-year work plan	For September 2024
	2) Review the designations of those Centres that completed 5 years	February 2025
	3) Ask the Contact Point to nominate a first point of contact to address requests for assistance, enquires, etc. on behalf of the Centre	October/November 2023

Subject	Issue	Status and Action
Reference Laboratories	1) Put under-performing labs on watch list	On going
	2) Implement the new system for evaluating annual reports and provide list of assigned reports to BSC members	For October 2023
	3) Send feedback to the Reference Laboratory network on the questionnaire	October 2023
	4) Develop a concept note for a global conference of Reference Centres	February 2024
	5) Explore enhancements to the annual report process: the possibility of filling in the annual report template throughout the year	On-going
Reference Centre Networks	1) Follow up with the three newly launched Reference Laboratory networks (ASF, PPR and rabies)	On-going
Standardisation/ Harmonisation	1) Project to extend the list of WOAHA-approved reference reagents	On-going
	2) Ask the networks to review the template and three guidelines for approved reagents with the view to making the procedure less stringent so more Reference Laboratories may apply for recognition	For February 2024
	3) Project to develop Replacement International Standard Bovine and Avian Tuberculin: finalise report and propose for adoption	On-going
Ad hoc Groups	1) <i>Ad hoc</i> Group on Sustainable Laboratories	On-going
Projects	1) Veterinary Biobanking (project)	On-going
Conferences, Workshops and Meetings with participation by BSC Members	1) Biosafety research roadmap	On-going
	2) ISWAVLD OIE Seminar: develop a theme and programme and speakers	June 2025 in Canada
Performance	1) Engage with the ongoing processes around performance issues with Reference Laboratories	On-going
Develop laboratory standards for emerging diseases	1) Discuss the <i>Terrestrial Code</i> chapter once adopted with the aim of introducing a corresponding chapter for the <i>Terrestrial Manual</i>	After May 2024
Case definitions	1) Follow up the implementation of the SOPs for case definitions	On-going

2 MEETING OF THE WOAH BIOLOGICAL STANDARDS COMMISSION

3 Paris, 4–8 September 2023

4

5

6 CHAPTER 1.1.5.

7 QUALITY MANAGEMENT IN VETERINARY
8 TESTING LABORATORIES

9 SUMMARY

10 *Valid laboratory results are essential for diagnosis, surveillance, and trade. Such results are ~~achieved by the~~*
11 *~~use assured through implementation of good a management practices, valid system that supports accurate~~*
12 *~~and consistent test and calibration methods, proper techniques, quality control and quality assurance, all~~*
13 *~~working together within a quality management system. Laboratory quality management includes technical,~~*
14 *~~managerial, and operational elements of testing performing, interpreting and the interpretation of reporting~~*
15 *~~test results. A quality management system enables the laboratory to demonstrate both competency and an~~*
16 *~~ability to generate consistent technically valid results that meet the needs of its customers. The need for~~*
17 *~~Mutual recognition and acceptance of test results for international trade, and the acceptance accreditation~~*
18 *~~of tests to international standards such as ISO/IEC²⁵ 17025:2005 (General Requirements for the~~*
19 *~~Competence of Testing and Calibration Laboratories) (ISO/IEC, 2005–2017b) requires good-suitable~~*
20 *~~laboratory quality management systems. This chapter is not intended to reiterate the requirements of~~*
21 *~~ISO/IEC 17025, nor has it been endorsed by accreditation bodies. Rather, it outlines the important issues~~*
22 *~~and considerations a laboratory should address in the design and maintenance of its quality management~~*
23 *~~system, whether or not it has been formally accredited regardless of formal accreditation status. Chapter~~*
24 *~~1.1.1 Management of veterinary diagnostic laboratories gives an introduction to veterinary diagnostic~~*
25 *~~laboratories introduces the components of governance and management of veterinary laboratories that are~~*
26 *~~necessary for the effective delivery of diagnostic services, and highlights the critical elements that should be~~*
27 *~~established as minimum requirements.~~*

28 **A. KEY CONSIDERATIONS FOR THE DESIGN AND MAINTENANCE OF A**
29 **LABORATORY QUALITY MANAGEMENT SYSTEM**

30 To ensure that the quality management system is appropriate and effective, the design must be carefully ~~thought out~~
31 ~~planned~~ and, where accreditation is sought, must address all criteria of the appropriate quality standard. The major
32 ~~categories of considerations and the their associated~~ key issues and activities ~~within each of these categories~~ are outlined
33 in the following eight sections of this chapter.

25 ISO/IEC: International Organization for Standardization/International Electrochemical Commission.

34 1. The work, responsibilities, and goals of the laboratory

35 Many factors affect the necessary elements and requirements of a quality management system. ~~These factors include,~~
36 including:

- 37 i) ~~Type of testing~~ done performed, e.g. research versus diagnostic work;
- 38 ii) ~~Purpose and requirements of the test results, e.g. for import or /export quarantine~~ testing, surveillance, emergency
39 disease exclusion, declaration of freedom from disease post-outbreak;
- 40 iii) ~~Potential impact of a questionable or, erroneous or unfavourable~~ result, e.g. detection of foot and mouth disease
41 (FMD) in an FMD-free country;
- 42 iv) ~~The tolerance level of Risk and liability~~ tolerance, e.g. vaccination vs versus culling or /slaughter;
- 43 v) ~~Customer needs (requirements, e.g. sensitivity and specificity of the test method, cost, turnaround time, strain or~~
44 genotype level of characterisation), e.g. for surveillance, or declaration of freedom after outbreak;
- 45 vi) ~~The role of the laboratory~~ Role in legal work or in regulatory programmes, e.g. for disease eradication and declaration
46 of disease freedom to the WOAHP;
- 47 vii) ~~The role of the laboratory~~ Role in assisting with, confirming, or overseeing the work of other laboratories (e.g. as a
48 reference laboratory);
- 49 viii) ~~Business goals of the laboratory,~~ including the need for any third-party recognition or accreditation.

50 2. Standards, guides, and references

51 The laboratory should ~~choose reputable and accepted~~ follow globally recognised standards and ~~guides~~ to assist in
52 designing the quality management system. For laboratories seeking ~~accreditation formal recognition~~ of testing competency,
53 and for all WOAHP Reference Laboratories, the use of ISO/IEC 17025 (ISO/IEC, ~~2005-2017b~~) or equivalent ~~will be is~~
54 essential. This standard ~~includes specifies~~ managerial and technical requirements and accredited laboratories ~~that are~~
55 compliant are regarded as competent. Further information on standards may be obtained from the national standards body
56 of each country, from the International Laboratory Accreditation Cooperation (ILAC)²⁶, and from accreditation bodies, e.g.
57 ~~the National Association of Testing Authorities (NATA), Australia, the United Kingdom Accreditation Service (UKAS), the~~
58 ~~American Association for Laboratory Accreditation (A2LA), etc.~~ Technical and international organisations such as AOAC
59 International (The Scientific Association Dedicated to Analytical Excellence; formerly the Association of Official Analytical
60 Chemists) and the International Organization for Standardization (ISO) publish useful references, guides, application
61 documents and standards that supplement the general requirements of ISO/IEC 17025. Other relevant documents may
62 include guides and application documents providing interpretative criteria and recommendations for the application of
63 ISO/IEC 17025 in the field of veterinary testing for both applicant and accredited facilities, e.g.
64 [https://www.nata.com.au/phocadownload/spec-criteria-guidance/animal-health/Animal-Health-ISO-IEC-17025-](https://www.nata.com.au/phocadownload/spec-criteria-guidance/animal-health/Animal-Health-ISO-IEC-17025-Appendix.pdf)
65 [Appendix.pdf](https://www.nata.com.au/files/2021/05/Animal-Health-ISO-IEC-17025-Appendix-effective-March2021.pdf) ~~https://www.nata.com.au/files/2021/05/Animal-Health-ISO-IEC-17025-Appendix-effective-March2021.pdf;~~
66 Newberry & Colling, 2021.

67 The ISO International Standard 9001 (ISO, 2015), ~~is a certification standard~~ specifies the requirements for quality
68 management systems and while it may be a useful ~~supplement framework to a~~ underpin a laboratory quality system,
69 fulfilment of its requirements ~~does~~ not necessarily ~~ensure or imply~~ assure technical competence (in the areas listed in
70 Section 3 *Accreditation*). Conformance to the requirements of ISO 9001 is assessed by a certification body that is
71 accredited ~~to undertake such assessments~~ by the national accreditation body to undertake such assessments. When a
72 laboratory meets the requirements of ISO 9001, the term *registration* or *certification* is used to indicate conformity, not
73 *accreditation*.

74 With the advent of stronger alliances between medical and veterinary diagnostic testing under initiatives such as “One
75 Health”, some laboratories may ~~wish to choose~~ to follow other ISO standards such as ISO 15189 Medical Laboratories –
76 Requirements for Quality and Competence (ISO/IEC, 2012), ~~which include 2022),~~ for testing of human samples, e.g. for
77 zoonotic diseases. It should be noted that for veterinary laboratories, limited availability of suitable material may render
78 validation difficult; under these circumstances it is necessary to highlight the limited validation status when reporting results
79 and their interpretation (Stevenson *et al.*, 2021).

80 3. Accreditation

81 ~~If the laboratory decides to proceed with~~ formal recognition of ~~its a laboratory's~~ quality management system and testing,
82 ~~then is sought~~ third party verification of its conformity with the selected standard(s) ~~will be is~~ necessary. ILAC has published
83 specific requirements and guides for laboratories and accreditation bodies. Under the ILAC system, ISO/IEC 17025 is to

26 ILAC: The ILAC Secretariat, PO Box 7507, Silverwater, NSW 2128, Australia; <http://ilac.org/>

84 be used for laboratory accreditation of testing or calibration activities. Definitions regarding laboratory accreditation may
85 be found in ISO/IEC International Standard 17000: Conformity Assessment – Vocabulary and General Principles (ISO/IEC,
86 2004a-2020). Accreditation is ~~not~~ dependent on demonstrated competence, which ~~is~~ encompasses significantly more
87 than having and following documented procedures. Providing a competent and customer-oriented service also ~~means that~~
88 the laboratory requires:

- 89 i) Adequate facilities and environmental controls;
- 90 ii) ~~Has~~ Appropriately qualified and trained personnel with a depth of technical knowledge commensurate with
91 appropriate level of authority;
- 92 iii) ~~Has appropriate~~ Equipment with planned that is appropriately verified and managed in accordance with the relevant
93 maintenance and calibration schedule;
- 94 ~~iv) Has adequate facilities and environmental control~~;
- 95 ~~v) Has procedures and specifications that ensure accurate and reliable results~~;
- 96 ~~vi) Implements continual improvements in testing and quality management~~;
- 97 ~~vii) Can assess the need for and implement appropriate corrective or preventive actions, e.g. customer satisfaction~~;
- 98 ~~viii) Accurately assesses and controls uncertainty in testing~~;
- 99 ix) Appropriate sample and materials management processes;
- 100 x) ~~Has~~ Technically valid and validated test methods, procedures and specifications ~~that are~~ documented in accordance
101 with the requirements of the applicable standard or guidelines, e.g. Chapter 1.1.6 *Principles and methods of validation*
102 *of diagnostic assays for infectious diseases* and chapters 2.2.1 to 2.2.8 *Recommendations for validation of diagnostic*
103 *tests and Special Issue of the Scientific and Technical Review (2021)*²⁷;
- 104 xi) ~~Demonstrates~~ Demonstrable proficiency in the applicable test methods ~~used~~ (e.g. by regular participation in
105 proficiency ~~tests on a regular basis testing schemes~~);
- 106 xii) Accurate assessment and control of the measurement of uncertainty in testing;
- 107 xiii) Good documentation practices, e.g. ALCOA+ principles (i.e. Attributable, Legible, Contemporaneous, Original,
108 Accurate, Complete, Consistent, Enduring, Available);
- 109 xiv) Non-conformance management process, including detection, reporting, risk-assessment and implementation of
110 effective corrective and preventive actions;
- 111 xv) Complaints management;
- 112 xvi) Adequate control of data and information;
- 113 xvii) Appropriate reporting and approval process;
- 114 xviii) Culture of continual improvement;
- 115 xix) Has demonstrable competence to generate technically valid results.

116 **4. Selection of an accreditation body**

117 To facilitate the acceptance of the laboratory's test results for trade, the accreditation standard used must be recognised
118 by the international community and the accreditation body recognised as competent to accredit laboratories. Programmes
119 for the recognition of accreditation bodies are, in the ILAC scheme, based on the requirements of ISO/IEC International
120 Standard 17011: Conformity Assessment – General Requirements for Accreditation Bodies Accrediting Conformity
121 Assessment Bodies (ISO/IEC, 2004b-2017a). Information on recognised accreditation bodies may be obtained from the
122 organisations that recognise them, such as the Asia-Pacific Accreditation Cooperation (APAC), the Inter-American
123 Accreditation Cooperation (IAAC), and the European Co-operation for Accreditation (EA).

124 Accreditation bodies may also be signatory to the ILAC and regional (e.g. APAC) mutual recognition arrangements (MRAs).
125 These MRAs are designed to reduce technical barriers to trade and further facilitate the acceptance of a laboratory's test
126 results in foreign markets. Further information on the ILAC MRA may be obtained from the www.ilac.org.

127 **5. Determination of the scope of the quality management system or of the laboratory's** 128 **accreditation**

27. Available at: <https://doc.woah.org/dyn/portal/index.xhtml?page=alo&alold=41245>

129 The scope of the quality management system should cover all areas of activity affecting all include all activities that impact
130 testing that is done at performed by the laboratory. Whilst only accredited laboratories are obliged to meet the requirements
131 of the relevant standard as detailed below, these, the guiding principles should be considered best practise and are relevant
132 to all testing laboratories.

133 ~~Laboratories accredited~~ A laboratory's accreditation to ISO/IEC 17025 have includes a specific list of these accredited tests
134 that are accredited, called, referred to as the schedule or scope of accreditation or the scope. Veterinary testing facilities
135 include government and private facilities, veterinary practices, university veterinary schools, and other laboratories for the
136 testing of animals and animal products for the diagnosis, monitoring and treatment of disease. In principle, if new testing
137 methods are introduced these must be assessed and accredited before they can be added to the scope, however a flexible
138 scope can be implemented that assesses the laboratory as competent to add tests to scope, which are then formally added
139 at the next accreditation visit. The quality management system should ideally cover all areas of activity affecting all testing
140 that is done at the laboratory. However, it is up to the laboratory to decide which tests are to be accredited and included in
141 the scope. If an accredited laboratory also offers unaccredited non-accredited tests, these must be clearly indicated as
142 such on any reports that claim or make reference to accreditation. Factors-It is ultimately the decision of the laboratory to
143 decide which tests require inclusion in the scope of accreditation, and factors that might affect the laboratory's choice of
144 tests for scope of accreditation this decision include:

- 145 i) ~~The impact of initial accreditation on resources within a given deadline;~~
- 146 ii) Associated risks and opportunities;
- 147 iii) Initial investment required (e.g. time, resources);
- 148 iv) A-Contractual requirement for accredited testing (e.g. for international trade, research projects);
- 149 v) ~~The~~ Importance of the test and the potential impact of an incorrect result;
- 150 vi) The cost of maintaining an accredited test versus frequency of use;
- 151 vii) Availability of personnel, facilities and equipment;
- 152 viii) Availability of appropriate materials and reference standards (e.g. standardised reagents, internal quality control
153 samples controls, reference cultures) and
- 154 ix) Access to proficiency testing schemes;
- 155 x) The quality assurance-control processes necessary for materials, reagents and media;
- 156 xi) The validation status, e.g. access to field samples from infected and non-infected animals, technical complexity and
157 reliability of the test method;
- 158 xii) ~~The~~ Potential for subcontracting of accredited tests.

159 **6. Quality assurance, quality control and proficiency testing**

160 Quality assurance (QA) is the ~~part element~~ of quality management focused on providing confidence that quality defined
161 requirements will be are fulfilled. The requirements may be internal or defined in an accreditation or certification standard.
162 QA is process-oriented and ensures provides the right things are being done in the right way appropriate inputs to prevent
163 problems arising.

164 Quality control (QC) is the systematic and planned monitoring of outputs to ensure ~~the minimum levels of quality~~
165 requirements have been met. For a testing laboratory, this ~~is to ensure test processes ensures tests~~ are working correctly
166 performing consistently and reliably, and results are within the expected acceptable parameters and limits. QC is test
167 orientated and ensures the results are as expected oriented and ensures detection of any problems that arise.

168 Proficiency testing (PT), sometimes referred to as external quality assurance ~~or (EQA)~~, is the ~~determination assessment~~
169 of a laboratory's performance by when testing a standardised panel of specimens of undisclosed content. Ideally, PT
170 schemes should be run managed by an external independent provider. Participation in proficiency testing schemes enables
171 the laboratory to assess and demonstrate the their testing reliability of results by in comparison with those from other
172 participating laboratories.

173 All laboratories should, where possible, participate in external proficiency testing schemes appropriate to ~~their testing~~
174 Participation the suite of tests provided; participation in such schemes is a requirement for accredited laboratories. This
175 provides an independent assessment of the testing methods used and as well as the level of staff competence. If such
176 schemes are not available, valid alternatives may be used, such as ring trials organised by reference laboratories, inter-
177 laboratory testing, use of certified reference materials or internal quality control samples, replicate testing using the same
178 or different methods, retesting of retained items, and or correlation of results for different characteristics of a specimen.

179 Providers and operators of proficiency testing programmes should be accredited to ISO/IEC 17043 – Conformity
180 Assessment – General Requirements for Proficiency Testing (ISO/IEC, 2010).

181 Proficiency testing material from accredited providers ~~has been~~ is well characterised and any spare material, once the
182 proficiency testing has been completed, can be useful to demonstrate staff competence or for test validation. Information
183 about selection and use of reference samples and panels is available in Chapter 2.2.6 *Selection and use of reference*
184 *samples and panels*. Proficiency testing and reproducibility scenarios are described by Johnson & Cabuang (2021) and
185 Waugh & Clark (2021), respectively.

186 7. Test methods

187 ISO/IEC 17025 requires the use of appropriate test methods and has requirements for their selection, development, and
188 validation to ~~show~~ demonstrate fitness for purpose.

189 This *Terrestrial Manual* provides recommendations on the selection of test methods for trade, diagnostic and surveillance
190 purposes in the chapters on specific diseases. Disease-specific chapters include, or will include in the near future, a table
191 of the tests available for the disease, graded against the test's fitness for purpose; these purposes are defined in the WOA
192 Validation Template (chapter 1.1.6), which identifies six main purposes for which diagnostic tests may be carried out. The
193 table is intended ~~to be as~~ a general guide to test application; ~~the fact that a test is recommended does not necessarily~~
194 mean that a laboratory is competent to perform it. The laboratory quality system should incorporate provision of evidence
195 of competency.

196 In ~~the veterinary profession laboratories~~, other standard methods (published in international, regional, or national
197 standards) or fully validated methods (having undergone a full collaborative study and that are published or issued by an
198 authoritative technical body such as the AOAC International) may be preferable to use, but ~~may not be~~ available. Many
199 veterinary laboratories develop or modify methods, and most laboratories have test systems that use non-standard
200 methods, or a combination of standard and non-standard methods. In veterinary laboratories, even with the use of standard
201 methods, some in-house evaluation, optimisation, or validation is generally ~~must be done~~ required to ensure valid results.

202 Customers and laboratory staff must have a clear understanding of the performance characteristics of the test, and
203 customers should be informed if the method is non-standard. Many veterinary testing laboratories will therefore need to
204 demonstrate competence in the development, adaptation, verification and validation of test methods.

205 This *Terrestrial Manual* provides more detailed and specific guidance on test selection, optimisation, standardisation, and
206 validation in chapter 1.1.6. ~~Chapter 1.1.6 refers to chapters 2.2.1–2.2.8~~ Recommendations for validation of diagnostic tests
207 ~~that~~ deal with the development and optimisation of fundamentally different assays such as antibody, antigen and nucleic
208 acid detections tests, measurement uncertainty, statistical approaches to test validation, selection and use of reference
209 samples and panels, validation of diagnostic tests for wildlife, and comparability experiments after changes in a validated
210 test method.

211 The following are key test method issues for those involved in the quality management of the laboratory.

212 7.1. Selection of the test method

213 Valid results begin with the selection of a test method that meets the needs of the laboratory's customers in
214 addressing their specific requirements (fitness for purpose). Some issues relate directly to the laboratory, others to
215 the customer.

216 7.1.1. Considerations for the selection of a test method

- 217 i) International acceptance;
- 218 ii) Scientific acceptance;
- 219 iii) Appropriate or current technology;
- 220 iv) Suitable performance characteristics (e.g. analytical and diagnostic sensitivity and specificity,
221 repeatability, reproducibility, isolation rate, limits of detection, precision, trueness, and
222 uncertainty);
- 223 v) Suitability of the test in the species and population of interest;
- 224 vi) Sample type (e.g. serum, tissue, milk) and its expected quality or state on arrival at the laboratory;
- 225 vii) Test target (e.g. antibody, antigen, live pathogen, nucleic acid sequence);

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- 226 viii) Test turnaround time;
 - 227 ix) Resources and time available for development, adaptation, evaluation;
 - 228 x) Intended use (e.g. export, import, surveillance, screening, diagnostic, confirmatory);
 - 229 xi) ~~Safety factors and biocontainment requirements;~~
 - 230 xii) Customer expectations;
 - 231 xiii) ~~Throughput of test~~ Sample numbers and required throughput (automation, robot);
 - 232 xiv) Cost of test, per sample;
 - 233 xv) Availability of reference standards, reference materials and proficiency testing schemes. (See
 - 234 also chapter 2.2.6.).

235 7.2. Optimisation and standardisation of the test method

236 Once the method has been selected, it must be set up at the laboratory. Additional optimisation is necessary, whether
237 the method was developed in-house (validation) or imported from an outside source (verification). Optimisation
238 establishes critical specifications and performance standards for the test process as used in a specific laboratory.

239 7.2.1. Determinants of optimisation

- 240 i) Critical specifications for equipment, ~~instruments consumables, and~~ reagents (e.g. chemicals,
241 biologicals), reference standards, reference materials, and internal controls;
- 242 ii) Robustness – critical control points and acceptable ranges, attributes or behaviour at critical
243 control points, using statistically acceptable procedures;
- 244 iii) Quality control activities necessary to monitor critical control points;
- 245 iv) The type, number, range, frequency, and arrangement of test run controls;
- 246 v) Criteria for ~~non-subjective~~ objective acceptance or rejection of ~~a batch of~~ test results;
- 247 vi) Criteria for ~~the~~ interpretation and reporting of test results;
- 248 vii) ~~A-Documented test method and reporting procedure for use by laboratory staff;~~
- 249 viii) Evidence of technical competence for those ~~who performing~~ the test ~~processes methods,~~
250 authorising test results and interpreting results.

251 7.3. Validation of the test method

252 Test method validation evaluates the test for ~~its~~ fitness for a given use purpose by establishing test performance
253 characteristics such as sensitivity, specificity, and isolation rate; and diagnostic parameters such as positive or
254 negative cut-off, repeatability, reproducibility and titre of interest or significance. Validation should be ~~done~~ performed
255 using an optimised, documented, and fixed procedure. The extent and depth of the validation process will depend on
256 logistical and risk factors. ~~It and~~ may involve any number of activities and amount of data, with subsequent data
257 analysis using appropriate statistical methods (Chapter 1.1.6). Acknowledging diagnostic test validation science as
258 a key element in the effective detection of infectious diseases, WOH recently published a Special Issue representing
259 an up-to-date compilation of the relevant standards (WOAH and non-WOAH) and guidance documents for all stages
260 of diagnostic test validation and proficiency testing, including design and analysis, as well as clear, complete and
261 transparent reporting of validation studies in the peer-reviewed literature (Colling & Gardner, 2021). It is important to
262 note that the current version of ISO 17025:2017 specifies that personnel must be authorised to perform validation
263 and related activities, which means that training in validation and verification methods, including results interpretation,
264 is likely to become more important to prove competence (Colling & Gardner, 2021).

265 7.3.1. Activities that validation might include

- 266 i) Field or epidemiological studies, including disease outbreak investigations and testing of samples
267 from infected and non-infected animals;
- 268 ii) Development of testing algorithms for specific purposes, e.g. surveillance, outbreak
269 investigations, etc.;
- 270 iii) Repeat testing in the same laboratory to establish the effect of variables such as operator,
271 reagents, equipment;
- 272 iv) Comparison with other, preferably standard methods and with reference standards (if available);

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- 273 v) Collaborative studies with other laboratories using the same documented method. Ideally
274 organised by a reference laboratory and including testing a panel of samples of undisclosed
275 composition or titre with expert evaluation of results and feedback to the participants to estimate
276 reproducibility;
- 277 vi) Reproduction of data from an accepted standard method, or from a ~~reputable peer-reviewed~~
278 publication (verification);
- 279 vii) Experimental infection ~~or disease outbreak~~ studies;
- 280 viii) Analysis of internal quality control data.

281 Validation is always a balance between cost, risk, and technical possibilities. There may be cases where
282 ~~quantities such as only basic~~ accuracy and precision can ~~only be given determined, e.g. when the disease is~~
283 not present in a simplified way country or region. Criteria and procedures for the correlation of test results for
284 diagnosis of disease status or for regulatory action must be developed. The criteria and procedures developed
285 should account for screening methods, retesting and confirmatory testing.

286 ~~Test validation is covered in chapter 1.1.6.~~

287 **7.4. Uncertainty of the test method**

288 Statistically relevant numbers of samples from infected and non-infected animals are discussed in chapter 1.1.6. test
289 validation and chapter 2.2.5 statistical approaches to validation.

290 **7.4. Estimation of Measurement Uncertainty**

291 Measurement of Uncertainty (MU) is “a parameter associated with the result of a measurement that characterises the
292 dispersion of values that could reasonably be attributed to the measure” (Eurachem, 2012). Uncertainty of
293 measurement does not imply doubt about a result but rather increased confidence in its validity. It is not the equivalent
294 to *error*, as it may be applied to all test results derived from a particular procedure.

295 Laboratories must estimate the MU for each test method resulting in a quantitative measurement included in their
296 scope of accreditation, and for any methods used to calibrate equipment, included in their scope of accreditation
297 (ISO/IEC 17025, 2005-2017b).

298 Tests can be broadly divided into two groups: quantitative (e.g. biochemical assays, enzyme-linked immunosorbent
299 assays [ELISA], titrations, real-time polymerase chain reaction [PCR], pathogen enumeration, etc.); and qualitative
300 (bacterial culture, parasite identification, virus isolation, endpoint PCR, immunofluorescence, etc.).

301 The determination of MU is well established in *quantitative* measurement sciences (ANSI, 1997). It may be given as
302 a numeric expression of reliability and is commonly shown as a stated range. Standard deviation (SD) and confidence
303 interval (CI) are examples of the expression of MU, for example the optical density result of an ELISA expressed as
304 $\pm n$ SD, where n is usually 1, 2 or 3. The confidence interval (usually 95%) gives an estimated range in which the
305 result is likely to fall, calculated from a given set of test data. For quantitative measurements, example for a top-down
306 or control-sample approach are provided for an antibody ELISA in chapter 2.2.4, and by the Australian government
307 webpage²⁸. An example for a quantitative PCR (TaqMan) assay is provided by Newberry & Colling (2021).

308 The ISO/IEC 17025 requirement for “quality control procedures for monitoring the validity of tests” implies that the
309 laboratory must use quality control procedures that cover all major sources of uncertainty. There is no requirement
310 to cover each component separately. Laboratories may establish acceptable specifications, criteria, ranges, etc., at
311 critical control points for each component of the test process. The laboratory can then implement appropriate quality
312 control measures at these critical points, or seek to reduce or eliminate the uncertainty effect of each component.

313 **7.4.1. Potential sources of uncertainty include:**

- 314 i) Sampling;
- 315 ii) Contamination;
- 316 iii) Sample transport and storage conditions;
- 317 iv) Sample processing;

28 Australian Government, Department of Agriculture, Fisheries and Forestry. Worked examples of measurement uncertainty. [Measurement uncertainty in veterinary diagnostic testing – DAFF \(agriculture.gov.au\)](#) (accessed 15 March 2023).

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- 318 v) Reagent quality, preparation and storage;
319 vi) Type of reference material;
320 vii) Volumetric and weight manipulations;
321 viii) Environmental conditions;
322 ix) Equipment effects;
323 x) Analyst or operator bias;
324 xi) Biological variability;
325 xii) Unknown or random effects.

326 Systematic errors or bias determined by validation must be corrected by changes in the method,
327 adjusted for mathematically, or have the bias noted as part of the report statement.

328 If an adjustment is made to a test or procedure to reduce uncertainty or correct bias then a new
329 source of uncertainty is introduced (the uncertainty of the correction). This must be assessed as part
330 of the MU estimate.

331 The application of the principles of MU to *qualitative* testing is less well defined. The determination
332 and expression of MU has not been standardised for veterinary (or medical, food, or environmental)
333 testing laboratories, but sound guidance exists and as accreditation becomes more important,
334 applications are being developed. The ISO/IEC 17025 standard recognises that some test methods
335 may preclude metrologically and statistically valid calculation of uncertainty of measurement. In such
336 cases the laboratory must attempt to identify and estimate all the components of uncertainty based
337 on knowledge of the performance of the method and making use of previous experience, validation
338 data, internal control results, etc.

339 Many technical organisations and accreditation bodies (e.g. AOAC International, ISO, NATA, A2LA,
340 Standards Council of Canada, UKAS, Eurachem, the Cooperation of International Traceability in
341 Analytical Chemistry) teach courses or provide guidance on MU for laboratories seeking
342 accreditation.

343 ~~The ISO/IEC 17025 requirement for "quality control procedures for monitoring the validity of tests"~~
344 ~~implies that the laboratory must use quality control procedures that cover all major sources of~~
345 ~~uncertainty. There is no requirement to cover each component separately. Laboratories may~~
346 ~~establish acceptable specifications, criteria, ranges, etc., at critical control points for each component~~
347 ~~of the test process. The laboratory can then implement appropriate quality control measures at these~~
348 ~~critical points, or seek to reduce or eliminate the uncertainty effect of each component. Measurement~~
349 ~~Uncertainty is covered in chapter 2.2.4.~~

350 **7.4.1. Components of tests with sources of uncertainty include:**

- 351 i) ~~Sampling;~~
352 ii) ~~Contamination;~~
353 iii) ~~Sample transport and storage conditions;~~
354 iv) ~~Sample processing;~~
355 v) ~~Reagent quality, preparation and storage;~~
356 vi) ~~Type of reference material;~~
357 vii) ~~Volumetric and weight manipulations;~~
358 viii) ~~Environmental conditions;~~
359 ix) ~~Equipment effects;~~
360 x) ~~Analyst or operator bias;~~
361 xi) ~~Biological variability;~~
362 xii) ~~Unknown or random effects.~~
-

363 ~~Systematic errors or bias determined by validation must be corrected by changes in the method,~~
364 ~~adjusted for mathematically, or have the bias noted as part of the report statement.~~

365 ~~If an adjustment is made to a test or procedure to reduce uncertainty or correct bias then a new~~
366 ~~source of uncertainty is introduced (the uncertainty of the correction). This must be assessed as part~~
367 ~~of the MU estimate.~~

368 Additional information on the analysis of uncertainty may be found in the Eurachem Guides to
369 Quantifying Uncertainty in Measurement (Eurachem, 2012) and Use of ~~uncertainty information in~~
370 ~~compliance assessment~~ Uncertainty Information in Compliance Assessment (Eurachem, 2007).

371 **7.5. Implementation and use of the test method**

372 Training should be a planned and structured activity with steps to ensure adequate supervision is maintained while
373 analysts are being trained. Depending on the complexity of the test and the experience of the analyst, training may
374 include any combination of reading and understanding the documented test method, initial demonstration,
375 performance of the test under supervision and independent performance. Analysts should ~~be able to demonstrate~~
376 proficiency in using the test method prior to ~~producing~~ being authorised to produce reported results, and on an
377 ongoing basis.

378 The laboratory must be able to demonstrate traceability for all accredited tests and the principle should apply to all
379 tests whether accredited or not. This covers all activities relating to test selection, development, optimisation,
380 standardisation, validation, verification, implementation, reporting, personnel, quality control and quality assurance
381 (see also Section 7.3.1. point vi). Traceability is achieved by using appropriate documented project management,
382 record keeping, data management and archiving systems.

383 **8. Strategic planning**

384 Laboratories should have evidence of continual improvement, which is an obligatory requirement for accredited
385 laboratories. The laboratory must ~~be knowledgeable of and stay maintain~~ current with knowledge of the relevant quality
386 and technical ~~management~~ standards and with methods used to demonstrate laboratory competence and establish and
387 maintain technical validity. Evidence of this may ~~be provided by~~ include:

- 388 i) Attendance at conferences, organisation of in-house or external meetings on diagnostics and quality
389 management;
- 390 ii) ~~Participation in~~ Membership of local and international organisations;
- 391 iii) ~~Participation in writing~~ Contribution to national and international standards (e.g. on ILAC and ISO committees);
- 392 iv) ~~Maintenance of current awareness of publications, writing through review of and reviewing publications about~~
393 ~~diagnostic methods~~ contribution to relevant literature;
- 394 v) Participation in training programmes, including visits to other laboratories;
- 395 vi) Conducting research;
- 396 vii) Participation in cooperative programmes (e.g. Inter-American Institute for Cooperation in Agriculture);
- 397 viii) Exchange of procedures, methods, reagents, samples, personnel, and ideas;
- 398 ix) Planned, continual professional development and technical training;
- 399 x) Management reviews;
- 400 xi) Analysis of customer feedback;
- 401 xii) Root cause analysis of anomalies and implementation of corrective, preventive and improvement actions, as
402 well as effectiveness reviews.

403

REFERENCES

404 ANSI (AMERICAN NATIONAL STANDARDS INSTITUTE) (1997). ANSI/NCS²⁹ Z540-2-1997 (R2012), US Guide to the Expression
405 of Uncertainty in Measurement, First Edition. American National Standards Institute, www.ansi.org.

406 COLLING A. & GARDNER I.A., EDS (2021). Diagnostic test validation science: a key element for effective detection and control
407 of infectious animal diseases. *Rev. Sci. Tech. Off. Int. Epiz.*, **40**, Available at
408 <https://doc.woah.org/dyn/portal/index.xhtml?page=alo&aloid=41245>

409 EURACHEM (2007). Eurachem/CITAC Guide: Use of Uncertainty Information in Compliance Assessment, First Edition.
410 Eurachem Secretariat. www.eurachem.org.

411 EURACHEM (2012). Eurachem/CITAC³⁰ Guide (CG4): Quantifying Uncertainty in Analytical Measurement, Third Edition.
412 Eurachem Secretariat. www.eurachem.org.

413 ISO (2015). ISO 9001:2015. Quality Management Systems – Requirements. International Organization for Standardization
414 (ISO), www.iso.org.

415 ISO/IEC (~~2004a~~–2020). ISO/IEC 17000:~~2004~~–2020. Conformity Assessment – Vocabulary and General Principles.
416 International Organization for Standardization (ISO), www.iso.org.

417 ISO/IEC (~~2004b~~–2017a). ISO/IEC 17011:~~2004~~–2017. Conformity Assessment – General Requirements for accreditation
418 Bodies Accrediting Conformity Assessment Bodies. International Organization for Standardization (ISO), www.iso.org.

419 ISO/IEC (~~2005~~–2017b). ISO/IEC 17025:~~2005~~–2017. General Requirements for the Competence of Testing and Calibration
420 Laboratories. International Organization for Standardization (ISO), www.iso.org.

421 ISO/IEC (2010). ISO/IEC 17043:2010. Conformity Assessment – General Requirements for Proficiency Testing.
422 International Organization for Standardization (ISO), www.iso.org

423 ISO/IEC (~~2022~~–2012). ISO/IEC 15189:~~2012~~–2022. Medical Laboratories – Requirements for Quality and Competence.
424 International Organization for Standardization (ISO), www.iso.org

425 JOHNSON P. & CABUANG L. (2021). Proficiency testing and ring trials. *Rev. Sci. Tech. Off. Int. Epiz.*, **40**, 189–203.

426 NEWBERRY K. & COLLING A. (2021). Quality standards and guidelines for test validation for infectious diseases in veterinary
427 laboratories. *Rev. Sci. Tech. Off. Int. Epiz.*, **40**, 227–237.

428 STEVENSON M., HALPIN K. & HEUER C. (2021). Emerging and endemic zoonotic diseases: surveillance and diagnostics. *Rev.*
429 *Sci. Tech. Off. Int. Epiz.*, **40**, 119–129.

430 WAUGH C. & CLARK G. (2021). Factors affecting test reproducibility among laboratories. *Rev. Sci. Tech. Off. Int. Epiz.*, **40**,
431 131–141.

432

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433

* *

434 NB: FIRST ADOPTED IN 1996 AS *GOOD LABORATORY PRACTICE, QUALITY CONTROL AND QUALITY ASSURANCE*.

435 MOST RECENT UPDATES ADOPTED IN 2017.

29 NCSL: The National Conference of Standards Laboratories.

30 CITAC: The Cooperation of International Traceability in Analytical Chemistry.

3 MEETING OF THE WOAH BIOLOGICAL STANDARDS COMMISSION

4 Paris, 4–8 September 2023

5
6 CHAPTER 1.1.9.

7 TESTS FOR STERILITY AND FREEDOM FROM
8 CONTAMINATION OF BIOLOGICAL MATERIALS
9 INTENDED FOR VETERINARY USE

10 INTRODUCTION

11 *The international trade-related movements of biological materials intended for veterinary use are subject to*
12 *restrictions imposed to minimise the spread of animal and human pathogens. Countries may impose*
13 *requirements for proof-of-freedom testing before allowing the regulated importation of materials of animal*
14 *derivation and substances containing such derivatives. Where chemical or physical treatments are*
15 *inappropriate or inefficient, or where evidence is lacking of the effectiveness of the treatment is lacking, there*
16 *may be general or specific testing requirements imposed by authorities of countries receiving such materials.*
17 *This chapter provides guidance on the approach to such-regulated testing, particularly as might be applied*
18 *to the movement of vaccine master seed and master cell stocks, and to related biological materials used in*
19 *manufacturing processes. ~~The term seed stocks is used when testing live products, for killed products the~~*
20 *~~preferred reference is master cell stocks.~~ While the onus for ensuring safety of a product remains with the*
21 *manufacturer and may be regulated by therapeutic guidelines, this chapter provides procedures that are*
22 *designed ~~in particular~~ to minimise the risk of undetected contaminants in veterinary therapeutics and*
23 *biological reagents causing the cross-border spread of agents of concern to ~~particular~~-importing countries.*
24 *~~In their review “Extraneous agent detection in vaccines” Farsang & Kulcsar, 2012 reported the following~~*
25 *~~examples of contamination of vaccines with extraneous agents: a) Foamy virus (Spumaretroviridae) was~~*
26 *~~identified as a contaminant of primary monkey kidney cultures used for vaccine production in the early 1950;~~*
27 *~~b) In the 1960s it was shown that yellow fever live attenuated vaccines prepared in chicken embryo~~*
28 *~~fibroblasts were infected with avian leukosis virus (ALV). c) Calicivirus was found in Chinese hamster ovary~~*
29 *~~(CHO) cells, d) Newcastle disease vaccine strains were found in different live poultry vaccines, e) in 1990 a~~*
30 *~~live attenuated multi component canine vaccine was contaminated with a serotype of Bluetongue virus~~*
31 *~~causing abortions and death in pregnant bitches, f) Fetal calf serum transmitted Pestiviruses (BVDV types~~*
32 *~~1 and 2) are one of the most common extraneous agents in veterinary and human vaccines, g) RD114 is a~~*
33 *~~replication competent feline endogenous gamma retrovirus which contaminated canine corona and~~*
34 *~~parvovirus vaccines, h) a notable case of human vaccine contamination may have been when in the 20th~~*
35 *~~century tens of millions of people worldwide were immunised with polio vaccines containing simian virus 40~~*
36 *~~(SV40). SV40 was found to cause cancer in animals and is associated with human brain, bone and lung~~*
37 *~~cancers, however, a clear connection was not found between this certain vaccine and any human tumour~~*
38 *~~case, i) a porcine circovirus 1 (PCV1) was found in a rotavirus vaccine widely used worldwide for children.~~*
39 *Farsang & Kulcsar (2012) and WHO (2015) describe case studies of veterinary and human vaccines*
40 *contaminated with extraneous agents and findings support the need of accurate and validated amplification*
41 *and detection methods as key elements for effective detection and control. Further examples are given in*
42 *Section G. Protocol examples below. Control of contamination with transmissible spongiform*
43 *encephalopathy (TSE) agents is not covered in this chapter because standard testing and physical*

44 treatments cannot be used to ensure freedom from these agents. Detection methods are described in
45 Chapter 3.4.5. Bovine spongiform encephalopathy.

46 Sterility is defined as the absence of viable microorganisms, which for the purpose of this chapter, includes
47 viruses. It should be achieved using aseptic techniques and validated sterilisation methods, including heating,
48 filtration, chemical treatments, and irradiation that fits the intended purpose. Freedom from contamination is
49 defined as the absence of specified viable microorganisms. This may be achieved by selecting materials
50 from sources shown to be free from specified microorganisms and by conducting subsequent procedures
51 aseptically. Adequate assurance of sterility and freedom from contaminating microorganisms can only be
52 achieved by proper control of the primary materials used and their subsequent processing. Tests on
53 intermediate products are necessary throughout the production process to check that this control has been
54 achieved.

55 Biological materials subject to contamination that cannot be sterilised before or during use in vaccine
56 production, such as ingredients of animal origin, e.g. serum and trypsin, primary and continuous cells and
57 cell lines, and viral or bacterial seed stocks, etc., should be tested for viable extraneous agents before use.
58 Assays to detect viral contaminants, if present, can be achieved by various culture methods, including use
59 of embryonated eggs, which are supported by cytopathic effects (CPE) detection/embryo death, fluorescent
60 antibody techniques and other suitable (fit for purpose), methods such as polymerase chain reaction (PCR)
61 and antigen detection ELISA (enzyme-linked immunosorbent assay). As is explained in more detail in this
62 chapter care must be taken when using PCR and ELISA techniques for detection as such tests do not
63 distinguish viable from non-viable agent detection. Specific assays to detect other contaminants, such as
64 fungi, protozoa and bacteria (including rickettsia and mycoplasma) are also described.

65 Avian materials and vaccines are required to be inoculated on to primary avian cell cultures or eggs for the
66 detection of avian viruses. A combination of general tests, for example to detect haemadsorbing,
67 haemagglutinating and CPE causing viruses and specific procedures aimed at the growth and detection of
68 specific viruses is recommended to increase the probability of detection. Assays to detect other
69 contaminants, such as bacteria, fungi, protozoa, rickettsia and mycoplasma are also described.

70 ~~Procedures applied~~ Testing procedures should be validated and found to be “fit for purpose” following
71 Chapter 1.1.6. Validation of diagnostic assays for infectious diseases of terrestrial animals, where possible.

72 It is a requirement of many regulators, that a laboratory testing report notes the use of validated procedures
73 and describes the validated procedures in detail including acceptance criteria. This gives the regulator
74 transparency in the procedures used in a testing laboratory.

75 The validation assessment of an amplification process in cell culture should include documentation of the
76 history of permissive cell lines used, reference positive controls and culture media products used in the
77 process of excluding adventitious agents, to ensure the process is sound and is not compromised. The
78 validation assessment should give information (published or in-house) of the limitations that may affect test
79 outcomes and an assessment of performance characteristics such as analytical specificity and sensitivity of
80 each cell culture system, using well characterised, reference positive controls.

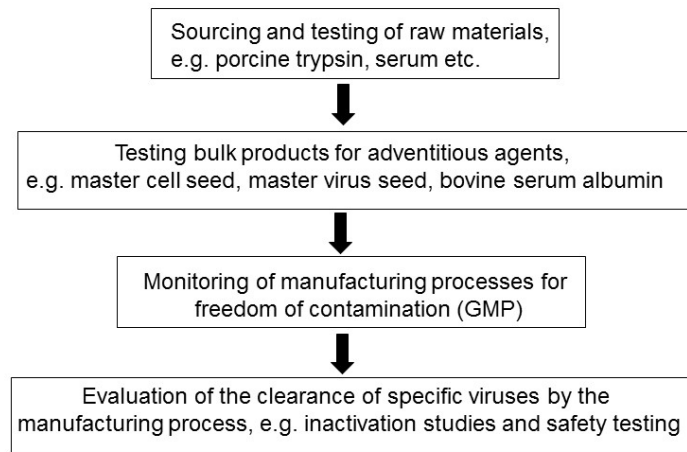
81 It is the responsibility of the submitter to ~~assure~~ ensure a representative selection and number of items to
82 be tested. ~~The principles of~~ Appendix 1.1.2.1 Epidemiological approaches to sampling: sample size
83 calculations of Chapter 1.1.2 Collection, submission and storage of diagnostic specimens ~~apply~~ describes
84 the principles to be applied. Adequate transportation is described in Chapter 1.1.2 and Chapter 1.1.3
85 Transport of biological materials describe transportation requirements.

86 A. AN OVERVIEW OF TESTING APPROACHES

87 Although testing is seen as a key component of biosafety in biological products intended for veterinary use, testing is not
88 enough to ensure a given product is free of viable infectious contaminants, and so a holistic, multifaceted approach must
89 be taken. Such an approach includes risk assessment, risk mitigation and management strategies (Barone et al., 2020).
90 In general:

- 91 • Primary materials must be collected from sources shown to be free from contamination and handled in such a way as
92 to minimise contamination and the opportunities for any contaminants to multiply (Figure 1).
- 93 • Materials that are not sterilised and those that are to be processed further after sterilisation must be handled aseptically.
94 Such materials will require further assessment of freedom of contaminants at certain stages of production to assure
95 freedom of adventitious agents.
- 96 • Materials that can be sterilised without their biological activities being affected unduly must be sterilised by a method
97 effective for the pathogens ~~concerned of concern~~. The method must reduce the level of contamination to be
98 undetectable, as determined by an appropriate sterility test study. ~~(See Section D.1. below)~~. If a sterilisation process is
99 used, it shall be validated to demonstrate that it is fit for purpose. Suitable controls will be included in each sterilisation
100 process to monitor efficiency.
- 101 • The environment in which any aseptic handling is carried out must be maintained in a clean state, protected from
102 external sources of contamination, and controlled to prevent internal contamination. Rules governing aseptic
103 preparation of vaccines are documented in Chapter 2.3.3 *Minimum requirements for the organisation and management*
104 *of a vaccine manufacturing facility*.

105 **Figure 1. ~~Testing algorithm~~ Risk assessment flowchart for vaccine production.**



106

107 Some procedures have been properly validated and found to be “fit for purpose”, whilst others may have undergone only
108 limited validation studies. For example, methods for bacterial and fungal sterility may have not been formally validated
109 although they have been used for many years. In particular, ~~the~~ *in-vivo* and ~~cell culture~~ *in-vitro* methods have essentially
110 unknown sensitivity and specificity (Sheets *et al.*, 2012) though there is an accepted theoretical sensitivity, regarding cell
111 culture of 1 ~~colony plaque~~ forming unit (CFU-PFU). For example, an evaluation of methods to detect bovine and porcine
112 viruses in serum and trypsin based on United States (of America) Code of Federal Regulations, Title 9 (9CFR) revealed
113 gaps in sensitivity, even within virus families (Marcus-Secura *et al.*, 2011). It is therefore important to interpret, and report
114 results in the light of specific conditions of cultures employed and considering sensitivity and specificity of detection
115 systems.

116 Newer, more sensitive methods such as molecular assays may afford the ability to detect contaminants, which may not be
117 successfully amplified in traditional culturing systems. The detection range can be broadened by using family specific
118 primers and probes if designed appropriately. However, most, if not all ~~such new~~ molecular-based tests are also able to
119 detect evidence for non-infectious contaminants, such as traces of nucleic acid from inactivated contaminants. ~~Follow up~~
120 ~~testing would be required to determine the nature of the contaminant, for example, non-infectious nucleic acid or infectious~~
121 ~~virus. Attempts at virus isolation or sequencing may remedy this.~~ Note: molecular assays if not designed as fit for purpose
122 may miss detection of contaminating agents or lack sensitivity to do so (Hodinka, 2013).

123 More recently metagenomic high throughput sequencing (HTS) workflows have shown potential for quality control of
124 biological products (van Borm *et al.*, 2013) and vaccines (Baylis *et al.*, 2011; Farsang & Kulcsar, 2012; Neverov &
125 Chumakov, 2010; Onions & Kolman, 2010; Victoria *et al.*, 2010) in particular for the identification and characterisation of
126 unexpected highly divergent pathogen variants (Miller *et al.*, 2010; Rosseel *et al.*, 2011) that may remain undetected using
127 targeted diagnostic tests. Nevertheless, targeted assays, e.g. amplification in cell culture followed by polymerase chain
128 reaction (PCR) may be superior to HTS for specific agent detection (Wang *et al.*, 2014) due to lack of sensitivity of HTS at
129 this time. Chapter 1.1.7. gives an overview of the standards for high throughput sequencing, bioinformatics and
130 computational genomics. Similarly, recent improvements in protein and peptide separation efficiencies and highly accurate

131 mass spectrometry have promoted the identification and quantification of proteins in a given sample. Most of these new
132 technologies are broad screening tools, limited by the fact that they cannot distinguish between viable and non-viable
133 organisms.

134 Given the availability of new technologies, there will be future opportunities and challenges to determine presence of
135 extraneous agents in biologicals intended for veterinary use for industry and regulators. Problems can arise when the
136 presence of genome positive results are interpreted as evidence for the presence of contamination (Mackay & Kriz,
137 2010). When using molecular technologies, it is important to understand the correlation between genome detection and
138 detection of live virus agent. It cannot be assumed that detection of genome corresponds to the presence of an infectious
139 agent.

140 **B. LIVING VIRAL VACCINES FOR ADMINISTRATION BY INJECTION, OR THROUGH** 141 **DRINKING WATER, SPRAY, OR SKIN SCARIFICATION**

142 1. Materials of animal origin ~~shall~~ should be ~~(a) sterilised, or (b) and~~ obtained from healthy animals that, in so far as is
143 possible, should be shown to be free from pathogens that can be transmitted from the species of origin to the species
144 to be vaccinated, or any species in contact with them by means of extraneous agents testing.

145 2. Seed lots of virus, any continuous cell line and biologicals used for virus growth ~~shall~~ should be shown to be free from
146 ~~viable~~ bacteria, fungi, mycoplasmas, protozoa, rickettsia, and extraneous viruses ~~and other pathogens~~ that can be
147 transmitted from the species of origin to the species to be vaccinated or any species in contact with them. ~~There may~~
148 ~~be some exceptions for a limited number of non-pathogenic bacteria and fungi to be present in live viral vaccines~~
149 ~~produced in eggs and administered through drinking water, spray, or skin scarification.~~

150 For ~~the~~ production of vaccines in embryonated chicken eggs and the quality control procedures for these vaccines, it
151 is recommended ~~(required in many countries)~~ that eggs from specific pathogen-free birds should be used.

152 3. Each batch of vaccine ~~shall~~ should pass tests for freedom from extraneous agents that are consistent with the
153 importing country's requirements for accepting the vaccine for use. Some examples of published methods that
154 document acceptable testing ~~procedures~~ processes in various countries include: ~~(US) Code of Federal Regulations~~
155 ~~(2015); European Pharmacopoeia (2014); European Commission (2006); World Health Organization (WHO) (1998;~~
156 ~~2012) and Department of Agriculture (of Australia) (2013).~~

- 157 • Code of Federal Regulations, Title 9 (9CFR) (of the United States of America) (2015).
- 158 • Department of Agriculture, Forest and Fisheries (Australia) (2013).
- 159 • Department of Agriculture, Forest and Fisheries (Australia) (2021b) Live Veterinary Vaccines.
- 160 • European Medicines Agency Sciences Medicines Health (2016).
- 161 • European Pharmacopoeia, 10th Edition (2021).
- 162 • World Health Organization (WHO) (1998; 2012).

163 4. Tests for ~~sterility~~ freedom of contamination ~~shall~~ should be appropriate to prove that the vaccine is free from viable
164 extraneous viruses, bacteria including rickettsia and mycoplasmas, fungi, and protozoa. Each country will have
165 ~~particular~~ requirements as to what agents ~~are necessary to exclude~~ should be tested for and ~~what by which~~
166 ~~procedures are acceptable~~. Such tests will include amplification of ~~viable~~ extraneous agents using cell culture that is
167 susceptible to ~~particular known~~ viruses of the species of concern, tests in embryonated eggs, bacterial, mycoplasma
168 and fungal culturing techniques and, where ~~necessary and possible~~ there is no alternative ~~ie, tests involving animal~~
169 inoculation. PCR, fluorescence antibody test (FAT), presence of colonies or cytopathic effects (CPE) and antigen
170 detection ELISA ~~will can~~ be used for detection purposes after amplification using culturing techniques to improve
171 specificity and sensitivity. If *in-vitro* or *in-vivo* amplification of the target agent is not possible, direct PCR may be
172 useful if validated for this purpose.

173 **C. LIVING VIRAL VACCINES FOR ADMINISTRATION THROUGH DRINKING WATER,** 174 **SPRAY, OR SKIN SCARIFICATION**

175 1. ~~Section B applies.~~

176 2. ~~A limited number of contaminating, non-pathogenic bacteria and fungi may be permitted (see Section 1.2.2 General~~
177 ~~Procedure for testing live viral vaccines produced in eggs and administered through drinking water, spray, or skin~~
178 ~~scarification for the presence of bacteria and fungi).~~

179

D.C. INACTIVATED VIRAL AND BACTERIAL VACCINES

180 1. Each batch of vaccine shall pass a test for inactivation of the vaccinal ~~virus seed~~ and should include inactivation studies
181 on representative extraneous agents if the virus or bacterial seed has not already been tested and shown to be free
182 from extraneous agents. An example of a simple inactivation study could include assessment of the titre of live vaccine
183 before and after inactivation and assessing the log₁₀ drop in titre during the inactivation process. This would give an
184 indication of the efficacy of the inactivation process. There is evidence that ~~virus~~-titration tests may not have sufficient
185 sensitivity to ensure complete inactivation. In these circumstances, a specific innocuity test would need to be developed
186 and validated to be fit for increased sensitivity. To increase sensitivity more than one passage would be required
187 depending on the virus or bacteria of concern. An example of this approach can be found at:
188 https://www.aphis.usda.gov/animal_health/vet_biologics/publications/memo_800_117.pdf (accessed 25 July 2023).

189 2. If studies on representative extraneous agents are required, then spiking inactivated vaccine with live representative
190 agents and following the example of an inactivation study ~~as in D.1 above would~~ could be useful. The inactivation
191 process and the tests used to detect live ~~virus agent~~ after inactivation must be validated and shown to be suitable for
192 their intended purpose.

193 In addition, each country may have ~~particular~~ its own requirements for sourcing or tests for sterility as detailed in
194 Section B above.

E. D. LIVING BACTERIAL VACCINES

195 1. See Section B applies.

196 2. Seed lots of bacteria shall be shown to be free from other bacteria as well as fungi and mycoplasmas, protozoa,
197 rickettsia, and extraneous viruses. Agents required for exclusion will be dependent on the country accepting the vaccine
198 for use. Use of antibiotics to 'inactivate' the living bacterial seed or vaccine prior to exclusion of viruses and fungi is
199 recommended to ensure testing in culture is sensitive. ~~Interference testing is recommended to ensure that the~~
200 ~~antibiotics used do not affect the growth of the extraneous virus or fungi that is being excluded. Sonication may also~~
201 ~~be useful~~

202 ~~Interference testing is required to ensure that antibiotics used (or sonication) does not affect the growth of extraneous~~
203 ~~virus or fungi being excluded, compromising the test outcome.~~

204 Due to the difficulties and reduced sensitivity in exclusion of extraneous bacteria and some mycoplasma, protozoa, and
205 rickettsia from high-titred seed lots of bacteria, the use of narrow-range antibiotics aimed specifically at reducing seed
206 lot bacteria is ~~recommended~~ useful if antibiotics do not affect the growth of bacteria being excluded. The optimal
207 concentration of antibiotics can be determined in a dilution experiment such as documented in 9CFR Section 113.25(d).
208 Other methods of exclusion of extraneous bacteria from bacterial seeds may include filtering for size exclusion such as
209 removing bacteria seed to look for mycoplasma contamination and use of selective culturing media. Such processes
210 would require validation-verification to ensure the process does not affect the sensitivity of exclusion of extraneous
211 agents of concern.
212

213 3. Sonication of a living bacterial seed may be useful when excluding specific viral agents. Once again, the inactivation
214 procedure would require a verification process to ensure the adventitious virus being excluded is not affected by the
215 treatment. Use of a suitable reference virus control during the exclusion process would be required.

216 4. Direct PCR techniques may be useful when culturing processes fail to be ~~sensitive~~ successful in detecting extraneous
217 bacteria from live bacterial seeds or vaccines.

F. INACTIVATED BACTERIAL VACCINES

218 1. ~~Section D applies. It should not be necessary to test for extraneous viruses that would not grow in bacteriological culture~~
219 ~~media as long as freedom from contamination of all starting materials can be assured. Complete inactivation of the~~
220 ~~vaccinal bacteria should be demonstrated by means of titration and innocuity tests—in some cases general bacterial~~
221 ~~sterility testing (Section I.2.1) may suffice.~~
222

223 G-E. SERA, PLASMA AND DIAGNOSTIC AGENTS FOR ADMINISTRATION TO 224 ANIMALS

- 225 1. Section B-4 applies for sera/diagnostic agents that are not inactivated. Section C applies for non-inactivated
226 sera/diagnostic agents.
- 227 2. Some countries require quarantine, health certification, and tests for specific diseases to be completed for all serum
228 and plasma donor animals, for example, 9CFR (2015) and Australian Quarantine Policy and Requirements for the
229 Importation of Live and Novel Veterinary Bulk and Finished Vaccines (1999). For some diseases, for example equine
230 infectious anaemia, the product (plasma) must be stored until the seroconversion period has been exceeded and the
231 donors tested negative.
- 232 ~~3. It is recommended that each batch of non inactivated serum be assessed for viable extraneous agents, including~~
233 ~~mycoplasma. Each batch of serum shall pass a test for freedom from extraneous agents. Suitable test methods have~~
234 ~~been published for various countries, for example, European Pharmacopoeia (2014); 9 CFR (2015) and Australian~~
235 ~~Quarantine Policy and Requirements for the Importation of Live and Novel Veterinary Bulk and Finished Vaccines~~
236 ~~(1999) and Department of Agriculture (of Australia) (2013).~~
- 237 4. ~~Inactivated serum, Section D applies.~~
- 238 5. ~~Section B or D may apply if a virus is used in the production of the diagnostic agent; Section E or F may apply if a~~
239 ~~bacterium is used.~~

240 H. F. EMBRYOS, OVA, SEMEN

241 Special precautions must be taken with relation to the use of embryos, ova, semen (Hare, 1985). Most countries will have
242 regulatory guidelines for import of these biologicals for veterinary use. Such guidelines can be found at various websites
243 such as the European Commission (2015), FAO and Department of Agriculture Forest and Fisheries (2021a; 2021b),
244 though ~~many such some~~ guidelines may give more detail in regard to the food safety aspect.

245 J. G. PROTOCOL EXAMPLES

246 1. General procedures Introduction to protocol examples

247 This section provides some examples to illustrate scope and limitations of testing protocols. It is not intended to be
248 prescriptive or exhaustive. Examples are based on standards and published methods to increase the sensitivity for
249 exclusion of live adventitious agents, using general and specific techniques.

250 In principle, proposed testing represents ~~an~~ attempted isolation of viable agents in culturing systems normally considered
251 supportive of the growth of each specified agent or group of general agents. After amplification, potential pathogens can
252 be detected further, by sensitive and specific diagnostic tests such as FAT or PCR ~~if as~~ required. General detection systems
253 can include haemabsorbance and CPE by immunohistochemistry staining methods. The example procedures for ~~sterility~~
254 detection of contamination testing and general detection of viable virus, fungi, protozoa and bacteria (including rickettsia
255 and mycoplasma, fungi and viruses) described below are derived from standards such as the 9CFR (2015), European
256 Pharmacopoeia, (2014)-10th Edition (2021), European Commission (2006), WHO Medicines Agency Sciences Medicines
257 Health (2016), Department of Agriculture, Forest and Fisheries (Australia) (2013) and World Health Organization (1998;
258 2012).

259 Individual countries or regions should adopt a holistic, risk-based approach to determine the appropriate testing protocols
260 based on their animal health status. As well as applying general testing procedures documented in national or regional
261 standards as mentioned above, it may be necessary to apply rigorous exclusion testing for specific agents that are exotic
262 to the particular country or region of concern.

263 General procedures ~~will do~~ not necessarily detect all extraneous agents that may be present in biological material; however,
264 they are useful as screening tests. Some examples of agents that may require specific methods for detection in biologicals
265 refer to Table 1 below. Procedures documented in the Review of Published Tests to Detect Pathogens in Veterinary
266 Vaccines Intended for Importation into Australia (2013) available from the Department of Agriculture, Forest and Water
267 Resources, Australia Fisheries are able to address such agents in offering sensitive testing approaches based on reputable
268 publications. A CVMP reflection paper published written by the European Medicines Agency Sciences Medicines Health

269 Committee of Veterinary Medicinal Products (CVMP) in (2016), adopted in May 2017, documents lists specific test method
 270 approaches for a number of agents, listed in Table 1, that cannot be excluded using general test procedures (Table 1).

271 Exclusion of specific agents requires procedures that maximise sensitivity by providing ideal amplification and detection of
 272 the pathogen in question. Extraneous agents, for example, Maedi Visna virus, ~~bovine immunodeficiency virus, (and other~~
 273 ~~retroviruses)~~, *Trypanosoma evansi* and porcine respiratory coronavirus are difficult to culture even using the most sensitive
 274 approaches. In these circumstances, application of molecular assays directly to the biological material ~~in question to~~
 275 ~~assess, assessing for~~ the presence of nucleic acid from adventitious agents offers an alternative. ~~Refer to Table 1.~~
 276 ~~Consideration must be noted as described in Section A.6 as, though detection of the presence of non-viable and host~~
 277 ~~associated agents may is also be detected using this procedure possible.~~

278 Table 1 gives examples of causative infectious agents that may be present in animal biologicals intended for veterinary
 279 use, for example PCV-1 in a rotavirus vaccine (WHO, 2015). BVDV is well known for its presence in many bovine
 280 associated biologicals, including cell culture. More recently, non-CPE pestivirus, BVD type 3 (HoBi-like) are found in foetal
 281 calf serum and cell culture. Classical Swine fever has contaminated various porcine cell lines used for African swine fever
 282 and FMDV diagnosis, and thus the potential for contamination of porcine based vaccines. PEDV is linked to spray-dried
 283 porcine plasma used for feed. This is not an exhaustive list of agents of concern or by any means required for exclusion
 284 by every country based on risk, they are just examples of infectious agents that are not culturable using general culturing
 285 procedures and require a more use of specialised culturing processes and specific detection process by means of the
 286 indirect fluorescent antibody test, PCR or ELISA, where applicable processes. Notably, some subtypes of an agent type
 287 may be detectable by general methods, and some may require specialised testing for detection. For example, bovine
 288 adenovirus subgroup 1 (serotypes 1, 2, 3 and 9) can be readily isolated using general methods (Vero cells) however bovine
 289 adenovirus subgroup 2 (serotypes 4, 5, 6, 7, 8 and 10) are not readily isolated and required specialised methods for
 290 isolation.

291 **Table 1. ~~Some~~ Examples of infectious agents of veterinary importance**
 292 **that require ~~specialist~~ specialised culturing and detection techniques**

Rotaviruses	Pestiviruses (non-CPE)	Turkey rhinotracheitis
Porcine epidemic diarrhoea virus	Bluetongue virus	<i>Brucella abortus</i>
Porcine circoviruses (PCV 1, 2)	Swine pox virus	Rickettsias
Swine/equine influenza, some strains	Some adenoviruses	Protozoa
Bovine respiratory syncytial virus	<u>Rhabdoviruses (e.g. rabies virus)</u>	Some fungi (e.g. <i>Histoplasma</i>)

293 **2. Example of detection of bacteria and fungi contamination**

294 **2.1. General procedure for assessing the sterility of viable bacteria and fungi**

295 Standard tests for detecting extraneous bacteria and fungi (sterility testing) in raw materials, master cell stocks, or
 296 final product are the membrane filtration test or the direct inoculation sterility test.

297 For the membrane filtration technique, a filter having a nominal pore size not greater than 0.45 µm and a diameter of at
 298 least 47 mm should be used. Cellulose nitrate filters should be used if the material is aqueous or oily; cellulose acetate
 299 filters should be used if the material is strongly alcoholic, oily or oil-adjuvanted. Immediately before the contents of the
 300 container or containers to be tested are filtered, the filter is moistened with 20–25 ml of Diluent A or B.

301 **2.1.1. Diluent A**

302 Diluent A is for aqueous products or materials. Dissolve 1 g peptic digest of animal tissue in water to
 303 make 1 litre, filter, or centrifuge to clarify, adjust the pH to 7.1 ± 0.2, dispense into containers in 100 ml
 304 quantities, and sterilise by steam.

305 **2.1.2. Diluent B**

306 Diluent B is for oil-adjuvanted products or materials: Add 1 ml polysorbate 80 to 1 litre Diluent A, adjust
 307 the pH to 7.1 ± 0.2, dispense into containers in 100 ml quantities, and sterilise by steam.

308 If the biological being tested has antimicrobial properties, the membrane is washed three times after
 309 sample application with approximately 100 ml of the appropriate diluent (A or B). The membrane is then
 310 transferred ~~whole~~ to culture media, aseptically cut into equal parts and placed in media, or the media is

311 transferred to the membrane in the filter apparatus. If the test sample contains merthiolate as a
 312 preservative, fluid thioglycolate medium (FTM) is used and the membranes are incubated at both 30–
 313 35°C and 20–25°C. If the test sample is a killed biological without merthiolate preservative, FTM is used
 314 at 30–35°C and soybean casein digest medium (SCDM) at 20–25°C. If the sample tested is a live viral
 315 biological, SCDM is used at both incubation temperatures. It has been suggested that sulfite-polymyxin-
 316 sulfadiazine agar be used to enhance the detection of *Clostridium* spp. when the membrane filtration
 317 technique is used (Tellez *et al.*, 2005).

318 If direct inoculation of culture media is chosen, a sterile pipette or syringe and needle are used to
 319 aseptically transfer the biological material directly into liquid media. If the biological being tested has
 320 antimicrobial properties, the ratio of the inoculum to the volume of culture medium must be determined
 321 before the test is started, for example as explained in 9CFR 113.25(d) and detailed testing procedures
 322 can be found for example in supplemental assay method [USDA SAM 903](https://www.aphis.usda.gov/animal_health/vet_biologics/publications/sam903.pdf)
 323 https://www.aphis.usda.gov/animal_health/vet_biologics/publications/sam903.pdf (accessed 24 July
 324 2023) (SAM) 903 USDA SAM 903, See
 325 https://www.aphis.usda.gov/animal_health/vet_biologics/publications (accessed 4 July 2022). To
 326 determine the correct medium volume to negate antimicrobial activity, 100 CFU of the control
 327 microorganisms listed in Table 2 are used. If the test sample contains merthiolate as a preservative, FTM
 328 is used in test vessels incubated at both 30–35°C and 20–25°C. Growth should be clearly visible after
 329 an appropriate incubation time (see Section I.2.1.3 *Growth promotion and test interference*). If the test
 330 sample is a killed biological without merthiolate, or a live bacterial biological, FTM is used at 30–35°C
 331 and SCDM at 20–25°C. If the test sample is a live viral biological, SCDM is used at both incubation
 332 temperatures. If the inactivated bacterial vaccine is a clostridial biological, or contains a clostridial
 333 component, the use of FTM with 0.5% added beef extract (FTMB) in place of FTM is preferred. It may
 334 also be desirable to use both FTM and SCDM for all tests.

335 **Table 2.** Some American Type Culture Collection³¹ strains with their respective
 336 medium and incubation conditions

Medium	Test microorganism	Incubation	
		Temperature (°C)	Conditions
FTM	<i>Bacillus subtilis</i> ATCC # 6633	30–35	Aerobic
FTM	<i>Candida krusei</i> ATCC # 6258	20–25	Aerobic
SCDM	<i>Bacillus subtilis</i> ATCC # 6633	30–35	Aerobic
SCDM	<i>Candida krusei</i> ATCC # 6258	20–25	Aerobic
FTMB	<i>Clostridium sporogenes</i> ATCC # 11437	30–35	Anaerobic
FTMB	<i>Staphylococcus aureus</i> ATCC #6538	30–35	Aerobic

337 For both membrane filtration and direct inoculation sterility tests, all media are incubated for no fewer
 338 than 14 days. At intervals during incubation, and after 14 days' incubation, the test vessels are
 339 examined for evidence of microbial growth. Microbial growth should be confirmed by subculture and
 340 Gram stain.

341 2.1.3. Example of growth promotion and test interference

342 The sterility of the media should be confirmed by incubating representative containers at the
 343 appropriate temperature for the length of time specified for each test.

344 The ability of the culture media to support growth in the presence and absence of product, product
 345 components, cells, seeds, or other test material should be validated for each product to be tested,
 346 and for each new batch or lot of culture media for example as outlined in 9CFR 113.25(b). Detailed
 347 testing procedures can be found for example in USDA SAMs 900-902, See USDA APHIS |
 348 Supplemental Assay Methods - 900 Series (accessed 22 July 2023)
 349 https://www.aphis.usda.gov/animal_health/vet_biologics/publications (accessed 4 July 2022).

31 American Type Culture Collection, 10801 University Boulevard, Manassas, Virginia 20110-2209, USA.

350 To test for ability to support growth in the absence of the test material, media should be inoculated
351 with 10–100 viable control organisms of the suggested ATCC strains listed in Table 2 and incubated
352 according to the conditions specified.

353 To test for ability of the culture media to support growth in the presence of the test material, containers
354 should be inoculated simultaneously with both the test material and 10–100 viable control organisms.
355 The number of containers used should be at least one-half the number used to test the product or
356 product component. The test media are satisfactory if clear evidence of growth of the control
357 organisms appears in all inoculated media containers within 7 days. In the event that growth is
358 evident, the organism should be identified to confirm that it is the organism originally added to the
359 medium. The sterility test is considered invalid if any of the media show inadequate growth response,
360 or if the organism recovered, is not the organism used to inoculate the material.

361 If the material being tested renders the medium turbid so that the presence or absence of microbial
362 growth cannot be readily determined by visual examination, 14 days after the beginning of incubation
363 transfer portions (each not less than 1 ml) of the medium to fresh vessels of the same medium and
364 then incubate the original and transfer vessels for not less than 4 days.

365 **2.2. ~~General procedure for testing live viral vaccines produced in eggs and administered~~** 366 **~~through drinking water, spray, or skin scarification for the presence of bacteria and fungi~~**

367 ~~Each batch of final container biological should have an average contamination of not more than one bacterial or~~
368 ~~fungal colony per dose for veterinary vaccines. From each container sample, each of two Petri dishes are inoculated~~
369 ~~with vaccine equal to ten doses if the vaccine is recommended for poultry, or one dose if recommended for other~~
370 ~~animals. To each plate 20 ml of brain heart infusion agar are added containing 0.007 IU (International Units) of~~
371 ~~penicillinase per ml. One plate should be incubated at 30–35°C for 7 days and the other at 20–25°C for 14 days.~~
372 ~~Colony counts are made at the end of each incubation period. An average colony count of all the plates representing~~
373 ~~a batch should be made for each incubation condition. If the average count at either incubation condition exceeds~~
374 ~~one colony per dose in the initial test, one retest to rule out faulty technique may be conducted using double the~~
375 ~~number of unopened final containers. If the average count at either incubation condition of the final test for a batch~~
376 ~~exceeds one colony per dose, the batch of vaccine should be considered unsatisfactory.~~

377 **2.3.2. Example of general procedure for testing seed lots of bacteria and live bacterial** 378 **biologicals for purity**

379 Each seed lot of bacteria or batch of live bacterial biological should be tested for purity by inoculation of SCDM, which
380 is incubated at 20–25°C for 14 days, and FTM, which is incubated at 30–35°C for 14 days. Using good practices in
381 sterile technique to avoid laboratory contamination, a sterile pipette or syringe and needle is used to aseptically
382 transfer the quantity of biological directly into the two types of culture medium. The minimum ratio of inoculum to
383 culture medium is 1/15. Both positive and negative controls are set up as well.

384 If the inoculum or growth of the bacterial vaccine renders the medium turbid so that the absence of atypical microbial
385 growth cannot be determined by visual examination, subcultures should be made from all turbid tubes on day 3
386 through until day 11. Subculturing is done by transferring 0.1–1.0 ml to differential broths and agar and incubating for
387 the balance of the 14-day period. Microscopic examination by Gram stain should also be done.

388 If no atypical growth is found in any of the test vessels when compared with a positive control included in the test, the
389 lot of biological may be considered satisfactory for purity. If atypical growth is found but it can be demonstrated by a
390 negative control that the media or technique were faulty, then the first test may should be repeated. If atypical growth
391 is found but there is no evidence invalidating the test, then a retest may should be conducted. Twice the number of
392 biological containers and test vessels of the first test are used in the retest. If no atypical growth is found in the retest,
393 the biological could be considered to be satisfactory for purity but the results from both the initial and retest should
394 be reported for assessment by the individual countries relevant regulatory agency if the laboratory is sure that the
395 first test result was not due to in-laboratory contamination. If atypical growth is found in any of the retest vessels, the
396 biological is considered to be unsatisfactory for purity. If, however, it can be demonstrated by controls that the media
397 or technique of the retest were faulty, then the retest may should be repeated.

398 **2.4.3. An Example of a specific test procedure for exclusion of *Brucella sp.* including *B. abortus*** 399 **(where general testing is not sufficient) for detection of *Brucella abortus***

400 It should be confirmed that each batch of culture medium supports the growth of *B. abortus* by inoculating plates and
401 flasks of biphasic medium with a known number of cells (around 100) of the fastidious *B. abortus* biovar 2. If the
402 media supports the growth of this biotype it will support all other biovars.

403 Inoculate 1.0 ml of prepared master or working ~~viral~~ live agent or cell seed material (not containing antibiotics) by
404 inoculating 50 µl of the test product into each of 10 flasks containing biphasic medium. At the same time 10 plates of
405 serum dextrose agar (SDA) are inoculated with 50 µl of inoculum and spread with a sterile bent glass Pasteur pipette
406 or hockey stick. An un-inoculated serum dextrose agar plate and a biphasic flask are also set up at the same time as
407 negative controls.

408 For assessment of inhibitory substances 50 µl of previously prepared master or working viral or cell seed material
409 and 10–100 CFU of *B. abortus* are inoculated on to duplicate SDA plates. Positive controls are prepared by inoculating
410 10–100 CFU of *B. abortus* on to duplicate SDA plates.

411 All plates and flasks are incubated at 37°C in a 5–10% CO₂ environment. Plates are incubated with the agar
412 uppermost and flasks with the agar slope vertical. Flasks are incubated with the cap loose.

413 Plates are checked for growth of colonies at days 4 and 8 of incubation. The biphasic medium is examined every 4 to
414 7 days for 28 days. After each examination of the flasks, they are tilted so that the liquid phase runs over the solid
415 phase, then righted and returned to the incubator.

416 During the incubation period, SDA plates with positive control and test material are visually compared with plates with
417 the positive control only and if there is no inhibition of growth of the organism in the presence of the test material, the
418 interference testing test is successful, and testing can be assured to be sensitive.

419 Any signs of growth of suspicious contaminating microorganisms on SDA plates, cloudiness or colonies in biphasic
420 flasks require follow-up testing by PCR to confirm whether *B. abortus* is present.

421 **2.54. An Example of a general procedure for detection of *Salmonella* contamination**

422 Each batch of ~~live virus~~ biological reagents made in eggs should be free from contamination with *Salmonella*. This
423 testing must be done before bacteriostatic or bactericidal agents are added. Five samples of each batch should be
424 tested; 5 ml or one-half of the container contents, whichever is the lesser, of the sample should be used to inoculate
425 100 ml of tryptose broth and tetrathionate broth. The inoculated broths should be incubated for 18–24 hours at 35–
426 37°C. Transfers from these broths should be made on to MacConkey and *Salmonella-Shigella* agar, incubated for
427 18–24 hours, and examined. If no growth typical of *Salmonella* is noted, the agar plates should be incubated an
428 additional 18–24 hours and again examined. If colonies typical of *Salmonella* are observed, further subculture on to
429 suitable differential media should be made for positive identification. Sensitive PCR tests are available for the
430 detection of *Salmonella* spp. in cultured material. If *Salmonella* is detected, the batch is determined to be
431 unsatisfactory.

432 **3. Example of detection of *Mycoplasma* contamination**

433 **3.1. An example of a general specific procedure for detection exclusion of *Mycoplasma*** 434 ***mycoides* subsp. *mycoides* (where general testing is not sufficient)**

435 Each batch of ~~live viral vaccine~~, each lot of master seed virus (MSV), each lot of primary and master cell stock (MCS),
436 and all ingredients of animal origin not steam-sterilised should be tested for the absence of mycoplasmas. Solid and
437 liquid media that will support the growth of small numbers of test organisms, such as typical contaminating organisms
438 *Acholeplasma laidlawii*, *Mycoplasma arginini*, *M. fermentans*, *M. hyorhinis*, *M. orale*, and *M. synoviae* should be
439 used. The nutritive properties of the solid medium should be such that no fewer than 100 CFU should occur with each
440 test organism when approximately 100–200 CFUs are inoculated per plate. An appropriate colour change should
441 occur in the liquid media when approximately 20–40 CFUs of each test organism are inoculated. The ability of the
442 culture media to support growth in the presence of product should be validated for each product to be tested, and for
443 each new batch or lot of culture media.

444 One sample of each lot of vaccine, e.g. MSV or MCS, should be tested. Four plates of solid medium are inoculated
445 with 0.25 ml of the sample being tested, and 10 ml of the sample inoculated into 100 ml of the liquid medium. An
446 alternative is to inoculate each of the plates with 0.1 ml and to inoculate 100 ml of liquid medium with 1 ml of the
447 sample being tested. Two plates are incubated at 35–37°C aerobically (an atmosphere of air containing 5–10% CO₂
448 and adequate humidity) and two plates are incubated anaerobically (an atmosphere of nitrogen containing 5–10%
449 CO₂ and adequate humidity) for 14 days. On day 3 or day 4 after inoculation, 0.25 ml from the liquid media are
450 subcultured on to two plates of solid media. One plate is incubated aerobically and the second anaerobically at 35–
451 37°C for 14 days. The subculture procedure is repeated on day 6, 7, or 8 and again on day 13 or 14. An alternative
452 method is to subculture on days 3, 5, 10, and 14 on to a plate of solid medium. All the subculture plates are incubated
453 for 10 days except for the 14-day subculture, which is incubated for 14 days. Liquid media is observed every 2–3
454 days and, if any colour change occurs, has to be subcultured immediately.

455

3.2. Interpretation of *Mycoplasma* test results

456 At the end of the incubation period (total 28 days), examine all the inoculated solid media microscopically for the
457 presence of mycoplasma colonies. The test sample passes the test if the growth of mycoplasma colonies has
458 occurred on the positive controls, and if growth has not occurred on any of the solid media inoculated with the test
459 material. If at any stage of the test, more than one plate is contaminated with bacteria or fungi, or is broken, the test
460 is invalid and should be repeated. If mycoplasma colonies are found on any agar plate, a suitable confirmatory test
461 on the colonies should be conducted, such as PCR. Some mycoplasmas cannot be cultivated, in which case the
462 MSV and MCS have to be tested using an indicator cell line such as Vero cells, DNA staining, or PCR methods.

463 Further detailed procedures can be found in Veterinary Medicinal Products, VICH GL34:
464 http://www.ema.europa.eu/docs/en_GB/document_library/Scientific_guideline/2013/03/WC500140352.pdf

465 Prior to beginning testing it is necessary to determine that each batch of media promotes the growth of *M. mycoides*
466 subsp. *mycoides* SC-(*Mmm*SC) type strain PG1. General mycoplasma broth and agar are used but contain porcine
467 serum as a supplement. Each batch of broth and agar is inoculated with 10–100 CFU of *Mmm*SC. The solid medium
468 is suitable if adequate growth of *Mmm*SC is found after 3–7 days' incubation at 37°C in 5–10% CO₂. The liquid
469 medium is suitable if the growth on the agar plates subcultured from the broth is found by at least the first subculture.
470 If reduced growth occurs another batch of media should be obtained and retested.

471 1 ml of cell or virus seed to be tested is inoculated into 9 ml of the liquid medium and 100 µl on to solid mycoplasma
472 agar. The volume of the product is inoculated so that it is not more than 10% of the volume of the medium. The liquid
473 medium is incubated at 37°C in 5–10% CO₂ and 100 µl of broth is subcultured on to agar at days 7, 14 and 21. The
474 agar plates are incubated at 37°C in 5–10% CO₂ for no fewer than 14 days, except those corresponding to day 21
475 subculture, which are incubated for 7 days. An un-inoculated mycoplasma broth and agar plate are incubated as
476 negative controls. For assessment of inhibitory substances, inoculate 1 ml of sample to be tested into 9 ml of the
477 liquid medium and 100 µl on to solid medium and add 10–100 CFU of *Mmm*SC to each. Prepare positive control by
478 inoculating 9 ml of mycoplasma broth and a mycoplasma agar plate with 10–100 CFU of *Mmm*SC. Incubate as for
479 samples and negative controls.

480 During incubation time, visually compare the broth of the positive control with sample present with the positive control
481 broth and, if there is no inhibition of the organism either the product possesses no antimicrobial activity under the
482 conditions of the test, or such activity has been satisfactorily eliminated by dilution. If no growth or reduced growth of
483 *Mmm*SC is seen in the liquid and solid medium with test sample when compared with the positive control, the product
484 possesses antimicrobial activity, and the test is not satisfactory. Modifications of the conditions to eliminate the
485 antimicrobial activity and repeat test are required.

486 If antimicrobial activity is present it is necessary to dilute the test product further. Repeat the test above using 1.0 ml
487 of sample in 39 ml of mycoplasma broth and then inoculate with 10–100 CFU of *Mmm*SC and incubate as above. All
488 broths and plates are examined for obvious evidence of growth. Evidence of growth can be determined by comparing
489 the test culture with the negative control, the positive control, and the inhibition control.

490 If evidence of microbial growth is found in the test samples the contaminating bacterium will be identified and
491 confirmed as *Mmm*SC by specific PCR assay.

3.2 General testing for exclusion of *Mycoplasma* sp.

493 General testing for exclusion of *Mycoplasma* sp. that are less fastidious may require up to 28 days in culture, using
494 general mycoplasma media. Some mycoplasmas cannot be cultivated, in which case the live biological sample will
495 have to be tested using an indicator cell line such as Vero cells, DNA staining, or PCR methods.

496 Further detailed procedures can be found in Veterinary Medicinal Products, VICH GL34:
497 http://www.ema.europa.eu/docs/en_GB/document_library/Scientific_guideline/2013/03/WC500140352.pdf

498 and

499 USDA SAM 910: https://www.aphis.usda.gov/animal_health/vet_biologics/publications/910.pdf, (both accessed 25
500 July 2023).

501 4. Example of detection of rickettsia and protozoa

502 There are no general test procedures for exclusion of rickettsia or protozoa. Procedures to exclude specific agents of
503 concern such as *Coxiella burnetii* (Q fever), *Ehrlichia canis*, *Trypanosoma evansi* and *Babesia caballi* can be found for

504 example, in the Review of Published Tests to detect pathogens in veterinary vaccines Intended for Importation into
505 Australia (Department of Agriculture [of Australia] [, Forest and Fisheries (2013)]. The review is based on the reading and
506 interpretation of applicable published papers from reputable journals and are regarded as examples of sensitive methods
507 for detection of specified agents.

508 **4.1. An Example of a specific test protocol based on published methods for exclusion of *Babesia*** 509 ***caballi* and *Theileria equi***

510 *Babesia caballi* and *Theileria equi* can be cultured *in vitro* in 10% equine red blood cells (RBC) in supportive medium
511 supplemented with 40% horse serum and in a micro-aerophilic environment. Culture isolation of *T. equi* is more
512 sensitive than for *B. caballi*. Giemsa-stained blood smears are prepared from cultures daily for 7 days (Avarzed *et*
513 *al.*, 1997; Ikadai *et al.*, 2001). *Babesia caballi* is characterised by paired merozoites connected at one end. *Theileria*
514 *equi* is characterised by a tetrad formation of merozoites or 'Maltese cross'. Confirmation of the diagnosis is by PCR
515 (see Chapter 2.5.8 *Equine piroplasmosis*). Molecular diagnosis is recommended for the testing of biological products
516 that do not contain whole blood or organs. Molecular diagnosis by PCR or loop-mediated isothermal amplification
517 (LAMP) assay are the most sensitive and specific testing methods for detection of the pathogens of equine
518 *piroplasmosis* (Alhassan *et al.*, 2007).

519 **5. Example of detection of virus viruses in biological materials**

520 In brief, general testing usually includes the use of continuous and primary cell lines of the source species, e.g. cells of
521 known susceptibility to the likely viral contaminants, which are inoculated for usually a period of up to 3–4 weeks with
522 weekly subcultures. Virus seeds also require testing on a primary cell line of the species in which the final product is
523 intended. At Day 21 or 28, assessment of the monolayers is done using H&E-appropriate histology staining procedures
524 to assess CPE, and haemadsorption with guinea-pig and chicken RBC to assess the presence of haemadsorbing agents.
525 Note that general testing is useful as a screening tool though not sufficiently sensitive enough to detect all viruses of
526 concern to all countries.

527 Specific testing requires test material to be inoculated on to sensitive, susceptible cells lines for the virus to be excluded;
528 the amplification process in cell culture is usually up to 28 days but depending of/on the virus, may require longer culturing
529 times. Detection of specific viral contaminants is by recognition of CPE in conjunction with more sensitive antigen detection
530 or molecular tests such as FAT and PCR and ELISA after the amplification process in cell culture is completed.

531 All testing using cell lines to amplify for target viruses is contingent on the sensitivity of the cells for the target agent and
532 the ability to recognise the presence of the agent in the cells. The quality, characteristics, and virus permissibility profile of
533 cell lines in use should be determined as fit for purpose and appropriately maintained. Positive and negative controls should
534 be used at all passages of cell culture to determine sensitivity and specificity. Interference testing should be performed at
535 first pass to ensure that the test sample does not inhibit the growth of the virus being excluded for.

536 **5.1. An example of general testing for the exclusion of viruses from virus and cell seed stocks** 537 **used in production of veterinary vaccines**

538 ~~If the test virus inoculum is cytopathogenic~~ If a virus seed is known to cause cytopathic effect (CPE) in a permissive
539 cell line, the effect must be specifically neutralised without affecting the likelihood of isolation of the target agent. ~~For~~
540 ~~affected cell type, 1 ml of the test master (or working) virus seed (MVS) is thawed or reconstituted and neutralised~~
541 ~~with the addition of 1 ml mono-specific antiserum.~~ The serum must be shown to be free from antibodies against any
542 agents for which the test is intended to detect. Antiserum must should be tested for nonspecific inhibiting affects. For
543 a general test, this can be difficult to ascertain. Serum should be of sufficiently high titre to neutralise the seed virus
544 effectively with the use of an approximately equal volume or less of serum. A microplate block titration is used-useful
545 to determine the titre-amount of the antiserum required to neutralise the MVS-a known amount of concern. The
546 antiserum CPE causing virus seed. This is allowed to neutralise the MVS at 37°C for 1 hour. The MVS and antiserum
547 mixture is then inoculated on to a 75 cm² flask with appropriate cells. If the MVS is known to be high-titred or difficult
548 to neutralise, the blocking antiserum can be added to the growth medium at a final concentration done in the normal
549 conditions required of 1–2% each test system (e.g. time, temperature, cell type etc.).

550 ~~Master cell~~ If a virus seed is known to be high-titred or difficult to neutralise, antiserum can be added to the growth
551 medium in a test system at a final concentration of 1–2%.

552 Cell seed stocks do not require a neutralisation process.

553 **5.1. Example of general testing procedures for the exclusion of viruses from virus and cell seed**
554 **stocks used in production of veterinary vaccines**

555 **5.1.1 Example of amplification in cell culture**

556 ~~The cells should be passaged weekly up to a 28 day period. Continuous and primary, 75 cm² area~~
557 ~~monolayers of the source species (and intended species as applicable) are infected with 1 ml of seed~~
558 ~~stocks and passaged weekly for between up to 21–28-days. Depending on the procedure followed,~~
559 ~~monolayers can be subcultured between passes or freeze/thawed to disrupt cells. Negative and positive~~
560 ~~controls should be also set up at each pass using the same cell population.~~ Certain relevant viruses may
561 be selected as indicators for sensitivity and interference (positive controls) but these will not provide
562 validation for the broader range of agents targeted in general testing. The final culture is examined for
563 cytopathology and haemadsorption.

564 **5.1.2 Example of general detection procedures: cytopathology**

565 May–Grünwald–Giemsa or H&E staining procedures are used to assess for cytopathological changes
566 associated with virus growth. Monolayers must have a surface area of at least 6 cm² and can be prepared
567 on appropriate chambered tissue culture slides and incubated for 7 days. The plastic wells of the slides
568 are removed leaving the rubber gasket attached to the slide. The slides are rinsed in Dulbecco's
569 phosphate buffered saline (PBS), fixed in acetone, methanol or formalin depending on the stain used
570 and placed on a staining rack. For May–Grünwald–Giemsa staining: the slides are stained for 15 minutes
571 at room temperature with May–Grünwald stain diluted 1/5 with absolute methanol. The May–Grünwald
572 stain is removed by inverting the slides. The slides are then stained for 20 minutes with Giemsa stain
573 diluted 1/15 in deionised water. The Giemsa stain is removed by inverting the slides and rinsing them in
574 deionised water for 10–20 seconds. The slides are air-dried and mounted with a coverslip using paraffin
575 oil. The May–Grünwald–Giemsa stain differentially stains ribonucleoprotein (RNP); DNA RNP stains red-
576 purple, while RNA RNP stains blue. The monolayers are examined with a conventional microscope for
577 the presence of inclusion bodies, an abnormal number of giant cells, or other cytopathology attributable
578 to a viral contaminant of the test product. The inoculated monolayers are compared with suitable control
579 non-inoculated monolayers. If specific cytopathology attributable to an extraneous virus is found, results
580 are reported, and additional specific testing may be conducted.

581 **5.1.3 Example of general detection procedures: haemadsorption**

582 Testing for haemadsorption ~~uses~~ requires the use of 75 cm² area monolayers established in tissue
583 culture flasks after the 28-day passage period described above. Guinea-pig, chicken, and any other
584 blood for use in this assay is collected in an equal volume of Alsever's solution and may be stored at 4°C
585 for up to 7 days. Immediately prior to use, the stored erythrocytes are again washed by adding 5 ml of
586 blood in Alsever's solution to 45 ml of calcium and magnesium-free PBSA (PBSA) and centrifuging in a
587 50 ml centrifuge tube at 500 **g** for 10 minutes. The supernatant is aspirated, and the erythrocytes are
588 suspended in PBSA and re-centrifuged. This washing procedure is repeated at least twice until the
589 supernatant is clear. Erythrocytes from each species are combined by adding 0.1 ml of each type of
590 packed blood cells to 100 ml of PBSA. The erythrocytes from different species may be kept separate or
591 combined, as desired. To each flask, add 5 ml of the erythrocyte suspension, and incubate the flasks at
592 4°C for 30 minutes. Monolayers are washed twice with PBSA and examined for haemadsorption. If no
593 haemadsorption is apparent, 5 ml of ~~the fresh~~ erythrocyte suspension is added to each flask; the flasks
594 are incubated at 20–25°C (room temperature) for 30 minutes, rinsed as before, and examined for
595 haemadsorption. Separate flasks may be used for each incubation temperature if desired. Monolayers
596 are examined for the presence of haemadsorption using an illuminated light box and microscopically.
597 Non-inoculated monolayers are used as negative controls. The PBSA and fresh erythrocytes should
598 prevent most nonspecific haemadsorption from occurring. If specific haemadsorption attributable to an
599 extraneous agent is found, results are reported, and additional specific testing may be conducted.

600 ~~Specific testing requires specialised test procedures that are sensitive to amplifying a particular agent in~~
601 ~~culture and then detection of that agent by means of fluorescence, antigen capture ELISA or PCR;~~
602 ~~whichever is more sensitive. Specific testing is usually required when general procedures are not~~
603 ~~adequate for effective exclusion of more fastidious, viruses. Some examples are listed in Table 4.~~

604 **5.2. ~~An~~ Examples of specific virus-agent exclusion testing from ~~of~~ biologicals used in the**
605 **production of veterinary vaccines**

606 **5.2.1. Example of porcine epidemic diarrhoea virus (PEDV)**

607 Trypsin presence is required at inoculation and in the culture medium for isolation of porcine epidemic
608 diarrhoea virus (PEDV) in Vero cells (CCL81, ATCC) to ensure the virus can enter host cells. Just
609 confluent monolayers (100%) are required; as under confluent monolayers (<90%) are more sensitive
610 to the presence of trypsin ~~and will be destroyed well before the 7 days required for each passage in~~
611 ~~culture~~. An over confluent or aging monolayer will not be sensitive for growth of PEDV. Maintenance
612 media (MM) formulation consists of Earle's MEM (minimal essential medium) (with 5.6 M HEPES [N-
613 2-hydroxyethylpiperazine, N-2-ethanesulphonic acid] and glutamine) + 0.3% Tryptose phosphate
614 broth, 0.02% yeast extract and 4 µg/ml TPCK treated trypsin. The addition of the trypsin into ~~the~~ MM
615 should occur on the day the media is to be used.

616 Prior to inoculation, confluent 75 cm² monolayers are washed twice with ~~the~~ MM (~~with trypsin added~~)
617 to remove growth media containing FCS. Virus or cell seed (1 ml) is added with 1 ml of MM to each
618 monolayer; incubate at 37°C for 2 hours, then add 30 ml/flask of MM. Negative control monolayers
619 of the same size are set up prior to inoculation of test material. Positive and interference controls are
620 set up last, and where possible, in a separate laboratory area to avoid contamination. Assessment
621 for sensitivity and interfering substances requires ~~assessment use~~ of PEDV reference virus of known
622 titre. A control for interference using co-inoculation of test sample and PEDV needs only to be set up
623 on the first pass. Positive controls must should be set up at every pass to ensure each monolayer
624 used gives expected sensitivity. PEDV virus is titrated in log dilutions starting at 10⁻¹ to 10⁻⁶ in MM
625 (depending ~~of on~~ the endpoint titre of reference virus) in duplicate rows of 6 wells of a 24-well tissue
626 culture plate. For the interference test, PEDV is titrated in the same dilution series but using MM
627 spiked with a 10% volume of test material. Decant off the growth media and discard. Wash plates to
628 ensure no FCS is present. Two washes using approximately 400 µl/well MM (with trypsin added) are
629 sufficient.

630 Add 100 µl of diluted virus on to each of two duplicate wells. Rock inoculated plates to distribute the
631 inoculum evenly over the surface of the monolayer. Incubate at 37°C with 5% CO₂ for 2 hours then
632 add a further 1 ml volumes/well of MM.

633 After 7 days, 75 cm² monolayers have cells disrupted using two freeze-thaw cycles at -80°C. Positive
634 control plates are read for end-point titres, and these are compared with virus in the presence of test
635 material to ensure titres are comparable and interference has not occurred. Freeze-thaw lysates are
636 clarified at 2000 **g** for 5 minutes and re-passed on to newly formed monolayers as for the first
637 passage. Passages are repeated until a total of four passages are completed at which point cell
638 lysates are assessed by PCR for detection of PEDV and day 7 monolayers in 24-well plates are fixed
639 and stained by IFA for FAT. If a seed virus is to be tested and requires neutralisation using antiserum,
640 extra care in the isolation of PEDV needs to be considered. Trypsin is rendered inactive in the
641 presence of serum proteins and without trypsin present, PEDV is unable to grow in cell culture grows
642 poorly, or not at all. Washing off the inoculum with two MM washes is required after an extended
643 adsorption time of up to 4 hours to ensure acceptable sensitivity.

644 **J.H. INFORMATION TO BE SUBMITTED WHEN**
645 **APPLYING FOR AN IMPORT LICENCE**

646 When undertaking risk analysis for biologicals, ~~Veterinary Authorities should follow the Terrestrial Manual~~ the manufacturer
647 should follow the requirements of the importing country. Requirements for each importing country should be accessible
648 and published online. The manufacturer or the Veterinary Authority of the exporting country should make available detailed
649 information, in confidence if as necessary, on the source of the materials used in the manufacture of the product (e.g.
650 substrates). They should make available details of the method of manufacture (and where appropriate inactivation) of the
651 substrates and component materials, the quality assurance procedures for each step in the process, final product testing
652 regimes, and the pharmacopoeia with which the product must conform in the country of origin. They should also make
653 available challenge organisms, their biotypes and reference sera, and other means of appropriate product testing.

654 For detailed examples of a risk-based assessment of veterinary biologicals for import into a country refer to:

- 655 • European Commission (2015). The Rules Governing Medicinal Products in the European Union. Eudralex. Volume 6.
656 Notice to applicants and regulatory guidelines for medicinal products for veterinary use

657 • Department of Agriculture, Forest and Fisheries of Australia (2021b). Live veterinary vaccines Summary of information
658 required for biosecurity risk assessment, Version 6 and Inactivated veterinary vaccines, Version 8.

659 • Outline of the Regulatory System of Veterinary Drugs in Japan (2015) Assurance of the Quality, Efficacy, and Safety
660 Based on the Law for Ensuring the Quality, Efficacy, and Safety of Drugs and Medical Devices.

661 When applying for an import licence other regulatory requirements may need to be addressed depending on the type of
662 sample and if the sample needs to be shipped out of country to a testing laboratory. For example, cell seeds may come
663 under certain requirements for permits such as the Convention for International Trade in Endangered Species of Wild
664 Fauna and Flora (CITES), where a cell line is derived from an endangered species, e.g. the cell line and its derivatives.
665 Applying for such a permit is time consuming and requires input from both the exporting and importing country.

666 Genetically modified organisms (GMOs) are becoming more frequent in use with changes in manufacturing technologies
667 and specialised, time-consuming procedures need to be in place. A laboratory that accepts a GMO product for testing shall
668 follow the procedures of the Office of the Gene Regulator (OGTR) to allow the GMO to be dealt with.

669 I. RISK ANALYSIS PROCESS

670 Risk analysis should be as objective and transparent as possible and should be performed in accordance with Section 2
671 of the *Terrestrial Code*, and certification in line with Section 5 of the *Terrestrial Code*. Of necessity, assessment of the
672 country and commodity factors and risk reduction measures will be based largely on manufacturers' data. These data
673 depend on quality assurance at all stages of manufacture, rather than on testing of the final product alone.

674 Domestic exposure may be influenced by the approved usage of the product. Veterinary Authorities may place limits on
675 usage of some products (e.g. restricting usage to institutions of appropriate biosecurity).

676 IJ. BIOCONTAINMENT

677 Suitable biocontainment may be necessary for many forms of biologicals. In particular, the importation of exotic micro-
678 organisms should be carried out in accordance with Chapter 1.1.4 *Biosafety and biosecurity: standard for managing*
679 *biological risk in the veterinary laboratory and animal facilities*.

680 Laboratories using high risk agents should have well researched and documented risk assessments in place prior to
681 working with such agents to ensure the safety of their staff and laboratory.

682 REFERENCES

683 ALHASSAN A., GOVIND Y., TAM N.T., THEKISOE O.M., YOKOYAMA N., INOUE N. & IGARASHI I. (2007). Comparative evaluation of
684 the sensitivity of LAMP, PCR and *in vitro* culture methods for the diagnosis of equine piro-plasmosis. *Parasitol. Res.*, **100**,
685 1165–1168.

686 AUSTRALIAN QUARANTINE POLICY AND REQUIREMENTS FOR THE IMPORTATION OF LIVE AND NOVEL VETERINARY BULK AND FINISHED
687 VACCINES (1999). Available online at:
688 <https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/ba/memos/1999/animal/99-085acleaned.pdf>
689 (Accessed 25 July 2023).

690 AVARZED A., IGARASHI I., KANEMARU T., HIRUMI, K., OMATA T., SAITOY., OYAMADA A., NAGASAWA H., TOYODA Y. & SUZUKI N.
691 (1997). Improved *in vitro* cultivation of *Babesia caballi*. *J. Vet. Med. Sci.*, **59**, 479–481.

692 BARONE P., WIEBE M.E., LEUNG J.C., HUSSEIN I.T.M., KEUMURIAN F.J., BOURESSA J., BRUSSEL A., CHEN D., CHONG M.,
693 DEGHANI H., GERENTES L., GILBERT J., GOLD D., KISS R., KREIL T.R., LABATUT R., LI Y, MÜLLBERG J., MALLET L., MENZEL C.,
694 MOODY M., MONPOEHO S., MURPHY M., PLAVSIC M., ROTH N.J., ROUSH D., RUFFING M., SCHICHO R., SNYDER R., STARK D.,
695 ZHANG C., WOLFRUM J., SINSKEY A.J. & SPRINGS S.L. (2020). Viral contamination in biologic manufacture and implications
696 for emerging therapies. *Nat. Biotechnol.*, **38**, 563–572.

697 BAYLIS S.A., FINSTERBUSCH T., BANNERT N., BLUMEL J. & MANKERTZ A. (2011). Analysis of porcine circovirus type 1 detected
698 in Rotarix vaccine. *Vaccine*, **29**, 690–697.

- 699 CODE OF FEDERAL REGULATIONS (OF THE UNITED STATES OF AMERICA) (CFR) (2015). Subchapter E. Viruses, serums, toxins
700 and analogous products; organisms and vectors. *In*: Code of Federal Regulations, Animals and Animal Products. Title 9,
701 Parts 101–124. US Government Printing Office, Washington DC, USA. Available online;
702 <https://www.law.cornell.edu/cfr/text/9/part-113> (Accessed 25 July 2023).
- 703 DEPARTMENT OF AGRICULTURE, WATER AND ENVIRONMENT (OF AUSTRALIA) (2013). Review of Published Tests to Detect
704 Pathogens in Veterinary Vaccines Intended for Importation into Australia, Second Edition. CC BY 3.0. Available online at:
705 <https://www.agriculture.gov.au/biosecurity-trade/policy/risk-analysis/animal/review-of-published-tests-to-detect-pathogens>
706 (Accessed 25 July 2023).
- 707 DEPARTMENT OF AGRICULTURE, WATER AND ENVIRONMENT (OF AUSTRALIA) (2021a). Inactivated veterinary vaccines Summary
708 of information required for biosecurity risk assessment. Version 8. Available online at:
709 [https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/aqis/importing/bio-products/vet-vaccines/inact-](https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/aqis/importing/bio-products/vet-vaccines/inact-vet-vacs.pdf)
710 [vet-vacs.pdf](https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/aqis/importing/bio-products/vet-vaccines/inact-vet-vacs.pdf) (Accessed 25 July 2023).
- 711 DEPARTMENT OF AGRICULTURE, WATER AND ENVIRONMENT (OF AUSTRALIA) (2021b). Live veterinary vaccines. Summary of
712 information required for biosecurity risk assessment. Version 6. Available online at:
713 [https://www.awe.gov.au/sites/default/files/sitecollectiondocuments/aqis/importing/bio-products/vet-vaccines/live-vet-](https://www.awe.gov.au/sites/default/files/sitecollectiondocuments/aqis/importing/bio-products/vet-vaccines/live-vet-vaccines.doc)
714 [vaccines.doc](https://www.awe.gov.au/sites/default/files/sitecollectiondocuments/aqis/importing/bio-products/vet-vaccines/live-vet-vaccines.doc) (Accessed 25 July 2023).
- 715 EUROPEAN COMMISSION (2006–2015). The Rules Governing Medicinal Products in the European Union. Eudralex. Volumes
716 4–9. European Commission, DG Health and Food Safety, Public health, EU Pharmaceutical information, Eudralex.
717 Available online at: http://ec.europa.eu/health/documents/eudralex/index_en.htm (accessed 25 July 2023).
- 718 EUROPEAN MEDICINES AGENCY SCIENCES MEDICINES HEALTH (2016). EMA/CVMP/IWP/251741/2015. Reflection paper on
719 methods found suitable within the EU for demonstrating freedom from extraneous agents of the seeds used for the
720 production of immunological veterinary medicinal products. Available online at:
721 [https://www.edqm.eu/en/d/95422?p_1_back_url=%2Fen%2Fsearch-](https://www.edqm.eu/en/d/95422?p_1_back_url=%2Fen%2Fsearch-edqm%3Fq%3DEMA%252FCVMP%252FIWP%252F251741%252F2015%26delta%3D40%26category%3D302281)
722 [edqm%3Fq%3DEMA%252FCVMP%252FIWP%252F251741%252F2015%26delta%3D40%26category%3D302281](https://www.edqm.eu/en/d/95422?p_1_back_url=%2Fen%2Fsearch-edqm%3Fq%3DEMA%252FCVMP%252FIWP%252F251741%252F2015%26delta%3D40%26category%3D302281)
723 (Accessed 25 July 2023).
- 724 EUROPEAN PHARMACOPOEIA ~~8-2 (2014)–(2021–2023)~~. European Directorate for the Quality of Medicines and Health Care
725 (EDQM), Council of Europe, Strasbourg, France. Available online at <http://online.edqm.eu/> (accessed 8 March 2017)
726 Current version available online at [European Pharmacopoeia \(Ph. Eur.\) 10th Edition – European Directorate for the Quality](http://online.edqm.eu/)
727 [of Medicines & HealthCare \(edqm.eu\)](http://online.edqm.eu/) (accessed 4 July 2022). Current version available online at [European Pharmacopoeia](http://online.edqm.eu/)
728 [\(Ph. Eur.\) 11th Edition – European Directorate for the Quality of Medicines & HealthCare \(edqm.eu\)](http://online.edqm.eu/) (accessed 25 July
729 2023).
- 730 FARSANG A. & KULCSAR G. (2012). Extraneous agent detection in vaccines – a review of technical aspects. *Biologicals*, **40**,
731 225–230.
- 732 HARE W.C.D. (1985). Diseases Transmissible by Semen and Embryo Transfer Techniques. OIE Technical Series No. 4.
733 World Organisation for Animal Health (OIE), Paris, France.
- 734 HODINKA R.L. (2013). Point: is the era of viral culture over in the clinical microbiology laboratory? *J. Clin. Microbiol.*, **51**, 2–4.
- 735 IKADAI H., MARTIN M.D., NAGASAWA H., FUJISAKI K., SUZUKI N., MIKAMI T., KUDO N., OYAMADA T. & IGARASHI I. (2001). Analysis
736 of a growth-promoting factor for *Babesia caballi* cultivation. *J. Parasitol.*, **87**, 1484–1486.
- 737 MARCUS-SECURA C., RICHARDSON J.C., HARSTON R.K., SANE N. & SHEETS R.L. (2011). Evaluation of the human host range
738 of bovine and porcine viruses that may contaminate bovine serum and porcine trypsin used in the manufacture of biological
739 products. *Biologicals*, **39**, 359–369.
- 740 MACKAY D. & KRIZ N. (2010). Current challenges in viral safety and extraneous agents testing. *Biologicals*, **38**, 335–337.
- 741 MILLER P.J., AFONSO C.L., SPACKMAN E., SCOTT M.A., PEDERSEN J.C., SENNE D.A., BROWN J.D., FULLER C.M., UHART M.M.,
742 KARESH W.B., BROWN I.H., ALEXANDER D.J. & SWAYNE D. (2010). Evidence for a new avian paramyxovirus serotype 10
743 detected in rockhopper penguins from the Falkland Islands. *J. Virol.*, **84**, 11496–11504.
- 744 NEVEROV A. & CHUMAKOV K. (2010). Massively parallel sequencing for monitoring genetic consistency and quality control
745 of live viral vaccines. *Proc. Natl Acad. Sci. USA*, **107**, 20063–20068.

- 746 ONIONS D. & KOLMAN J. (2010). Massively parallel sequencing, a new method for detecting adventitious agents. *Biologicals*,
747 **38**, 377–380.
- 748 OUTLINE OF THE REGULATORY SYSTEM OF VETERINARY DRUGS IN JAPAN (2015). Assurance of the Quality, Efficacy, and Safety
749 Based on the Law for Ensuring the Quality, Efficacy, and Safety of Drugs and Medical Devices.
750 https://www.maff.go.jp/nval/english/regulatory/pdf/Outline_RegulatorySystem_VMPs.pdf (Accessed 25 July 2023).
- 751 ROSSEEL T., LAMBRECHT B., VANDENBUSSCHE F., VAN DEN BERG T. & VAN BORM S. (2011). Identification and complete genome
752 sequencing of paramyxoviruses in mallard ducks (*Anas platyrhynchos*) using random access amplification and next
753 generation sequencing technologies. *Virology*, **8**, 463.
- 754 SHEETS R., LOEWER, J., RAYDCHAUDHURI G. & PETRICCIANI J. (2012). Adventitious agents, new technology, and risk
755 assessment, 19–20 May 2011, Baltimore, MD. *Biologicals*, **40**, 162–167.
- 756 TELLEZ S., CASIMIRO R., VELA A.I., FERNANDEZ-GARAYZABAL J.F., EZQUERRA R., LATRE M.V., BRIONES V., GOYACHE J., BULLIDO
757 R., ARBOIX M. & DOMINGUEZ L. (2005). Unexpected inefficiency of the European pharmacopoeia sterility test for detecting
758 contamination in clostridial vaccines. *Vaccine*, **24**, 1710–1715.
- 759 VAN BORM S., ROSSEEL T., STEENSELS M., VAN DEN BERG T. & LAMBRECHT B. (2013). What's in a strain? Viral metagenomics
760 identifies genetic variation and contaminating circoviruses in laboratory isolates of pigeon paramyxovirus type 1. *Virus Res*,
761 **171**, 186–193.
- 762 VICTORIA J.G., WANG C., JONES M.S., JAING C., MCLOUGHLIN K., GARDNER S. & DELWART E.L. (2010). Viral nucleic acids in
763 live-attenuated vaccines: detection of minority variants and an adventitious virus. *J. Virol.*, **84**, 6033–6040.
- 764 WANG J., LUNT R., MEEHAN B. & COLLING A. (2014). Evaluation of the potential role of next-generation sequencing (NGS) in
765 innocuity testing. Technical Report CSIRO, Australian Animal Health Laboratory.
- 766 WORLD HEALTH ORGANIZATION (WHO) (1998). WHO Expert Committee on Biological Standardization. World Health
767 Organization Technical Report Series, Report No. 858. World Health Organization, Geneva, Switzerland.
- 768 WORLD HEALTH ORGANIZATION (WHO) (2012). WHO Expert Committee on Biological Standardization. World Health
769 Organization Technical Report Series, Report No. 964. World Health Organization, Geneva, Switzerland. Available online
770 at: https://apps.who.int/iris/bitstream/handle/10665/89142/9789241209779_eng.pdf (Accessed 25 July 2023).
- 771 World Health Organisation (WHO) (2015) Expert Committee on Biological Standardization Sixty-fifth report. Technical
772 report series 993, 2015. Annex 2 Scientific principles for regulatory risk evaluation on finding an adventitious agent in a
773 marketed vaccine. Available online at: [https://cdn.who.int/media/docs/default-source/biologicals/cell-](https://cdn.who.int/media/docs/default-source/biologicals/cell-substrates/annex2_adventitious_agent_in_marketed_vaccine_eng.pdf?sfvrsn=e5de04a_3&download=true)
774 [substrates/annex2_adventitious_agent_in_marketed_vaccine_eng.pdf?sfvrsn=e5de04a_3&download=true](https://cdn.who.int/media/docs/default-source/biologicals/cell-substrates/annex2_adventitious_agent_in_marketed_vaccine_eng.pdf?sfvrsn=e5de04a_3&download=true) (Accessed 25
775 July 2023)

FURTHER READING

- 776
- 777 Details of methods and culture media ~~will can~~ be found in the following books and also in commercial catalogues.
- 778 BARROW G.I. & Feltham R.K.A., eds. (1993). Cowan and Steel's Manual for the Identification of Medical Bacteria, Third
779 Edition. Cambridge University Press, Cambridge, UK.
- 780 COLLINS C.H., LYNE P.M. & GRANGE J.M., eds. (1995). Collins and Lyne's Microbiological Methods, Seventh Edition.
781 Butterworth Heinemann, Oxford, UK.
- 782 MURRAY P.R., ED. (2003). Manual of Clinical Microbiology, Eighth Edition. American Society for Microbiology Press,
783 Washington DC, USA.

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785

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* *

786 **NB:** FIRST ADOPTED IN 1989. MOST RECENT UPDATES ADOPTED IN 2017.

35 1. Samples for use in determining MU

36 Repeatability is the level of agreement between results of replicates of a sample both within and between runs of the same
37 test method in a given laboratory. During assay development, repeatability is estimated by evaluating variation in results
38 of independent replicates from a minimum of three (preferably five) samples representing analyte activity within the
39 operating range of the assay (see ~~the WOAHS Validation Standard, Chapter 1.1.6~~ Validation of diagnostic assays for
40 infectious diseases of terrestrial animals, Sections A.2.5 Robustness and B.1.1 Repeatability, and Chapter 2.2.6 Selection
41 and use of reference samples and panels, Section 3.4 A.4.2). Typically, the variation in replicate results is expressed as
42 RSD or CV. The significant feature is that repeatability studies can be used to define the expected precision of the assay
43 in the detection of a range of analyte concentrations.

44 The use of internal quality or process controls over a range of expected results has become part of daily quality control
45 and quality assurance operations of accredited facilities (see ~~the WOAHS Validation Standard, chapter 1.1.6~~, Sections A.2.6
46 Calibration of the assay to standard reagents and B.5.1 Monitoring the assay, and Chapter 2.2.6, Section 4.4 C.1). These
47 results provide a continuous monitor relative to different aspects of repeatability, e.g. intra- and inter-assay variation, intra-
48 and inter-operator variation and intra- and inter-batch variation, which, when subjected to statistical analysis, provide an
49 expression of the level of robustness (precision) of a test procedure. The monitoring of assay quality control parameters
50 for repeatability provides evidence that the assay is or is not performing as expected. For control samples to provide valid
51 inferences about assay precision, they should be treated in exactly the same way as test samples in each run of the assay,
52 e.g. including sample preparation such as extraction steps or dilution of serum samples for an antibody enzyme-linked
53 immunosorbent assay (ELISA).

54 The variation of the results for control samples can also be used as an estimate of those combined sources of uncertainty
55 and is called the “top-down” approach. This approach recognises that the components of precision will be manifest in the
56 ultimate measurement. So monitoring the precision of the measurement over time will effectively show the combined effects
57 of the imprecision associated with component steps.

58 The imprecision or uncertainty of the measurement process associated with a test result becomes increasingly more
59 important the closer the test value is to the diagnostic cut-off value. This is because an interpretation is made relative to
60 the assay threshold regarding the status of the test result as positive, negative, or inconclusive (as will be described in the
61 following example). In this context, low-weak positive samples, like those used in repeatability studies or as the low-weak
62 positive control, are most appropriate for estimation of MU. The rationale being that MU, which is a function of assay
63 precision, is most critical at decision-making points (i.e. thresholds or cut-offs), which are usually near the lower limit of
64 detection for the assay. In this chapter, the application of MU with respect to cut-off (threshold) values, whether
65 recommended by test-kit manufacturers or determined in the diagnostic laboratory, is described.

66 MU, using the top-down approach, ideally requires long-term accumulated data from a weak positive control sample after
67 multiple test runs over time, with multiple operators and variable conditions. The examples given below are based on 10
68 data points but higher numbers will increase robustness.

69 2. Example of MU calculations in ELISA serology

70 For most antibody detection tests, it is important to remember that the majority of tests are measurements of antibody
71 activity relative to a threshold against which a dichotomous interpretation of positive or negative is applied. This is important
72 because it helps to decide where application of MU is appropriate. In serology, uncertainty is frequently most relevant at
73 the threshold between positive and negative determinations. Results falling into this zone are also described as
74 intermediate, inconclusive, suspicious or equivocal (see ~~the WOAHS Validation Standard, chapter 1.1.6~~, Section B.2.4
75 Selection of a cut-off (threshold) value for classification of test results).

76 A limited data set from a competitive ELISA for antibody to avian influenza virus is used as an example of a “top-down”
77 approach for serology. A low-weak positive control sample was used to calculate MU at the cut-off level³².

78 2.1. Method of expression of MU

79 As the uncertainty is to be estimated at the threshold, which is not necessarily the reaction level of the low-weak
80 positive control serum, the relative standard deviation (RSD), or coefficient of variation (CV), if expressed as a
81 percentage, provides a convenient transformation:

³² The Australian Government, Department of Agriculture, Fisheries and Forestry, has compiled worked examples for a number of diagnostic tests Available online at: <https://www.agriculture.gov.au/agriculture-land/animal/health/laboratories/tests/measurement-uncertainty> (accessed 22 June 2023)

$$RSD (X) = SD (X) / (X)$$

82 To simplify assessment, the transformed result is regarded as the assay output result, which is the averaged across
 83 the number of replicates (\bar{X}). In the case of this example, a competitive ELISA, results are “normalised” (as defined
 84 in the ~~WHO Validation Standard, chapter 1.1.6~~, Section A.2.7 *‘Normalising’ test results to a working standard*) to a
 85 working standard by forming a ratio of all optical density (OD) values to the OD result of a non-reactive (negative)
 86 control (OD_N). This ratio is subtracted from 1 to set the level of antibody activity on a positive correlation scale; the
 87 greater the level, the greater the calculated value. This adjusted value is expressed as a per cent and referred to as
 88 the percentage inhibition or PI value. So for the ~~low-weak~~ positive control serum (OD_L), the transformation to obtain
 89 the per cent inhibition values for the ~~low-weak~~ positive control (PI_L) is:

$$PI_L = 100 \times [1 - \{OD_L / OD_N\}]$$

90 The relative standard deviation becomes:

$$RSD (PI_L) = SD (PI_L) / (PI_L)$$

93 2.2. Example

94 A limited data set for the AI competitive ELISA example is shown below. In the experiment, the operator tested the
 95 ~~low-weak~~ positive control serum ten times in the same run. Ideally in the application of this “top down” method, a
 96 larger data set would be used, which would enable accounting for effects on precision resulting from changes in
 97 operator and assay components (other than only the control serum).

98 **Table 1. Top-down or control sample approach for an influenza antibody C-ELISA**

Test	PI (%)
1	56
2	56
3	61
4	64
5	51
6	49
7	59
8	70
9	55
10	42

99 Mean PI = 56.3; Std Dev (SD) = 7.9; Assays (n) = 10

100 2.3. Calculating uncertainty

101 From the limited data set,

$$102 RSD (PI_L) = SD / \text{Mean } 7.9 / 56.3 = 0.14 \text{ (or as coefficient of variation = 14\%)}$$

103 Expanded uncertainty (U) is the statistic defining the interval within which the value of the measure and is believed
 104 to lie within a specified level of confidence, usually 95%. Expanding the uncertainty is done by multiplying the RSD
 105 (PI_L) by a factor of 2; this allows the calculation of an approximate 95% confidence interval around the threshold value
 106 (in this case at PI = 50%), assuming normally distributed data.

$$107 U (95\%CI) = 2 \times RSD = 0.28$$

108 This estimate can then be applied at the threshold level

$$109 95\% CI = 50 \pm (50 \times 0.28) = 50 \pm 14\%$$

110

2.4. Interpretation

111 Any positive result (PI > 50%) that is less than 64% is not positive with 95% confidence. Similarly, a negative result
112 (PI < 50%) that is higher or equal to a PI of 36 is not negative at the 95% confidence level. This zone of lower
113 confidence may correlate with the “grey zone” or “inconclusive/suspect zone” for interpretation that should be
114 established for all tests (Greiner *et al.*, 1995).

3. Example of MU calculation in molecular tests

116

3.1. Example

117 For real-time PCRs, replicates of positive controls with their respective cycle threshold (CT) values can be used to
118 estimate MU using the top-down approach (Newberry & Colling, 2021). The method of expression follows the same
119 formula as for the ELISA example above. This example uses data from replicate runs of a weak positive control
120 sample (10 runs) of an equine influenza hydrolysis probe assay.

121

Table 2. Top-down or control sample approach for an equine influenza TaqMan A assay

<u>Test</u>	<u>Ct value</u>
<u>1</u>	<u>33.60</u>
<u>2</u>	<u>33.20</u>
<u>3</u>	<u>33.96</u>
<u>4</u>	<u>33.18</u>
<u>5</u>	<u>33.96</u>
<u>6</u>	<u>32.72</u>
<u>7</u>	<u>33.57</u>
<u>8</u>	<u>33.45</u>
<u>9</u>	<u>32.80</u>
<u>10</u>	<u>33.20</u>

122

Mean = 33.36; Std Dev (SD) = 0.43; Assay n=10

123

3.2. Calculating uncertainty

124

From the limited data set.

125

RSD (PI_r) = SD/Mean 0.43/33.36 = 0.0128 (or as coefficient of variation = 1.28%)

126

Expanded uncertainty (U) is the statistic defining the interval within which the value of the measure and is believed
127 to lie within a specified level of confidence, usually 95%. Expanding the uncertainty is done by multiplying the RSD
128 (PI_r) by a factor of 2; this allows the calculation of an approximate 95% confidence interval around the threshold value
129 (in this case at Ct value = 37), assuming normally distributed data.

130

U (95%CI) = 2 × RSD = 0.0255

131

This estimate can then be applied at the threshold level

132

95% CI = 37± (37 × 0.0255) = 37 ± 0.94

133

The mean cycle threshold (Ct) value after 10 runs is 33.36 and the standard deviation is 0.43. The relative standard
134 deviation is 0.0128. The expanded uncertainty (95% CI) is 2 × the relative standard deviation = 0.0255. Measurement
135 of uncertainty (MU) is most relevant at the cut-off (Ct = 37) and can be applied by multiplication (37 × 0.0255 = 0.94).
136 Subtraction from the threshold (37-0.94) provides the lower 95% confidence limit (Ct = 36.06) and addition (37+0.94)
137 the upper 95% confidence limit (Ct = 37.94).

3.3. Interpretation of the results

Any positive result (Ct < 37) that is higher than 36 Ct is not positive with 95% confidence. Similarly, any negative result (Ct > 37) that is less than 38 Ct is not negative with 95% confidence.

B. OTHER APPLICATIONS

The top-down approach should be broadly applicable for a range of diagnostic tests including molecular tests. For the calculation of tests using a typical two-fold dilution series for the positive control such as virus neutralisation, complement fixation and haemagglutination inhibition tests geometric mean titre (i.e. mean and SD of log base 2 titre values) of the positive control serum should be calculated. Relative standard deviations based on these log scale values may then be applied at the threshold (log) titre, and finally transformed to represent the uncertainty at the threshold. However, in all cases, the approach assumes that the variance about the positive control used to estimate the RSD is proportionally similar at the point of application of the MU, for example at the threshold. If the RSD varies significantly over the measurement scale, the positive control serum used to estimate the MU at the threshold should be selected for an activity level close to that threshold. The Australian Government, Department of Agriculture, Fisheries and Water Resources Forestry, has compiled worked examples for a number of diagnostic tests (see footnote 1), (DAFF, 2010), which are available online at:

<http://www.agriculture.gov.au/animal/health/laboratories/tests/worked-example-measurement>

For quantitative real time PCRs (qPCR) replicates of positive controls with their respective cycle threshold (CT) values can be used to estimate MU using the top-down approach.

Other approaches and variations have been described, i.e. for serological tests (Dimech *et al.*, 2006; Goris *et al.*, 2009; Toussaint *et al.*, 2007). Additional work and policy Central documents are available from the National Pathology Accreditation Advisory Group and Life Science. The central document to MU is the Guide to the expression of uncertainty in measurement (GUM), ISO/IEC Guide, (1995) and Eurachem/CITAC Guide, 2012 CG 4: Quantifying uncertainty in analytical measurement.

Scope and limitations of the top-down approach

Methods for quantifying uncertainty (addressing MU) for tests vary. When estimating MU for quantitative, biologically based diagnostic tests, where variations in the substrate or matrix have large and unpredictable effects, a top-down approach is recommended (Dimech *et al.*, 2006; Eurachem 2012; Goris *et al.*, 2009; ISO/IEC Guide 98-3:2008; Newberry & Colling, 2021; Standards Council of Canada, 2021; and footnote 1). The advantage of this method is that quality control data are generated during normal test runs and can be used to estimate the precision of the assay and express it at the cut-off. The application at the cut-off depends on the performance of the test at different analyte concentrations, e.g. variation is likely to increase at higher diluted samples. The top-down approach does not identify individual contributors to measurement uncertainty but rather provides an overall estimate. Measurement uncertainty does not replace test validation; however, the validation process includes assessments of repeatability through quality control samples which facilitate calculation of MU.

REFERENCES

AMERICAN ASSOCIATION FOR LABORATORY ACCREDITATION (A2LA). Policy on estimating measurement uncertainty for life science testing labs https://portal.a2la.org/policies/A2LA_P103b.pdf (accessed 22 November 2018).

Australian Government, Department of Agriculture and WATER RESOURCES. Worked examples of measurement uncertainty <http://www.agriculture.gov.au/animal/health/laboratories/tests/worked-example-measurement> (accessed 22 November 2018).

AUSTRALIAN GOVERNMENT DEPARTMENT OF HEALTH AND AGEING (2007). Requirements for the estimation of measurement uncertainty, National Pathology Accreditation Advisory Group. [http://www.health.gov.au/internet/main/publishing.nsf/Content/B1074B732F32282DCA257BF0001FA218/\\$File/dhaeou.pdf](http://www.health.gov.au/internet/main/publishing.nsf/Content/B1074B732F32282DCA257BF0001FA218/$File/dhaeou.pdf) (accessed 22 November 2018).

DIMECH W., FRANCIS B., KOX J. & ROBERTS G. (2006). Calculating uncertainty of measurement for serology assays by use of precision and bias. *Clin. Chem.*, **52**, No. 3, 526–529.

183 ELLISON S.L.R. & WILLIAMS A. (EDS) (2012). Eurachem/CITAC Guide CG 4: Quantifying uncertainty in analytical
184 measurement, 3rd Edition. Eurachem, Teddington, United Kingdom, Section 3. Available at:
185 www.eurachem.org/images/stories/Guides/pdf/QUAM2012_P1.pdf (Accessed 10 June 2023).

186 GORIS N., VANDENBUSSCHE F., HERR, C., VILLERS, J., VAN DER STEDE, Y. & DE CLERCQ K. (2009). Validation of two real-time
187 PCR methods for foot-and-mouth disease diagnosis: RNA-extraction, matrix effects, uncertainty of measurement and
188 precision. *J. Virol. Methods*, **160**, 157–162.

189 GREINER M., SOHR D. & GOEBEL P.A. (1995). Modified ROC analysis for the selection of cut-off values and the definition of
190 intermediate results of serodiagnostic tests, *J. Immunol. Methods*, **185**, 123–132.

191 ~~ISO/IEC (1995). Guide to the expression of uncertainty in measurement (GUM), ISO/IEC Guide 98:1995. International~~
192 ~~Organization for Standardization (ISO), www.iso.org.~~

193 ~~ISO/IEC (2005). ISO/IEC 17025:2005~~2017. General Requirements for the Competence of Testing and Calibration
194 Laboratories. International Organization for Standardization (ISO), www.iso.org.

195 ISO/IEC GUIDE 98-3:2008 (E). Uncertainty of measurement – Part 3 Guide to the expression of uncertainty in measurement
196 (GUM:1995), International Organization for Standardization (ISO), www.iso.org (accessed 10 June 2023).

197 SCC- STANDARDS COUNCIL OF CANADA. Requirements and Guidance for method Verification and Validation in Testing
198 Laboratories (RG-MVVT), 2021-05-24. <http://www.scc.ca/> (accessed 10 June 2023).

199 TOUSSAINT J.F., ASSAM P., CAIJ B., DEKEYSER F., KNAPEN K., IMBERECHTS H., GORIS N., MOLENBERGHS G., MINTIENS K., & DE
200 CLERCQ K. (2007). Uncertainty of measurement for competitive and indirect ELISAs. *Rev. sci. tech. Off. int. Epiz.*, **26**, 649–
201 656.

202 NEWBERRY K. & COLLING A (2021). Quality standards and guidelines for test validation for infectious diseases in veterinary
203 laboratories. *Rev. Sci. Tech. Off. Int. Epiz.*, 40, 227–237. Available at
204 <https://doc.woah.org/dyn/portal/index.xhtml?page=alo&alold=41245> (accessed 22 June 2023)

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206

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* *

207 **NB: There is a WOAHO Collaborating Centre for**
208 **Diagnostic Test Validation Science in the Asia-Pacific Region (please consult the WOAHO Web site:**
209 **<https://www.woah.org/en/what-we-offer/expertise-network/collaborating-centres/#ui-id-3>**

210 **Please contact the WOAHO Collaborating Centre for any further information on validation.**

211 **NB: FIRST ADOPTED IN 2014.**

MEETING OF THE WOAHP BIOLOGICAL STANDARDS COMMISSION

Paris, 4–8 September 2023

CHAPTER 2.2.6.

SELECTION AND USE OF
REFERENCE SAMPLES AND PANELS

INTRODUCTION

The WOAHP Validation Recommendations provide detailed information and examples in support of the WOAHP Validation Standard that is published as Chapter 1.1.6 Principles and methods of Validation of diagnostic assays for infectious diseases of terrestrial animals *this Terrestrial Manual, or Chapter 1.1.2 of the Aquatic Manual. The Term “WOAHP Validation Standard” in this chapter should be taken as referring to those chapters.*

Reference samples and panels are essential from the initial proof of concept in the development laboratory through to the maintenance and monitoring of assay performance in the diagnostic laboratory and all of the stages in between. The critical importance of reference samples and panels cannot be over-emphasised. The wrong choice of reference materials can lead to bias and flawed conclusions right from development through to validation and use. Therefore, care must be exercised in selecting reference samples and designing panels.

Fig. 1. Reference samples and panels grouped based on similar characteristics and composition. The topics and alphanumeric subheadings (e.g. Proof of concept, A.2.1) refer to the relevant section in the WOAHP Validation Standard, Chapter 1.1.6 Validation of diagnostic assays for infectious diseases of terrestrial animals.

Group A		Group B		Group D
Proof of concept, A.2.1.		Asp, B.1.2.		Standard method comparison, B.2.6.
Operating range, A.2.2-3.		Analytical accuracy, <u>ancillary tests</u> B.1.4.		Provisional recognition, B.2.6-7.
<u>ASe, B.1.3.</u>		Reference samples and panels		Biological modifications, B.5.2.2.
Optimisation, A.2.-3-2.		Group C		Group E
Robustness, A.2.5- <u>Preliminary repeatability, A.2.8.</u>		Repeatability B.1.1.		DSp and DSe Gold standard, B.2.1.
Calibration <u>and process control,</u> A.2.6.		Preliminary reproducibility, B.2.6-7.		Group F
Process control, A.2.6.		Reproducibility, B.3.		DSp and DSe no gold standard B.2.2.
<u>ASe, B.1.3.</u>		Proficiency testing, B.5.1.		
Technical modifications, B.5.2.1.				
Reagent replacement, B.5.2.3.				

A_{Sp} = Analytical specificity; A_{Se} = Analytical sensitivity; D_{Sp} = diagnostic specificity; D_{Se} = diagnostic sensitivity

25 ~~As can be seen in Figure 1, Reference samples and/or panels are mentioned throughout the WOA~~
26 ~~Validation Standard, chapter 1.1.6. As defined in the glossary of the OIE Quality Standard and Guidelines~~
27 ~~for Veterinary Laboratories: Infectious Diseases, "Reference materials are "substances whose properties are~~
28 ~~sufficiently homogenous and well established to be used for the calibration of an apparatus, the assessment~~
29 ~~of a measurement method, or for assigning values to materials"³³. In the context of test method validation,~~
30 ~~reference materials or samples contain the analyte of interest in varying concentrations or activities~~
31 ~~reactivities and are used in developing and evaluating the candidate assay's analytical and diagnostic~~
32 ~~performance characteristics. In our case, Analyte means the specific component of a test sample that is~~
33 ~~detected or measured by the test method, e.g. antibody, antigen or nucleic acid. These Reference samples~~
34 ~~may be sera, fluids, tissues, excreta, feed and/or environmental samples that contain the analyte of interest~~
35 ~~and are usually harvested from infected animals and their environments. However, in some cases, they may~~
36 ~~be prepared in the laboratory from an original starting material (e.g. a dilution of a high positive serum in~~
37 ~~negative serum) or perhaps created by spiking the chosen matrix with a derived analyte (e.g. a bacterial or~~
38 ~~viral culture, a recombinant/expressed protein, or a genomic construct). Whether natural or prepared, they~~
39 ~~are used in experiments throughout the development process, carry over into the validation pathway and~~
40 ~~can be used to monitor performance throughout the lifespan of the assay.~~

41 ~~In Figure 1, reference samples and panels are grouped based on similar characteristics and composition~~
42 ~~and these groupings will be the basis for the following descriptions. As a cross reference, the appropriate~~
43 ~~Section of the OIE Validation Standard is indicated under each particular application of the reference sample~~
44 ~~or panel.~~

45 ~~Reference samples may be used for multiple purposes from the initial stages of development and~~
46 ~~optimisation, through Stage 1 and into continual monitoring and maintenance of the assay. Wherever~~
47 ~~possible, large quantities of these reference samples should be collected or prepared and preserved for~~
48 ~~long-term use. Switching reference samples during the validation process introduces an intractable variable~~
49 ~~that can severely undermine interpretation of experimental data and therefore, the integrity of the~~
50 ~~development and validation process. For assays that may target multiple species, the samples should be~~
51 ~~representative of the primary species of interest. It is critical that these samples reflect both the target analyte~~
52 ~~and the matrix in which it is found in the population for which the assay is intended. The reference materials~~
53 ~~should appropriately represent the range of analyte concentration to be detected by the assay.~~

54 ~~It is important to emphasise that, no matter Whether reference samples are selected from natural sources~~
55 ~~or prepared in the laboratory, all selection criteria or and preparation procedures, as well as testing~~
56 ~~requirements, need to be fully described and put into document control. Not only is this good quality~~
57 ~~management practice, but it will provide both an enhanced level of continuity and confidence throughout the~~
58 ~~lifespan of the assay. Summaries of the data to be collected and documented for reference material can be~~
59 ~~found in Figure 2. For more detail on best practice and quality standards for the documentation of~~
60 ~~provenance of reference material refer to Watson et al. (2021).~~

33 https://www.techlab.fr/Commun/UK_Def_MRC.asp

Figure 2. Documentation of reference material should be thorough to ensure i) transparency of intended purpose during assay development; ii) the correct sample types are used in all stages of assay development and validation; iii) accurate replacement of depleted reagents; and iv) appropriate choice of reference material during assay modification and re-validation. Minimum descriptive metadata are listed for pathogen, animal host, tissue type and phase of infection.

<u>Pathogen data</u>	<u>Animal host and sample type data</u>	<u>Phase of Infection data</u>
<ul style="list-style-type: none"> ▪ <u>Strain/isolate</u> ▪ <u>Serotype</u> ▪ <u>Genotype</u> ▪ <u>Lineage</u> ▪ <u>Tests used for characterisation</u> 	<ul style="list-style-type: none"> ▪ <u>Natural infection</u> ▪ <u>Experimental infection and protocol used</u> ▪ <u>Species</u> ▪ <u>Breed</u> ▪ <u>Age</u> ▪ <u>Sex</u> ▪ <u>Reproductive status</u> ▪ <u>Vaccination history</u> ▪ <u>Herd history</u> 	<ul style="list-style-type: none"> • <u>Clinical signs</u> • <u>Antibody profiles</u> • <u>Pathogen loading and shedding</u> • <u>Tests used to determine status of disease/infection (case definition)</u>
	<ul style="list-style-type: none"> • <u>Tissue type/s (matrix) used</u> • <u>For spiked samples – detail source of analyte and diluent (matrix) used</u> • <u>Details relating to pooling of samples</u> 	

A. GROUP A

The question of pooling of samples to create a reference sample is often asked. If reference material is harvested from a single animal, it is important to ascertain whether or not it is representative of a typical course and stage of infection within the context of the population to be tested. If not, this could lead to bias and flawed conclusions related to validation. Pooling is a good alternative but it is imperative to pool from animals that are in a similar phase of infection. This is particularly important for antibody detection systems. Pooling also addresses the issue of the larger quantities of reference material to be stored for long term use, especially when dealing with smaller host species. Before pooling any samples, it is preferable that they be independently tested to demonstrate that they are similar with respect to analyte concentration and/or reactivity. There should be an assessment following pooling to ensure that unforeseen interference is not introduced by the pooling of multiple samples, for example differing blood types or antibody composition within the independent samples could cross-react within the pool, thus causing the pooled sample to behave differently in the specified assay than the individual samples when tested independently.

It is often difficult to obtain individual samples that truly represent analyte concentrations or reactivities across the spectrum of the expected range. Given the dynamics of many infections or responses to pathogens, intermediate ranges are often very transient. In the case of antibody responses, early infection phases in individual animals often result in highly variable and heterogeneous populations of antibody isotypes and avidities. In general, these do not make good reference samples for assessing the analytical characteristics of an assay. They are nonetheless important for different types of reference panels as will be discussed later. For most applications in Group A, it is acceptable to use prepared samples that are spiked with known concentrations of analyte or a dilution series of a high positive in negative matrix to create a range of concentrations.

Whether natural or prepared, reference samples should represent the anticipated range of analyte concentrations, from low-weak to high-strong positive, which would be expected during a typical course of infection. A negative reference sample should be included as a background monitor. If a negative (matrix) is used as diluent for preparation of a positive reference sample (e.g. a negative serum used to dilute a high positive serum or tissue spiked with a construct), that negative should definitely be included as the negative reference sample.

~~As mentioned above, all reference samples should be well characterised. This includes documentation on both the pathogen and donor host. For pathogens, this may include details related to strain, serotype, genotype, lineage, etc. The source of the host material should be well described with respect to species, breed, age, sex, reproductive status, vaccination history, herd history, etc. Wherever possible, the phase of infection should be noted. This could include details related to clinical signs, antibody profiles, pathogen load or shedding, etc. Equally important, tests that are used to determine disease/infection status need to be well documented (see Section E of this chapter for further explanation). In some cases, experimental infection/exposure may be the only viable option for the production of reference material. In this case, all of the above considerations plus the experimental protocol should be detailed.~~

99 Above all else, natural or prepared, reference materials must be unequivocal with respect to their status as representing
100 either a true positive or a true negative sample. This may require that the status be confirmed using another test or battery
101 of tests. For example, many antibody reference sera are characterised using multiple serological tests. This provides not
102 only confidence but additional documented characteristics that may be required when attempting to replace or duplicate
103 this reference material in the future.

104 Recommendations regarding stability and storage of reference materials are available: [https://www.woah.org/en/what-we-](https://www.woah.org/en/what-we-offer/veterinary-products/#ui-id-4)
105 [offer/veterinary-products/#ui-id-4](https://www.woah.org/en/what-we-offer/veterinary-products/#ui-id-4)

106 **1. Proof of concept (WOAH Validation Standard, Chapter 1.1.6, Section A.2.1)**

107 ~~The WOA Validation Standard, Chapter 1.1.6~~ states that test methods and related procedures must be appropriate for
108 specific diagnostic applications in order for the test results to be of relevance. In other words, the assay must be 'fit for
109 purpose'. Many assays are developed with good intentions but without a specific application in mind. At the very outset, it
110 is critical that the diagnostic purpose(s) should be defined with respect to the population(s) to be tested. The most common
111 purposes are listed in broad terms in Section A of ~~the WOA Validation Standard, chapter 1.1.6~~. As such, they are inclusive
112 of more narrow and specific applications. However, these specific purpose(s) need to be clearly defined from the outset
113 and are critically important in the context of a fully validated assay. As will be seen in the following descriptions, clearly
114 defining the application will have impact on both the selection of reference samples and panels and the design of analytical
115 and diagnostic evaluations.

116 **2. Operating range (WOAH Validation Standard, Chapter 1.1.6, Section A.2.2–3) and** 117 **analytical sensitivity (WOAH Validation Standard, Chapter 1.1.6, Section B.1.3)**

118 **2.1. Analytical approaches Operating range and analytical sensitivity**

119 The operating range of the assay ~~is defines the lower and upper analyte detection limits and~~ the interval of analyte
120 concentrations (amounts) over which the method provides suitable accuracy and precision. ~~It also defines the lower~~
121 ~~and upper detection limits the assay. To establish this range, The operating range is established by serial dilution, to~~
122 ~~extinction, of replicates of a high-strong positive reference sample is selected. This high positive sample, either~~ natural
123 ~~or prepared, is serially diluted to extinction. Dilutions of the strong positive are made in a negative matrix~~
124 ~~representative of the typical sample matrix of samples type taken from animals in the population targeted by the~~
125 ~~assay. This includes antibody assays where a high-replicates of a strong positive reference serum should be diluted~~
126 ~~in a negative reference serum to create the dilution series. Analytical sensitivity (ASe) is measured by replicates of~~
127 ~~the lower limit of detection (LOD) of an analyte in an assay. The same high-strong positive reference sample may be~~
128 ~~used to determine both the operating range and the analytical LOD.~~

129 **2.2. Comparative approaches to analytical sensitivity**

130 If the intended purpose is to detect low levels of analyte or subclinical infections, it may be difficult to obtain the
131 appropriate reference materials from early stages of the infection process. In some cases, it may be useful to
132 determine a comparative ASe by running a panel of samples on the candidate assay and on another independent
133 assay. Ideally this panel of samples would be serially collected from either naturally or experimentally infected animals
134 and should represent infected animals early after infection, ~~en~~ through to the development of clinical or fulminating
135 disease, if possible. This would provide a relative comparison of ASe between the assays, ~~as well as,~~ and a temporal
136 comparison of the earliest point of detection relative to the pathogenesis of the disease.

137 An experiment like the one described above, provides a unique opportunity to collect reference samples representing
138 a natural range of concentrations that would be useful for other validation purposes. Care must be taken to avoid use
139 of such samples when inappropriate (consult Group D below). Wherever possible serial samples should be collected
140 from ~~at least five a statistically sound number of~~ animals throughout the course of infection. In cases where sampling
141 is lethal (e.g. requiring the harvest of internal organ tissues), the number of animals required ~~would be a minimum~~
142 ~~depends on need and fitness of five per sampling event the experimental approach. In all cases approval from an~~
143 ~~ethics committee is required~~. For smaller host species, ~~this the~~ number may need to be increased in order to collect
144 sufficient reference material. Given that experiments like this require a high commitment of resources, it would be
145 wise to maximise the collection of not only the currently targeted reference samples but additional materials (e.g.
146 multiple tissues, fluids, etc.) that may be useful as reference materials in the future.

147 **3. Optimisation (WOAH Validation Standard, Chapter 1.1.6, Section A.2.32) and preliminary**
148 **repeatability (WOAH Validation Standard, Chapter 1.1.6, Section A.2.68)**

149 Optimisation is the process by which the most important physical, chemical and biological parameters of an assay are
150 evaluated and adjusted to ensure that the performance characteristics of the assay are best suited to the intended
151 application. At least three reference samples representing negative, ~~low-weak~~ and ~~high-strong~~ positive may be chosen
152 from either natural or prepared reference samples. Optimisation experiments are rather exhaustive especially when assays
153 with multiple preparatory and testing steps are involved. It is very important that a sufficient quantity of each reference
154 sample be available to complete all optimisation experiments. Changing reference samples during the course of
155 optimisation is not recommended as this will result in the addition of an uncontrolled variable and a disruption in the
156 continuity of optimisation evidence.

157 Assessment of repeatability should begin during assay development and optimisation stages. ~~Repeatability and~~ is further
158 verified during Stage 1 of assay validation (Section B.1.1 ~~of chapter 1.1.6~~). The same reference samples should be used
159 ~~for both processes, again throughout~~ to provide continuity of evidence.

160 **4. Calibration and process controls (WOAH Validation Standard, Chapter 1.1.6, Section**
161 **A.2.6)**

162 **4.1. International, national or in-house analyte reference standards**

163 International reference standards are highly characterised, contain defined concentrations of analyte, and are usually
164 prepared and held by international reference laboratories. They are the reagents to which all assays and/or other
165 reference materials should be standardised. National reference standards are calibrated by comparison with an
166 international standard reagent whenever possible. In the absence of an international standard, a national reference
167 standard may be selected or prepared and it then becomes the standard of comparison for the candidate assay. In
168 the absence of both of the above, an in-house standard should be selected or prepared by the development laboratory
169 within the responsible organisation. In all cases, thorough documentation of reference material should be observed
170 as summarised in Figure 2. All of the standard reagents, whether natural or prepared, must be highly characterised
171 through extensive analysis, and preferably the methods for their characterisation, preparation, and storage have been
172 published in peer-reviewed publications (Watson et al., 2021). These reference standards should also be both stable
173 and innocuous.

174 Reference standards, especially antibody, are usually provided in one of two formats. They may be provided as a
175 single positive reagent of given titre with the expectation that the candidate assay will be standardised to give an
176 equivalent titre. This is a straight forward analytical approach but many of these 'single' standards have been prepared
177 from highly positive samples as a pre-dilution in a negative matrix in order to maximise the number of aliquots
178 available. The drawback here is that there is no accounting for any potential matrix effect in the candidate assay as
179 there is no matrix control provided. The other approach is to provide a negative and a ~~low-weak~~ and ~~high-strong~~
180 positive set of reference standards that are of known concentrations or reactivities and are within the operating range
181 of the standard method that was used to prepare them. The negative provided in the set must be the same as the
182 negative diluent used to prepare the weak and strong positive reference standard, if the positive standards were
183 diluted. This compensates for any potentially hidden matrix effect. In addition, this set of three acts as a template for
184 the selection and/or preparation of process controls (discussed below).

185 Classically, the above standards usually have been polyclonal antibody standards and to a lesser extent, conventional
186 antigen standards used for calibration of serological assays. However, today, reference standards could also be
187 monoclonal antibodies or recombinant/expressed proteins or genomic constructs, if they are to be used to calibrate
188 assays to a single performance standard.

189 **4.2. Working standards or process controls**

190 Working standard reagent(s), commonly known as quality or process controls, are calibrated to international, national,
191 or in-house standard reagents. They are selected or prepared in the local matrix which is found in the population for
192 which the assay is intended. Ideally, negative and ~~low-weak~~ and ~~high-strong~~ positive working standards should be
193 selected or prepared. Concentrations and/or reactivities should be within the normal operating range of the assay.
194 Large quantities should be prepared, aliquoted and stored for routine use in each diagnostic run of the assay. The
195 intent is that these controls should mimic, as closely as possible, field samples and should be handled and tested like
196 routine samples. They are used to establish upper and lower control limits of assay performance and to monitor
197 random and/or systematic variability using various control charting methods. Their daily performance will determine
198 whether or not an assay is in control and if individual runs may be accepted. As such, these working reference
199 samples are critically important from a quality management standpoint.

200 **5. Technical modifications (WOAH Validation Standard, Chapter 1.1.6, Section B.5.2.1)**

201 Technical modifications to a validated assay such as changes in instrumentation, extraction protocols, and conversion of
202 an assay to a semi-automated or fully automated system using robotics will typically not necessitate full revalidation of the
203 assay. Rather, a methods comparison study may be done to determine if these minor modifications to the assay protocol
204 will affect the test results. Consult See chapter 2.2.8 Comparability of assays after changes in a validated test method for
205 description of experiments and statistical approaches to assay precision in the face of technical modifications that are
206 appropriate for comparability testing (Bowden & Wang, 2021; Reising et al., 2021).

207 In general, these approaches require the use of three reference samples, a negative, a weak and a low and high strong
208 positive. Again these samples to represent the entire operating range of both assays. Samples may be either natural or
209 prepared. The important point to re-iterate here is that the same reference samples that were used in the developmental
210 stages of the assay may be used to assess modifications after the method has been put into routine diagnostic use. This
211 provides a higher level of confidence assessing potential impacts because the performance characteristics of these
212 reference samples have been well characterised. At the very least, if new reference samples are to be used, they should
213 be selected or prepared using the same criteria or preparation procedures established for previous materials. Again as
214 enhances the continuity of evidence.

215 **6. Reagent replacement (WOAH Validation Standard, Chapter 1.1.6, Section B.5.2.3)**

216 When a reagent such as a process control sample is nearing depletion, it is essential to prepare and repeatedly test a
217 replacement before such a control is depleted. The prospective replacement should be included in multiple runs of the
218 assay in parallel with the original control to establish their proportional relationship. It is important to change only one
219 control reagent at a time to avoid the compound problem of evaluating more than one variable.

220 ~~Again, it cannot be over-emphasised that any~~ Replacement reference reagent should be selected or prepared using the
221 same criteria or preparation procedures established for previous materials. Again as this enhances the continuity of evidence
222 and confidence in the assay and underlines the importance of documentation of reference material data (Figure 2).

223 **B. GROUP B**

224 **1. Analytical specificity (WOAH Validation Standard, Chapter 1.1.6, Section B.1.2)**

225 Analytical specificity (ASp) is the degree to which the assay distinguishes between the target analyte and other components
226 that may be detected in the assay. ~~This is a relatively broad definition that is often not well understood. ASp may be broken~~
227 ~~down into different elements as described below.~~

228 The choice of reference samples that are required to assess ASp is highly dependent on the specific intended purpose or
229 application ~~that was originally envisaged defined~~ at the development stage of the assay. Assessment of ASp is a crucial
230 element in proof of concept and verification of fitness for purpose and may be broken down into three elements: selectivity,
231 exclusivity and inclusivity.

232 Selectivity: an important element is the extent to which a method can accurately detect and or quantify the targeted analyte
233 in the milieu of nucleic acids, proteins and/or antibodies in the test matrix. This is sometimes termed 'selectivity'. An
234 example is the use of reference samples for tests that are designed to differentiate infected from vaccinated animals (DIVA
235 tests).

236 Reference samples need to be selected and tested from i) non-infected/non-vaccinated, ii) non-infected/vaccinated, iii)
237 infected/non-vaccinated, and iv) infected/vaccinated animals. These samples may be collected under field conditions but
238 it is important that an accurate history be collected, ideally with respect to the animals, but at least to the herds involved,
239 including vaccination practices and disease occurrences (Figure 2). Alternatively, it may be necessary to produce this
240 material in experiments like those described in Section A.2.2 of this chapter, ~~but~~ including a combination of experimentally
241 vaccinated and challenged animals. ~~Application of the 3 Rs (replacement, reduction and refinement) aims to avoid or~~
242 minimise the number of animals used in experiments. For enzyme-linked immunosorbent assays (ELISAs), it is important
243 to avoid use of the vaccine as capture antigen in the assay (e.g. indirect ELISA enzyme-linked immunosorbent assay [I-
244 ELISA]), because carrier proteins in the vaccine may stimulate non-specific antibody responses in vaccinated animals that
245 may be detected in ELISA leading to false positives in the assay. Similarly to the comparative approach described above
246 with respect to ASe, at least five animals in each group should be considered. For smaller host species, this number may
247 need to be increased in order to collect sufficient reference material, leading to false positives in the assay. Depending on
248 the DIVA test, a single experiment could be designed to assess aspects of both ASe and ASp.

249 A second element, sometimes termed 'exclusivity', Exclusivity is the capacity of the assay to detect an analyte or genomic
250 sequence that is unique to a targeted organism, and excludes all other other known organisms that are potentially cross-
251 reactive. This is especially true in serological assays where there are many examples of antigens expressed by other
252 organisms that are capable of eliciting cross-reacting antibody. An attempt should be made to obtain reference samples
253 from documented cases of infections and/or organisms that may be cross-reactive. Depending on the type of assay, these
254 reference materials may represent the organism itself, host-derived samples, or genomic sequences. A profile for the
255 exclusivity of the assay should be established, and expanded on a continual basis as potentially cross-reactive organisms
256 arise.

257 ~~Thirdly, a critical design consideration~~ Inclusivity relates to the capacity of an assay to detect one or several strains or
258 serovars of a species, several species of a genus, or a similar grouping of closely related ~~organisms~~ viruses, bacteria or
259 antibodies. This defines the scope of detection and thus the fitness for purpose. ~~Reference samples are required to define~~
260 ~~the scope of the assay~~ The scope of the assay defines the choice of reference samples and the results will determine proof
261 of fitness. If for example an assay is developed as a screening test to detect all known genotypes or serotypes of a virus,
262 then reference samples from each representative type should be tested. As new lineages or serotype variants arise, they
263 too should be tested as part of the test profile, which should be updated on an ongoing basis.

264 **2. Analytical accuracy of adjunct ancillary tests (WOAH Validation Standard, Chapter 1.1.6,** 265 **Section B.1.4)**

266 Some test methods or procedures are solely analytical tools ~~and are usually applied~~ used to further characterise an analyte
267 that has been detected in a primary assay, ~~for example assays like~~ Examples are the virus neutralisation tests used to
268 type an isolated virus or characterise an antibody response and subtyping of haemagglutinin genes by polymerase chain
269 reaction of avian influenza virus. Such ~~adjunct~~ ancillary tests must be validated for analytical performance characteristics,
270 ~~but and differ from~~ to routine diagnostic tests because they do not require validation for diagnostic performance
271 characteristics. The analytical accuracy of these tests is often dependant on the use of reference ~~reagents~~ material. These
272 reagents, whether they are antibody for typing strains of organisms or reference strains of the organism, etc., should be
273 thoroughly documented, as required for any other reference material (Figure 2), with respect to their source, identity and
274 performance characteristics.

275

C. GROUP C

276 Reference samples in Group C may be used for a number of purposes. In the initial development stages, they may be
277 used in the assessment of assay repeatability and both preliminary reproducibility in Stage 1 and the more in depth
278 assessment of reproducibility in Stage 3 of the Validation Pathway. However, these samples have a number of other
279 potential uses once the assay is transferred to the diagnostic laboratory. They may be used as panels for training and
280 qualifying of analysts, and for assessing laboratory proficiency in external ring testing programmes. Ideally, 20 or more
281 individual samples should be prepared in large volumes. About a quarter (25%) should be negative samples and the
282 remainder (75%) should represent a collection of positives spanning the operating range of the assay. They should be
283 aliquoted into individual tubes in sufficient volumes for single use only and stored for long term use (Chapter 1.1.2
284 Collection, submission and storage of diagnostic specimens). The number of aliquots of each that will be required will
285 depend on how many laboratories will be using the assay on a routine diagnostic basis and how often proficiency testing
286 is anticipated. Ideally, they should be prepared in an inexhaustible quantity, but this is seldom feasible. At a minimum,
287 several hundred or more aliquots of each should be prepared at a time if the assay is intended for use in multiple
288 laboratories. This allows assessment of laboratory proficiency by testing the same sample over many testing intervals – a
289 useful means of detecting systematic error (bias) that may creep into long term use of an assay.

290 These samples may be natural or prepared from either single or pooled starting material. The intent is that they should
291 mimic as closely as possible a true test sample. Because mass storage is always a problem, it may be necessary to store
292 these materials in bulk and prepare working aliquots from time to time. However, if storage space is available, it is
293 preferable to prepare and store large numbers of aliquots at one time because bulk quantities of analyte, undergoing
294 freeze-thaw cycles to prepare a few aliquots at a time, may be subject to degradation. Because this type of reference
295 material is consumed at a fairly high rate, they will need to be replaced or replenished on a continual basis. As potential
296 replacement material is identified during routine testing or during outbreaks, it is advisable to work with field counterparts
297 to obtain bulk reference material and store it for future use. Alternatively, it may be necessary to produce this material in
298 experiments like those described in Section A.2.2 of this chapter. Similar to the comparative approach described above
299 with respect to ASe, at least five animals in each group should be considered. For smaller host species, this number may
300 need to be increased in order to collect sufficient reference material.

301 **1. Repeatability (WOAH Validation Standard, Chapter 1.1.6, Section B.1.1) and preliminary**
302 **reproducibility provisional assay recognition (WOAH Validation Standard, Chapter 1.1.6,**
303 **Section B.2.6)**

304 Repeatability is the level of agreement between results of replicates of a sample both within and between runs of the same
305 test method in a given laboratory. Repeatability is estimated by evaluating variation in results of replicates from a minimum
306 of three (preferably five) samples representing analyte activity within the operating range of the assay. Consult Chapter
307 2.2.4 *Measurement uncertainty* for statistical approaches for measures of uncertainty for assessments of repeatability.

308 Reproducibility is the ability of a test method to provide consistent results, as determined by estimates of precision, when
309 applied to aliquots of the same samples tested in different laboratories. However, preliminary reproducibility estimates of
310 the candidate assay should be determined during developmental stages. A small panel of three (but preferably five)
311 representing negative, weak and ~~both low and high~~ strong positives, like those described above, would be adequate. This
312 type of panel could also be used for a limited evaluation of reproducibility to enhance provisional acceptance status for the
313 assay. The test method is usually assessed in ~~one~~ two or more laboratories with a high level of experience and proficiency
314 in assays similar to the candidate assay. The panel of 'blind' samples is evaluated using the candidate assay in each of
315 these laboratories, using the same protocol, same reagents and comparable equipment. This is a scaled-down version of
316 Stage 3 of assay validation. ~~Consult Chapter 2.2.4 for further explanation of the topic and its application.~~

317 **2. Reproducibility (WOAH Validation Standard, Chapter 1.1.6, Section B.3)**

318 Reproducibility is an important measure of the precision of an assay when used in a cross-section of laboratories located
319 in distinct or different regions or countries using the identical assay (protocol, reagents and controls). As the number of
320 laboratories increases, so does the number of variables encountered with respect to laboratory environments, equipment
321 differences and technical expertise. ~~These~~ An overview of the factors affecting testing reproducibility is provided in Waugh
322 & Clark (2021). Reproducibility studies are a measure of an assay's capacity to remain unaffected by substantial changes
323 or substitutions in test conditions anticipated in multi-laboratory use (e.g. shipping conditions, technology transfer, reagents
324 batches, equipment, testing platforms and/or environments). ~~Each of~~ At least three laboratories should test the same panel
325 of 'blind' samples containing a minimum of 20 samples, representing negative and a range of positive samples. If selected
326 negative and/or positive samples ~~in the panel~~ are duplicated, in the panel then it may be possible to assess both assay
327 reproducibility and within-laboratory repeatability estimates may be augmented by replicate testing of these samples when
328 used in the reproducibility studies.

329 **3. Proficiency testing (WOAH Validation Standard, Chapter 1.1.6, Section B.5.1)**

330 A validated assay in routine use in multiple laboratories needs to be continually monitored to ensure uniform performance
331 and provide overall confidence in test results. This is assessed through external quality assurance programmes. Proficiency
332 testing is one measure of laboratory competence derived by means of an inter-laboratory comparison; implied is that
333 participating laboratories are using the same (or similar) test methods, reagents and controls. Results are usually
334 expressed qualitatively, i.e. either negative or positive, to determine pass/fail criteria. However, ~~for single dilution assays,~~
335 where semi-quantitative results ~~provide are provided,~~ additional data for assessment of analysis may assess non-random
336 error among the participating laboratories. Refer to Johnson & Cabuang (2021) for an overview of proficiency testing and
337 ring trials.

338 Proficiency testing programmes are varied depending on the type of assay in use. For single dilution type assays, panel
339 sizes ~~also vary but a minimum of five samples, representing negative and both low and high positives, like those described~~
340 ~~above, would be adequate.~~ Proficiency testing is not unlike a continuous form of reproducibility assessment. However,
341 reproducibility, by definition, is a measure of the assay's performance in multiple laboratories; whereas proficiency testing
342 is an assessment of laboratory competence in the performance of an established and validated assay. Measurements of
343 precision can be estimated for both the reproducibility and repeatability data if replicates of the same reference sample are
344 included in this 'blind' panel. ~~Consult Chapter 2.2.4 for further explanation of the topic and its application. vary but a~~
345 minimum of five samples, representing negative weak and strong positives, would be adequate.

346 **D. GROUP D**

347 Reference samples in Group D differ from the previous Groups in that each sample in the panel should be from a different
348 individual animal. As indicated in Chapter 2.2.8 Comparability of assays after changes in a validated test method,
349 experimental challenge studies often include repeated sampling of individual animals to determine the progression of
350 disease, but this is a different objective ~~than to~~ comparing performance characteristics that would be associated with
351 diagnostic sensitivity (DSe) and diagnostic specificity (DSp) of a test method. Serially drawn samples, taken on different

352 days from the same animal, cannot be used as representative of individual animals in populations targeted by the assay,
353 because such samples violate the rule of independence of samples required for such studies.

354 Care must be taken in choosing the reference samples and the standard (independent) method used in this type of
355 comparison to ensure that the analytes being detected (if different) demonstrate the same type of pathogenic profile in
356 terms of time of appearance after exposure to the infectious agent, and relative abundance in the test samples chosen.

357 **1. Standard method comparison and provisional recognition (WOAH Validation Standard,
358 Chapter 1.1.6, Sections B.2.6-5 and B.2.6)**

359 There are situations where it is not possible or desirable to fulfil Stage 2 of the Validation Pathway because appropriate
360 samples from the target population are scarce and animals are difficult to access (such as for exotic diseases). However,
361 a small but select panel of highly characterised test samples representing the range of analyte concentration should be
362 run in parallel in the candidate assay method and by a WOA standard method, as published in the *WOAH Manuals*.
363 Biobanks may be a useful resource in this context, providing well-characterised samples supported with metadata to
364 enhance transparency and provenance of samples used in method comparisons (Watson et al., 2021). If the methods are
365 deemed to be comparable (Chapter 2.2.8), and depending on the intended application of the assay, the choice may be
366 made that further diagnostic validation is not required. For example, if the intended application is for screening of imported
367 animals or animal products for exotic pathogens or confirmation of clinical signs, full validation beyond a test method
368 comparison may not be feasible or warranted.

369 Experience has shown that the greatest obstacle to continuing through Stage 2 of the Validation Pathway is the number of
370 defined samples required to estimate diagnostic performance parameters with a high degree of certainty (WOAH Validation
371 Standard, chapter 1.1.6, Section B.2). In some cases, provisional recognition by international, national or local authorities
372 may be granted for an assay that has not been completely evaluated past analytical stages. The different rationales for
373 provisional acceptance are well explained in the WOAH Validation Standard, chapter 1.1.6. In all cases however, sound
374 evidence must exist for comparative estimates of DS_p and DS_e based on a small select panel of well-characterised
375 samples containing the targeted analyte.

376 Ideally, for both comparison with a standard method or provisional recognition, a panel of, for example, 60 samples could
377 be assembled to ensure sufficient sample size for statistical analysis of the resulting data. This would include 30 'true'
378 negatives and 30 'true' positives. Wherever possible, the positives should reflect the range of analyte concentrations or
379 activities expected in the target population. As mentioned above, each sample in this panel must represent an individual
380 animal. Consult Chapter 2.2.5 for statistical approaches to determining methods comparability using diagnostic samples.

381 **2. Biological modifications (WOAH Validation Standard, Chapter 1.1.6, Section B.5.2.2)**

382 There may be situations where changes to some of the biologicals used in the assay may be necessary and/or warranted.
383 This may include changes to reagents themselves or a change to a different type of specimen which contains the same
384 analyte as targeted in the original validated assay (e.g. from serum to saliva). At the very least, all of the analytical criteria
385 of the validation pathway must be re-assessed before proceeding. If the analytical requisites are met, the remaining
386 question relates to whether or not a full diagnostic validation is required. A similar approach to the above using a panel of
387 60 individual reference samples may be considered. However, in this case the original test method would be considered
388 as the standard (independent) test and the modified method would be considered the candidate. Consult Chapter 2.2.5 for
389 statistical approaches to determining methods comparability using diagnostic samples.

390 **E. GROUP E**

391 Reference animals and reference samples in this Group E are well described in the WOAH Validation Standard, chapter
392 1.1.6, Section B.2.1). However, there are a few points that are worth re-iterating here.

393 **1. 'Gold standard'³⁴ – diagnostic specificity and diagnostic sensitivity (WOAH Validation
394 Standard, Chapter 1.1.6, Section B.2.1)**

395 For conventional estimates of DS_p, negative reference samples refer to true negative samples, from animals that have
396 had no possible infection or exposure to the agent. In some situations, where the disease has never been reported in a
397 country or limited to certain regions of a country, identification of true negative reference samples is usually not a problem.
398 However, where the disease is endemic, samples such as these may be difficult to locate. It is often possible to obtain

34 The term "Gold Standard" is limited to a perfect reference standard as described in the WOAH Validation Standard, chapter 1.1.6,
Section B.2.1.2, and Chapter 2.2.5 *Statistical approaches to validation*, Introduction and Figure 1.

399 these samples from regions within a large country or perhaps different countries where the disease in question does not
400 occur or has either been eradicated or has never had the disease in question.

401 ~~Again~~ For conventional estimates of DSe, positive reference samples refer to true positives. Care must be taken to ensure
402 that the sample population is representative of the population that will be the target of the validated assay. It is generally
403 problematic to find sufficient numbers of true positive reference animals, as determined by isolation of the organism. It may
404 be necessary to resort to samples from animals that have been tested by a combination of methods that unequivocally
405 classify animals as infected/exposed as discussed in ~~the WOAHS Validation Standard, chapter 1.1.6.~~

406 ~~The important point here is that~~ All samples, irrespective of origin, must be documented as they would for any other
407 reference sample ~~so as to~~ unequivocally to classify animals as infected or exposed, dependent on the fitness for purpose
408 and proposed use of the test. As mentioned in Section A, and summarised in Figure 2, of this chapter, all reference samples
409 should be well characterised. ~~This includes documentation on both the pathogen and donor host. For pathogens, this may~~
410 include details related and data documented to strain, serotype, genotype, lineage, etc. ~~The source of the host material~~
411 should be well described with respect to species, breed, age, sex, reproductive status, vaccination history, herd history,
412 etc. ~~Wherever possible, the phase of infection should be noted. This could include details related clinical signs, antibody~~
413 profiles, pathogen load or shedding, etc. ~~In some cases, experimental infection/exposure may be the only viable option~~
414 ensure appropriate sample selection for the production of reference material (see the OIE Validation Standard, Section
415 B.2.3). ~~In this case, all of the above and the experimental protocol should be detailed intended purpose.~~

416 Particularly relevant to these reference samples, the tests that are used to determine their so called 'true' disease/infection
417 status need to be well documented in order to assess potential errors in estimates that may be carried over into the
418 estimates for the candidate assay. Indeed, when using imperfect standard assays to define reference animal or sample
419 status, the DSe and DSp performance estimates of the candidate assay may be flawed and often overestimated. Consult
420 Chapter 2.2.5 for statistical considerations. Situations where a perfect reference is available for either positive or negative
421 animals, and one where the reference is perfect for both are described for diagnostic test validation by Heuer & Stevenson
422 (2021).

423

F. GROUP F

424 **1. Animals of unknown status – diagnostic specificity and diagnostic sensitivity (WOAH** 425 **Validation Standard, Chapter 1.1.6, Section B.2.2)**

426 Latent-class models are introduced in ~~the WOAHS Validation Standard, chapter 1.1.6.~~ They do not rely on the assumption
427 of a perfect reference (standard or independent) test but rather estimate the accuracy of the candidate test and the
428 reference standard with the combined test results. Because these statistical models are complex and require critical
429 assumptions, statistical assistance should be sought to help guide the analysis and describe the sampling from the target
430 population(s), the characteristics of other tests included in the analysis, the appropriate choice of model and the estimation
431 methods based on peer-reviewed literature. Consult Chapter 2.2.5 for statistical considerations.

432 Reference populations, not individual reference samples, used in latent-class studies need to be well described. ~~This~~
433 includes documentation on both the pathogen and donor host. For pathogens, this may include details related to strain,
434 serotype, genotype, lineage, etc., that may be circulating in the population. The source of the host material should be well
435 described with respect to species, breed, age, sex, reproductive status, vaccination history, herd history, etc. as
436 summarised in Figure 2. ~~Wherever possible, the phase of infection in the populations should be noted with respect to~~
437 morbidity or mortality events, recovery, etc.

438 As a special note, if latent class models are to be used to ascribe estimates of DSe and DSp and include multiple
439 laboratories in the design, it is possible to incorporate an assessment of reproducibility into the assessment. ~~As stated~~
440 above, statistical advice should be sought in this respect. Bayesian latent class models are complex and require adherence
441 to critical assumptions. Statistical assistance should be sought to help guide the analysis and describe the sampling from
442 the target population(s), the characteristics of other tests included in the analysis, the appropriate choice of model and the
443 estimation methods (based on peer-reviewed literature). See chapter 2.2.5 for details and Cheung *et al.*, 2021.

444

FURTHER READING

445 BOWDEN T.R., CROWTHER J.R. & WANG J. (2021). Review of critical factors affecting analytical characteristics of serological
446 and molecular assays. *Rev. Sci. Tech. Off. Int. Epiz.*, 40, 53–73. doi:10.20506/rst.40.1.3208.

447 CHEUNG A., DUFOUR S., JONES G., KOSTOULAS P., STEVENSON M.A., SINGANALLUR N.B. & FIRESTONE S.M. (2021). Bayesian
448 latent class analysis when the reference test is imperfect. *Rev. Sci. Tech. Off. Int. Epiz.*, 40, 271–286.
449 doi:10.20506/rst.40.1.3224

450 JOHNSON P. & CABUANG L. (2021). Proficiency testing and ring trials. *Rev. Sci. Tech. Off. Int. Epiz.*, 40, 189–203.
451 <https://doi.org/10.20506/rst.40.1.3217>

452 HEUER C. & STEVENSON M.A. (2021). Diagnostic test validation studies when there is a perfect reference standard. *Rev. Sci.*
453 *Tech. Off. Int. Epiz.*, 40, 261–270. doi:10.20506/rst.40.1.3223

454 REISING M.M., TONG C., HARRIS B., TOOHEY-KURTH K.L., CROSSLEY B., MULROONEY D., TALLMADGE R.L., SCHUMANN K.R., LOCK,
455 A.B. & LOIACONO C.M. (2021). A review of guidelines for evaluating a minor modification to a validated assay. *Rev. Sci.*
456 *Tech. Off. Int. Epiz.*, 40, 217–226. doi:10.20506/rst.40.1.3219

457 WATSON J.W., CLARK G.A. & WILLIAMS D.T. (2021). The value of virtual biobanks for transparency purposes with respect to
458 reagents and samples used during test development and validation. *Rev. Sci. Tech. Off. Int. Epiz.*, 40, 253–259.
459 doi:10.20506/rst.40.1.3222.

460 WAUGH C. & CLARK G. (2021). Factors affecting test reproducibility among laboratories. *Rev. Sci. Tech. Off. Int. Epiz.*, 40,
461 131–143. doi:10.20506/rst.40.1.3213

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463

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* *

464 **NB: There is a WOAHA Collaborating Centre for**
465 **Diagnostic Test Validation Science in the Asia-Pacific Region (please consult the WOAHA Web site:**
466 **<https://www.woah.org/en/what-we-offer/expertise-network/collaborating-centres/#ui-id-3>**
467 **Please contact the WOAHA Collaborating Centre for any further information on validation.**

468
469

NB: FIRST ADOPTED IN 2014.

MEETING OF THE WOHAI BIOLOGICAL STANDARDS COMMISSION

Paris, 4–8 September 2023

CHAPTER 3.1.5.

CRIMEAN–CONGO HAEMORRHAGIC FEVER

...

B. DIAGNOSTIC TECHNIQUES

Table 1. Diagnostic test formats for Crimean–Congo haemorrhagic fever virus infections in animals

Method	Purpose					
	Population freedom from infection	Individual animal freedom from infection prior to movement	Contribute to eradication policies	Confirmation of clinical cases in animals	Prevalence of infection – surveillance	Immune status in individual animals or populations post-vaccination
Detection and identification of the agent^(a)						
Real-time RT-PCR	–	+++	–	+++ ^(b)	+ ^(c)	–
Virus isolation in cell culture	–	–	–	+ ^(b)	–	–
Detection of immune response						
IgG ELISA	+++	+	–	++ ^(d)	+++	–
Competitive ELISA	+++	+	–	++ ^(d)	+++	–
IgM ELISA	–	++	–	++ ^(e)	–	–

Key: +++ = recommended for this purpose; ++ recommended but has limitations; + = suitable in very limited circumstances; – = not appropriate for this purpose.

RT-PCR = reverse-transcription polymerase chain reaction; ELISA = enzyme-linked immunosorbent assay.

^(a)A combination of agent identification methods applied on the same clinical sample is recommended.

^(b)Molecular testing/isolation can be used to confirm acute infection in rare cases in animals showing clinical signs as viraemia tends to be transient.

^(c)RT-PCR is used for the screening of tick populations in the context of surveillance studies.

^(d)Serological evidence of active infection with CCHFV has been demonstrated by seroconversion based on a rise in total or IgG antibody titres on samples taken at 2–4 weeks apart.

^(e)Serological evidence of active infection with CCHFV has been demonstrated by the detection of IgM antibodies specific to CCHFV using two different ELISAs based on two different antigens.

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MEETING OF THE WOAHP BIOLOGICAL STANDARDS COMMISSION

Paris, 4–8 September 2023

CHAPTER 3.3.6.

AVIAN TUBERCULOSIS

SUMMARY

Description of the disease: Avian tuberculosis, or avian mycobacteriosis, is ~~an important~~ a significant disease that affects companion, captive exotic, wild, and domestic birds and mammals. The disease is most often caused by *Mycobacterium avium* subsp. *avium* (*M. a. avium*), a member of the *M. avium* complex. However, more than ten other mycobacterial species have been reported to infect birds. The most significant cause of poultry disease is *M. a. avium*.

Clinical signs of the disease vary depending on the organs involved. The classical presentation is characterised by chronic and progressive wasting and weakness. ~~Diarrhoea is common and joint swelling are standard features in infected flocks.~~ Some birds may show respiratory signs, and occasionally, sudden death occurs. Some birds may develop granulomatous ocular lesions.

Mycobacterium tuberculosis, the agent that most commonly causes human tuberculosis (gene IS6110) is ~~less commonly~~ rarely the cause of infection in birds, and it is often as a result of transmission from pet bird owners.

Members of *M. avium* complex: *M. a. avium* (serotypes 1–3; containing gene segments IS901 and IS1245), *M. avium* subsp. *hominissuis* (serotypes 4–6, 8–11, and 21; lacking gene segment IS901 and containing segment IS1245) and *M. intracellulare* (serotypes 7, 12–20, and 22–28; lacking both IS901 and IS1245) can also infect an extensive range of mammals such as swine, cattle, deer, sheep, goats, horses, cats, dogs, and exotic species. In humans, all members of the *M. avium* complex and *M. genavense* ~~are capable of inducing~~ can induce a progressive disease that is refractory to treatment, ~~mostly~~ mainly in immunocompromised patients.

~~All manipulations involving~~ Due to the contagious nature of this group of organisms, handling of open live cultures or of material from infected birds must only be carried out ~~with~~ after an appropriate bio ~~risk management~~ risk assessment and the implementation of biosafety measures designed to avoid infection.

Diagnosis of avian tuberculosis in birds depends on the demonstration of ~~the above mentioned~~ a mycobacterial species in live or dead birds or the detection of an immune response, cellular or humoral, culture examination, or gene segments ~~IS6110, IS901 and IS1245~~ by polymerase chain reaction (PCR) in the excretions or secretions of live birds.

Detection of the agent: Where clinical signs of avian tuberculosis are seen in the flock, or typical tuberculous lesions are present in birds at necropsy, the demonstration of acid-fast bacilli in smears or sections made from affected organs is sufficient for a quick positive diagnosis. If acid-fast bacilli are not found but typical tuberculous signs or lesions are present in the birds, a culture of the organism or PCR must be attempted. ~~PCR could also be carried out directly on tissue samples.~~ Any acid-fast organism isolated should be identified by nucleic-acid-based tests or chromatographical (e.g. high-performance liquid chromatography [HPLC]) criteria; serotyping of isolates of *M. avium* complex members or PCR for 16S rRNA gene followed by sequencing, or the presence of an amplicon for the insertion sequences IS6110, IS901, and IS1245 could also be performed.

43 **Tuberculin test and serological tests:** These tests are normally typically used to determine the disease
44 prevalence of disease in a flock or to detect infected birds. When used to detect the presence of avian
45 tuberculosis in a flock, they should be supported by the necropsy of any birds that give positive reactions.

46 In domestic fowl, the tuberculin test in the wattle is the test of choice. This test is less useful in other species
47 of bird. A better test, especially in waterfowl, is The whole blood stained-antigen agglutination test is better,
48 especially in waterfowl. It is more reliable and has the advantage that it will can give a result within a few
49 minutes while the bird is still being held.

50 **Requirements for vaccines and diagnostic biologicals:** No vaccines are available for use in birds. Avian
51 tuberculin purified protein derivative (PPD) is the standard preparation for use in the tuberculin test of
52 domestic poultry. Avian PPD is also used as a component in the comparative intradermal tuberculin test in
53 cattle (see Chapter 3.1.13 Mammalian tuberculosis [infection with *Mycobacterium tuberculosis* complex]).

54 A. INTRODUCTION

55 Several mycobacterial species can be involved in the aetiology of avian tuberculosis and, also known as
56 mycobacteriosis. Avian tuberculosis is most commonly produced caused by infection with *Mycobacterium avium* subsp.
57 *avium* (serotypes 1, 2, and 3: containing specific gene segment IS901 and nonspecific segment IS1245) and less frequently
58 by *M. genavense* (Guerrero *et al.*, 1995; Pavlik *et al.*, 2000; Salamatian *et al.*, 2020; Sattar *et al.*, 2021; Tell *et al.*, 2001).
59 Avian mycobacteriosis is also caused by other two members of the *M. avium* complex: *M. avium* subsp. *hominissuis*
60 (serotypes 4–6, 8–11, and 21: lacking gene segment IS901 and containing segment IS1245 and mainly infecting humans
61 and pigs) and *M. intracellulare* (serotypes 7, 12–20, and 22–28: lacking both gene segments IS901 and IS1245) and by
62 *M. intracellulare*, *M. scrofulaceum*, *M. fortuitum*, and other potentially pathogenic mycobacterial species including
63 *M. scrofulaceum* and *M. fortuitum*. Under some circumstances, an extensive range of mammalian species, such as swine,
64 cattle, deer, sheep, goats, horses, cats, dogs, and exotic animals, can be infected by these mycobacterium species
65 (Dvorska *et al.*, 2004; Kunze *et al.*, 1992; Mijs *et al.*, 2002; Shitaye *et al.*, 2009; Tell *et al.*, 2001; Thorel *et al.*, 1997; 2001).
66 *Mycobacterium tuberculosis* and *M. bovis* are less common as causal rarely the causative agents of tuberculosis in birds
67 (Hoop, 2002; Lanteri *et al.*, 2011; Peters *et al.*, 2007; Schmidt *et al.*, 2022; Tell *et al.*, 2001).

68 *Mycobacterium avium* species with standing in nomenclature as of 2023³⁵ (Arahal *et al.*, 2023) consists of four three
69 subspecies: *M. avium* subsp. *avium*, *M. avium* subsp. *hominissuis*, *M. avium* subsp. *silvaticum*, and *M. avium* subsp.
70 *paratuberculosis* (Mijs *et al.*, 2002; Thorel *et al.*, 1990). The latter is the causal agent of Johne's disease, or
71 paratuberculosis, in ruminants and other mammalian species (see Chapter 3.1.16 Paratuberculosis [Johne's disease]).
72 *Mycobacterium a. silvaticum*, which like *M. avium* subsp. *paratuberculosis* grows *in-vitro* only on media with Mycobactin,
73 which can cause avian tuberculosis in wood pigeons (Thorel *et al.*, 1990). With the widespread use of whole genome
74 sequencing (WGS) and bioinformatics, some studies have investigated the classification of species belonging to the genus
75 *Mycobacterium* and have proposed that *M. avium* be three subspecies *M. avium* subsp. *avium*, *M. avium* subsp.
76 *paratuberculosis*, and *M. avium* subsp. *lepraemurium*. Further subdividing *M. avium* subsp. *avium* into three variants *M.*
77 *avium* subsp. *avium* var. *avium*, *M. avium* subsp. *avium* var. *silvaticum*, and *M. avium* subsp. *avium* var. *hominissuis* (Riojas
78 *et al.*, 2021; Tortoli *et al.*, 2019).

79 All *M. a. avium* isolates from birds and mammals, including humans, have a multiple repetitive sequence IS901 in their
80 genome and produce a characteristic three-band pattern in IS1245 restriction fragment length polymorphism (RFLP) as
81 described and standardised previously (Dvorska *et al.*, 2003; Ritacco *et al.*, 1998). This repetitive sequence is also present
82 in *M. a. silvaticum* and RFLP analysis can help with identification. IS901 has only been detected in *M. avium* strains with
83 serotypes 1, 2 and 3 (Pavlik *et al.*, 2000; Ritacco *et al.*, 1998) that are apparently more pathogenic to birds than other
84 serotypes (Tell *et al.*, 2001). On the basis of genetic and phenotypic differences it has recently been proposed to
85 differentiate *M. a. avium* into two subspecies based on the target organism: *M. a. hominissuis* for human and porcine
86 isolates and *M. a. avium* for bird type isolates (Mijs *et al.*, 2002). *Mycobacterium a. hominissuis* has polymorphic multiband
87 IS1245 RFLP patterns and is able to grow between 24 and 45°C (Mijs *et al.*, 2002; Van Soolingen *et al.*, 1998). It is worth
88 noting that the typical features of bird isolates, the three-band pattern in IS1245 RFLP and presence of IS901, have also
89 been found in cervine and bovine isolates of *M. a. avium*.

90 Avian tuberculosis in birds is most prevalent in gallinaceous poultry and in wild birds raised in captivity. Turkeys are quite
91 susceptible, but ducks, geese, and other water birds are comparatively resistant. The practices of allowing poultry to roam
92 at large on the farm (free range) and of keeping the breeders for several years are conducive to the spread of the causal
93 agent of avian tuberculosis among them. Infected individuals and contaminated environments (water and soil) are the main
94 primary sources of infection. The above-mentioned mycobacterial species causing avian tuberculosis can survive for
95 several months in the environment (Dvorska *et al.*, 2007; Kazda *et al.*, 2009; Shitaye *et al.*, 2008; Tell *et al.*, 2001).

35 <https://psn.dsmz.de/species/mycobacterium-avium>

96 In most cases, infected birds usually show no clinical signs but they may eventually become lethargic and emaciated.
97 Many affected birds show diarrhoea and swollen joints, and comb and wattles may regress and become pale. Affected
98 birds, especially gallinaceous poultry, are usually older than 1 year. Some show respiratory signs and, including sudden
99 death may occur, dyspnoea is less common, and granulomatous ocular lesions (Pocknell *et al.*, 1996) as well as and skin
100 lesions have been reported. Under intensive husbandry conditions, sudden death may occur, often associated with severe
101 lesions in the liver; such lesions are easily observed at post-mortem examination (Salamatian *et al.*, 2020; Tell *et al.*, 2001).

102 The primary lesions of avian tuberculosis in birds-poultry (chickens and turkeys) are nearly always in the intestinal tract.
103 Such lesions take the form of deep ulcers filled with caseous material containing many mycobacterial cells, and these are
104 discharged into the lumen and appear in the faeces. Before the intestinal tract is opened, the ulcerated areas appear as
105 tumour-like masses attached to the gut wall, but Still, when the intestine is opened, the true nature of the mass becomes
106 evident. Typical caseous lesions are nearly always found in the liver and spleen, and; these organs are usually are greatly
107 enlarged because of the formation of new tuberculous tissue. The lungs and other tissues are ordinarily free from lesions
108 even in advanced cases (Salamatian *et al.*, 2020; Tell *et al.*, 2001; Thorel *et al.*, 1997).

109 Among domestic animals (mammals), domestic pigs (*Sus scrofa f. domesticus*) are the most susceptible to avian
110 tuberculosis. Usually, no clinical manifestations are observed in such animals. Avian tuberculosis is suspected when
111 tuberculous lesions are found in the head and mesenteric lymph nodes on meat inspection after slaughter. Findings of
112 tuberculous lesions that involve other organs (liver, spleen, lungs, etc.) are rare, usually occurring at the advanced stage
113 of the disease. *Mycobacterium a. avium* accounted for up to 35% of the *Mycobacteria* isolated from such tuberculous
114 lesions (Dvorska *et al.*, 1999; Pavlik *et al.*, 2003, 2005; Shitaye *et al.*, 2006). Unlike the other species mentioned previously,
115 cattle are highly resistant to the causative agent of avian tuberculosis, and tuberculous lesions are detected in head lymph
116 nodes, or occasionally in liver lymph nodes, only on meat inspection. *Mycobacterium a. avium* can be successfully isolated
117 from tuberculous lesions in mesenteric lymph nodes from juvenile cattle: the isolation rate from cattle under 2 years of age
118 was 34.4% in contrast to 13.0% from cattle over 2 years of age (Dvorska *et al.*, 2004).

119 Pet and wild birds with avian mycobacteriosis have clinical presentations often exacerbated by age and viral and fungal
120 co-infections (Schmidt *et al.*, 2022; Schmitz *et al.*, 2018b). The presence of nonspecific clinical signs and the absence of
121 gross finds during necropsy in psittacine and passeriform birds may confound diagnosis. Furthermore, differences in body
122 condition and gross pathology are observed, where psittacines have more severe lesions than passeriform birds. These
123 differences could also be attributed to the fact that they are often more likely infected with *M. genavense* than *M. avium*
124 (Schmitz *et al.*, 2018a). The advent of more affordable WGS has allowed the study of *M. avium* and *M. genavense* and
125 their epidemiology in a large captive population of birds belonging to multiple taxa for over 22 years. In this large bird
126 population, 68% of all birds at necropsy had isolates that were infected with *M. avium* or *M. genavense*. The WGS study
127 of these mycobacterium isolates demonstrated strong evidence of disease clustering among those birds infected with *M.*
128 *avium* but not among those harbouring *M. genavense* (Witte *et al.*, 2021). This works sheds light on the epidemiology of
129 mycobacterium among captive birds, and future studies are necessary to understand these pathogens' epidemiology better
130 and to help identify its reservoirs.

131 It is essential to bear in mind that all members of *M. avium*-complex and *M. genavense* are capable of giving rise to a
132 progressive disease in humans that is refractory to treatment, especially in immunocompromised individuals (Narsana *et*
133 *al.*, 2023; Pavlik *et al.*, 2000; Tell *et al.*, 2001). Members of *Mycobacterium avium* complex are classed in Risk Group 2 for
134 human infection and should be handled with appropriate measures All *Mycobacterium* species can cause infection in
135 people (Cowman *et al.*, 2019). Caution should be exercised by those working with birds in environments infected with
136 *Mycobacterium*, especially those immunosuppressed. All laboratory manipulations with live cultures or potentially
137 infected/contaminated material must be performed at an appropriate biosafety and containment level determined by
138 conducting a thorough risk assessment as described in Chapter 1.1.4 Biosafety and biosecurity: Standard for managing
139 biological risk in the veterinary laboratory and animal facilities. Biocontainment measures should be determined by risk
140 analysis as described in Chapter 1.1.4. The CDC's online Manual for Biosafety in Microbiological and Biomedical
141 Laboratories is also a good reference³⁶.

36 https://www.cdc.gov/labs/pdf/SF_19_308133-A_BMBL6_00-BOOK-WEB-final-3.pdf

142

B. DIAGNOSTIC TECHNIQUES

143

Table 1. Test methods available for the diagnosis of avian tuberculosis and their purpose

Method	Purpose					
	Population freedom from infection	Individual animal freedom from infection prior to movement	Contribute to eradication policies	Confirmation of clinical cases	Prevalence of infection – surveillance	Immune status in individual animals or populations post-vaccination
Detection and identification of the agent^(a)						
Ziehl–Neelsen staining	–	–	–	++	–	–
Culture	–	–	–	++	–	–
Haemagglutination (stained antigen)	±	+++	±	–	++	–
PCR	+++	±	++	+++	±	–
Detection of immune response						
Haemagglutination (stained antigen)	±	+++	±	±	++	±
Tuberculin test	++	+++	+	–	++	–

144

Key: +++ = recommended for this purpose; ++ recommended but has limitations;

145

+ = suitable in very limited circumstances; – = not appropriate for this purpose.

146

PCR = polymerase chain reaction.

147

^(a)A combination of agent identification methods applied to the same clinical sample is recommended.

148

1. Identification of the agent

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If there is a characteristic history of avian tuberculosis in a flock and typical lesions are found in birds at post-mortem, the detection of acid-fast bacilli (AFB) in smears or sections from affected organs, stained by the Ziehl–Neelsen method usually is normally sufficient to establish a diagnosis. Confirmation of *M. avium* subspecies should be carried out by PCR or other molecular techniques (Kaevska *et al.*, 2010; Slana *et al.*, 2010). Occasionally a case will occur, presumably as a result of due to large infecting doses giving rise to acute overwhelming disease, in which affected organs, most obviously the liver, have a 'morocco leather' appearance with fine greyish or yellowish mottling. In such cases AFB may not be found in such cases, but careful inspection will reveal parallel bundles of brownish refractile bacilli. Prolongation of the hot carbol-fuchsin stage of Ziehl–Neelsen staining to 10 minutes will usually reveal that these are indeed AFB, with unusually high resistance to penetration of the stain. Recently, DNA probes and polymerase chain reaction (PCR), and WGS techniques have been used to identify the agent at the species and subspecies level specifically. Traditionally, *M. a. avium* is separated from common nonchromogenic slow-growing organisms by their ability to grow at 42°C (*M. a. avium*). *Mycobacterium genavense* is particularly fastidious and has special unique requirements for growth and identification (Shitaye *et al.*, 2010).

161

1.1. Culture

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If there is a characteristic flock history and suggestive lesions are found at necropsy, but no AFB are seen in smears or sections, an attempt must be made to isolate the causative organism from the necropsy material. The liver or spleen is usually the best organ to use, but if the carcass is decomposed, bone marrow may prove more satisfactory as it could be less contaminated. As with the culture of *M. bovis*, non-sterile specimens need to be processed with detergent, alkali, or acid to eliminate rapidly growing microorganisms before culture (see Chapter 3.1.13 *Mammalian tuberculosis [infection with Mycobacterium tuberculosis complex]*). *Mycobacterium a. avium* grows best on media such as Lowenstein–Jensen, Herrold's medium, Middlebrook 7H10 and 7H11, or Coletsos, with 1% sodium pyruvate added. It may occasionally be necessary to incorporate mycobactin J, as it is used for the isolation of to isolate *M. a. paratuberculosis genavense* and *M. a. silvaticum*. Growth may be confined to the edge of the condensation water. Cultures should be incubated for at least 8–12 weeks, less if using liquid media. Typically, *M. a. avium* produces 'smooth' colonies within 2–4 weeks; rough variants do occur. Shorter incubation times can be achieved using the liquid culture BACTEC system or the automated fluorescent MGIT 960 culture system. *Mycobacterium a. avium* can also be detected in massively infected tissue by a conventional PCR, which also allows acceleration of the accelerates

175 pathogen detection and identification (Moravkova *et al.*, 2008). ~~Currently, Direct detection and quantification of~~
176 *M. a. avium* using IS901 quantitative real-time PCR can be considered as the best fast and inexpensive method
177 ~~(despite its rather high cost per test)~~ (Kaevska *et al.*, 2010; Slana *et al.*, 2010).

178 For *M. genavense*, the optimal medium is liquid media supplemented with Mycobactin J (an iron chelator) and then
179 plated onto a solid medium is such as Middlebrook 7H11 medium acidified to pH 6 and supplemented with blood and
180 charcoal (Realini *et al.*, 1999). The incubation period at 37°C with 5–7% CO₂ should be extended for at least 6 months
181 42 days. If samples are directly plated onto solid media, plates should be held for at least 12 weeks. Bacterial growth
182 should be prepared in a smear and stained using an acid-fast stain. All acid-fast organisms should be identified using
183 MALDI-TOF (matrix assisted laser desorption ionisation–time of flight [mass spectrometry]) or PCR (Buckwalter *et*
184 *al.*, 2016; Hall *et al.*, 2003; Shitaye *et al.*, 2010).

185 Typing of mycobacteria to the species and subspecies level requires a specialised laboratory. Conventional
186 biochemical tests for species identification are lengthy and fail to distinguish between *M. avium* and *M. intracellulare*.
187 Thus, a miscellaneous group of mycobacteria that includes both species is usually classified under the ~~denomination~~
188 ~~of *M. avium* complex~~ denomination. Seroagglutination, ~~which is based on the~~ sugar residue specificity of surface
189 glycopeptidolipids, allows classification the parsing of *M. avium* complex organisms into 28 serovars (Wolinsky &
190 Schaefer, 1973). More sophisticated typing methods directed at cell-wall-specific targets are currently available, such
191 as enzyme-linked immunosorbent assays with monoclonal antibodies to major serovars, ~~and high-performance liquid~~
192 chromatography (HPLC), and WGS. Based on DNA–rRNA hybridisation serovars 1 to 6, 8 to 11, and 21 are currently
193 have been ascribed to *M. a. avium* and *M. a. hominissuis*, and serovars 7, 12 to 20, and 25 to *M. intracellulare*.
194 However, no consensus was achieved on other serovars, and some isolates cannot be serotyped (Inderlied *et al.*,
195 1993). For final species and subspecies identification, the current methods are WGS and bioinformatic analysis of
196 isolates obtained from sick birds. Avian tuberculosis in birds is commonly caused by *M. a. avium* types 1, 2, or 3. If
197 the isolate is not one of these three serotypes, further molecular identification tests (IS901-PCR) must be carried out
198 conducted in a specialised laboratory. However, it should be ~~borne in mind noted~~ superficial tuberculous lesions
199 in caged pet birds, especially psittacines, may be caused by *M. tuberculosis*, and IS6110 PCR should be used for
200 precise identification should always be attempted (Hoop, 2002; Lanteri *et al.*, 2011; Peters *et al.*, 2007; Schmidt *et*
201 *al.*, 2008; Tell *et al.*, 2001).

202 1.2. Nucleic acid recognition methods

203 Specific and reliable genetic tests for speciation ~~are currently have been~~ available (Saito *et al.*, 1990)–, including
204 commercial nucleic acid hybridisation probes have become a ‘gold standard’ reference method for distinction between
205 distinguishing *M. avium*, and *M. intracellulare* cultures, and *M. genavense* can also be distinguished with these tests.
206 A further probe that covers the whole *M. avium* complex was also developed, as genuine *M. avium* complex strains
207 have been described that fail to react with specific *M. avium* and *M. intracellulare* probes (Soini *et al.*, 1996).
208 Nevertheless, identification errors were reported due to the cross-reactivity, which may have serious consequences
209 (van Ingen *et al.*, 2009). Various in-house molecular methods have been reported ~~for the identification of to identify~~
210 mycobacterial cultures, including MAC–members of the *Mycobacterium avium* complex. The following gene segments
211 could be used to identify *Mycobacterium avium* isolates as *M. avium* in one multiplex PCR reaction: IS900, IS901, IS1245.
212 The isolates of *M. a. avium*/*M. a. silvaticum* are IS900–, IS901+, IS1245+, the isolates of *M. a. hominissuis* are
213 IS900–, IS901–, IS1245+, and the isolates of *M. a. paratuberculosis* are IS900+, IS901–, IS1245– (Kaevska *et al.*,
214 2010; Moravkova *et al.*, 2008). A multiplex 16S rRNA PCR and sequencing method for differentiating *M. avium* from
215 *M. intracellulare* and *M. tuberculosis* complex has some advantages (Cousins *et al.*, 1996). 16S rRNA is currently
216 commercially available. Similarly, many veterinary diagnostic laboratories commonly perform in-house PCR and
217 sequencing (Kirschner *et al.*, 1993) may also be used. Culture-independent in-house molecular tests have been
218 developed for the detection to detect and identification of identify species belonging to the *M. avium* complex directly
219 from samples (Hall *et al.*, 2003; Kaevska *et al.*, 2010). WGS of isolates has recently become the go-to molecular
220 method to identify mycobacterium isolates from birds with great accuracy. It enables, with the use of bioinformatic
221 tools, not only an accurate identification of species and subspecies, but also helps to determine the organism
222 relatedness within a flock or environment (Witte *et al.*, 2021). In recent years, veterinary diagnostic laboratories have
223 extensively adopted real-time PCR methods to detect *M. a. avium* directly from different specimens (faeces, tissues,
224 formalin-fixed tissues, and environmental samples). The technique rapidly detects fastidious and slow-growing
225 microorganisms, such as *M. a. avium* (Tell *et al.*, 2003a; 2003b).

226 Several commercial diagnostic PCR tests for detecting *M. a. avium* are available. Still, users should consider the skill
227 set and equipment necessary to perform such tests. Furthermore, it is important to determine the fitness for the
228 purpose of these tests before implementation. The interpretation of the results of these molecular tests also requires
229 veterinary expertise.

230 *Mycobacterium a. avium*, the causative agent of avian tuberculosis (Thorel *et al.*, 1990), previously designated as
231 *M. avium* species only, is assigned to serotypes 1 to 3 within the *M. avium* complex of 28 serotypes (Wolinsky &
232 Schaefer, 1973). As revealed by molecular biological studies, the detected insertion sequence IS901 (Kunze *et al.*,

233 1992) is possessed not only by the isolates of the above-named serotypes, but also by isolates, virulent for birds, that
234 could not be typed because agglutination occurred (Pavlik *et al.*, 2000). In epidemiological studies, a standardised
235 IS901-RFLP methods replaced serotyping (Dvorska *et al.*, 2003).

236 2. Immunological methods

237 Tests used for export depend on the importing requirement of individual countries. In the main, the tuberculin test or the
238 haemagglutination (stained antigen) test are most frequently used for export testing of poultry.

239 2.1. Tuberculin test

240 The tuberculin test is the most widely used test ~~in-for~~ domestic fowl and the only test for which an international
241 standard for the reagent exists. Tuberculin is the standard avian purified protein derivative (PPD). Birds are tested by
242 intradermal inoculation in the wattle with 0.05 ml or 0.1 ml of tuberculin (containing approximately 2000 International
243 Units [IU]), using a ~~very~~ fine needle of approximately 26 gauge, 10 mm ~~long~~ × 0.5 mm. The test is read after 48 hours
244 ~~and~~. A positive reaction is any swelling at the site, from a small firm nodule approximately 5 mm in diameter to gross
245 oedema extending into the other wattle and down the neck. ~~With practice~~. Even very small wattles on immature birds
246 can be inoculated successfully. However, ~~in immature birds~~ the comb may be used in immature birds, although the
247 results are not ~~so-as~~ reliable. Tuberculin testing of the wattle in turkeys is much less reliable-consistent than in the
248 domestic ~~fowl-chickens~~. Inoculation in the wing web has been recommended as ~~being~~ more efficient, but this is still
249 not as good as ~~for domestic fowl in chickens~~. Other birds may also be tested in the wing web, but results are not
250 generally satisfactory. The bare ornamental skin areas on Muscovy ducks and some ~~species of~~ pheasant species
251 can be used, but reliability-dependability is doubtful, and interpretation is difficult. Testing in the foot web of waterfowl
252 has also been described; the test is not very sensitive and is often complicated by infections of the inoculation site.

253 In the common pheasant, the tuberculin test can be performed in either of two ways. In the first, 0.05 ml or 0.1 ml of
254 tuberculin is injected into the skin of the lower eyelid. A positive result is indicated by marked swelling at the injection
255 site after 48 hours. Alternatively, 0.25 ml of tuberculin is injected into the thoracic muscles, and the birds are observed
256 for 6–10 hours. Infected birds will show signs of depression and keep aside from the flock, and there may be cases
257 of sudden death. No clinical signs will be provoked in uninfected birds.

258 2.2. Stained antigen test

259 The stained-antigen agglutination test has been used with good results, especially in domestic and ornamental
260 waterfowl. A drop (0.05–0.1 ml) of the antigen is mixed with the same volume of fresh whole blood, obtained by
261 venipuncture, on a white porcelain or enamel tile. The mixture is rocked for 2 minutes and examined for agglutination.
262 The agglutination may be coarse, in which case it is obvious, or quite fine, in which case it may be most clearly seen
263 as an accumulation of the malachite-green-stained antigen around the edge of the drop, leaving the centre a normal
264 blood-red colour. This test is especially useful for screening large flocks for immediate culling and therefore has
265 advantages over the tuberculin test for controlling the disease, even in domestic fowl. It has also been claimed that it
266 is more reliable in domestic poultry than the tuberculin test.

267 2.2.1. Preparation of the antigen

268 An antigen stained with 1% malachite green is used for the rapid whole blood plate agglutination test
269 (Rozanska, 1965). The strain used to prepare the stained antigen must be smooth and not auto-
270 agglutinate in saline suspension. It must conform to the characteristics of *M. a. avium*, preferably
271 obtained from a culture collection, to guarantee its authenticity.

272 A strain that will detect infection with any serotype is recommended instead of the specific serotype
273 most likely to be encountered (in Europe, serotype 2 for domestic fowl, serotype 1 for waterfowl, and
274 birds and swine in the USA). Using a highly specific strain for the serotype is recommended. The
275 specificity of strains can be determined only by testing them as antigens, although, in general, a
276 serotype 2 antigen will always detect serotype 3 infection and vice versa. Serotype 1 strains detect a
277 wide spectrum of infections and frequently detect infections with mycobactin-dependent
278 mycobacteria or *M. a. silvaticum*. There is no reason not to use a culture containing more than one
279 strain of *M. a. avium* if it shows the desired properties of sensitivity and specificity. Consistency of
280 results between batches will be easier using pure cultures.

281 The organism should be grown in a suitable liquid medium, such as Middlebrook 7H9 containing 1%
282 sodium pyruvate. Good growth should be obtained in approximately 7 days. The liquid culture is used
283 as a seed for bulk antigen preparation.

284 Antigen for agglutination tests is best obtained on a solid medium, such as Löwenstein–Jensen or
285 7H11, containing 1% sodium pyruvate instead of glycerol, using Roux flasks or large bottles. Using

286 a solid medium maximizes the chance of detecting contamination, and antigens grown in some liquid
287 media are not agglutinated by specific antibodies. Liquid seed culture should be diluted (based on
288 experience) to give discrete colonies on the solid medium. This will usually give the best yield
289 increasing the chance of detecting contamination. About 10 ml of inoculum will usually allow it to
290 wash over the whole surface and provide sufficient moisture to keep the air in the bottle near 100%
291 humidity.

292 The bottles are incubated at 37°C, and good growth should be obtained in 14–21 days with most
293 strains. The antigen is harvested by adding sterile glass beads and twice the volume of sterile normal
294 saline (containing 0.3% formalin) as was used to inoculate the bottle. The bottle is then shaken gently
295 to wash off all the growth, and the washing is collected into a sterile bottle and re-incubated at 37°C
296 for 7 days. The killed bacilli are washed twice in sterile normal saline with 0.2% formalin by
297 centrifugation and re-suspension. This sequence is safer than the original method in which the
298 washing was carried out before the incubation that kills the organisms. Finally, bacilli are again
299 centrifuged and re-suspended in sterile normal saline containing 0.2% formalin and 0.4% sodium
300 citrate to a concentration of about 10¹⁰ bacteria per ml. This corresponds to a concentration ten times
301 that which matches tube No. 4 on McFarland's scale.

302 Cultures for antigen should be inspected for contamination daily for the first 5 days of incubation. The
303 suspension made from the culture washings is also re-examined microscopically (for likely
304 contaminants such as yeasts) and rechecked by culture to ensure that the formalin has killed the
305 mycobacteria.

306 **2.2.2. Validation of the antigen**

307 Cultures should be checked by Gram staining for contamination by organisms other than
308 mycobacteria.

309 One or more batches for agglutinating antigen must be tested for efficacy in using serum from
310 naturally or artificially infected tuberculous birds by comparison with a standard preparation of known
311 potency. When using animals for research or reagent testing, approval of the procedures and the use
312 of animals by the institution's ethics committee should be sought before any testing occurs. The
313 potency relative to that of the standard preparation must not differ significantly from that declared on
314 the label. Each bottle of antigen must be tested with normal chicken serum (to detect
315 autoagglutination) and *M. a. avium* positive chicken serum of low and high antibody content. This
316 should be done, where possible, alongside a previous batch of stained antigens. Those bottles that
317 give satisfactory agglutination reactions with the antisera can now be pooled and the antigen stained.
318 This is done by adding 3 ml of 1% malachite green solution per 100 ml of suspension. The stained
319 antigen should be checked using whole blood, just as the unstained antigen was tested with serum.
320 The agglutinating antigen should stay in the refrigerator for at least 6 months at 4°C and much longer
321 if frozen at –20°C or below. If a batch has not been used for several weeks, it should be rechecked,
322 especially for autoagglutination.

323 It is critical to perform a safety test of the unwashed antigen by culture and incubation to ensure that
324 all the bacilli are dead.

325 **Note on limitation of use**

326 Neither the tuberculin test with avian tuberculin nor the stained-antigen agglutination test is likely to be of any value in
327 cases of *M. tuberculosis* infection in ~~caged~~pet birds.

328 **C. REQUIREMENTS FOR DIAGNOSTIC BIOLOGICALS**

329 **1. Background**

330 No vaccines are available.

331 Avian tuberculin is a preparation of purified protein derivatives (PPD-A) made from the heat-treated products of growth of
332 *M. a. avium*. It is used by intradermal injection to reveal delayed hypersensitivity ~~as a means of identifying to identify~~ birds
333 infected with or sensitised to the same species of tubercle bacillus *Mycobacterium*. Importantly it is also used ~~as an~~to aid

334 to differential diagnosis in the comparative intradermal tuberculin test for bovine tuberculosis (see Chapter 3.1.13). An
335 international standard preparation of PPD-A is being developed by WOAHP to replace the former WHO Standard³⁷.

336 The general principles as given in Chapter 1.1.8 *Principles of veterinary vaccine production*, should be followed for
337 injectable diagnostic biologicals such as tuberculin. The standards set out here and in chapter 1.1.8 are intended to be
338 general in nature and may be supplemented by national and regional requirements.

339 2. Outline of production and minimum requirements for tuberculin production

340 2.1. Characteristics of the seed

341 2.1.1. Biological characteristics of the master seed

342 Strains of *M. a. avium* used to prepare seed cultures should be purchased from a culture collection
343 and identified as to species by appropriate tests. Several strains are recommended by for this
344 purpose in different countries. For example, in the European Union (EU), for example, are, D4ER
345 and TB56. Reference may also be made to are recommended. The relevant national
346 recommendations should be followed. Globally there are commercial sources for PPD-A.

347 2.1.2. Quality criteria (sterility, purity, freedom from extraneous agents)

348 Seed cultures should be shown to be free from contaminating organisms and to be capable of
349 producing tuberculin with of sufficient potency. The necessary tests are described below.

350 2.2. Method of manufacture

351 2.2.1. Procedure

352 The seed material is kept as a stock of freeze-dried cultures. If the cultures have been grown on solid
353 media, it will be necessary to adapt the organism to grow as a floating culture. This is most easily
354 accomplished by incorporating a piece of potato in the flasks of liquid medium (e.g. Watson Reid's
355 medium). When the culture has been adapted to a liquid medium, it can be maintained by a passage
356 at 2–4-week intervals (Angus, 1978; Haagsma & Angus, 1995).

357 The organism is cultivated in modified Dorset-Henley's synthetic medium, then killed by heating in
358 flowing steam and filtered to remove cells. The protein in the filtrate is precipitated chemically
359 (ammonium sulphate or trichloroacetic acid [~~TTCA~~] are used), washed, and resuspended. An
360 antimicrobial preservative that does not give rise to false-positive reactions, such as phenol (not more
361 than 0.5% [w/v]), may be added. Mercurial derivatives should not be used. Glycerol (not more than
362 10% [w/v]) or glucose (2.2% [w/v]) may be added as a stabiliser. The product is dispensed aseptically
363 into sterile neutral glass containers, ~~which are~~ then sealed to prevent contamination. The product
364 may be freeze-dried.

365 2.2.2. Requirements for ingredients

366 The production culture substrate must be shown to be capable of producing produce a product that
367 conforms to the standards of the European Pharmacopoeia (2000–2024³⁸) standards or other
368 international standards such the WHO (WHO, 1987). It must be free from ingredients known to cause
369 toxic or allergic reactions.

370 2.2.3. In-process controls

371 The production flasks, inoculated from suitable seed cultures, are incubated for the appropriate time
372 period. Any flasks showing contamination or grossly abnormal growth should be discarded after
373 autoclaving. As incubation proceeds, the surface growth of many cultures becomes moist and may
374 sink into the medium or to the bottom of the flask. In PPD-A tuberculin, the pH of the dissolved
375 precipitate (the so-called concentrated tuberculin) should be pH 6.6–6.7. The Kjeldahl method
376 determines the protein level (total organic nitrogen) of the PPD-A concentrate is determined by the
377 Kjeldahl method. Total nitrogen and trichloroacetic acid precipitable nitrogen are usually compared.

378 2.2.4. Final product batch tests

³⁷ PPD of *M. avium* tuberculin, WHO (1955) Technical Report Series, no.96, 11.

³⁸ https://www.edqm.eu/en/d/234640?p1_back_url=%2Fen%2Fsearch%3Fq%3Dpurified%2Bprotein%2Bderivative

-
- 379 i) Sterility
- 380 Sterility testing is generally performed according to the European Pharmacopoeia (2000-2024) or
381 other guidelines (see ~~also~~ Chapter 1.1.9 *Tests for sterility and freedom from contamination of*
382 *biological materials intended for veterinary use*).
- 383 ii) Identity
- 384 One or more batches of tuberculin may be tested for specificity together with a standard preparation
385 of bovine tuberculin by comparing the reactions produced in guinea-pigs sensitised with *M. bovis*
386 using a procedure similar to that described in Section C.2.2.4.iv. ~~In guinea-pigs sensitised with~~
387 ~~*M. bovis*~~. The potency of the preparation of avian tuberculin must be shown to be not more than 10%
388 of the potency of the standard preparation of bovine tuberculin used in the potency test. The use of
389 animals for this purpose should be reviewed and approved by your institution's ethical committee.
- 390 iii) Safety
- 391 Tuberculin PPD_A can be examined for freedom from living mycobacteria using the culture method
392 described previously. This culture method, which does not require the use of animals, is used in many
393 laboratories, and its use is encouraged over the use of animals for this purpose. The following is the
394 previously described method, using experimental animals to evaluate the safety of PPD. The use of
395 animals for this purpose should be reviewed and approved by the institution's ethics committee. Two
396 guinea-pigs, each weighing not less than 250 g and ~~that have not been treated previously~~ treated
397 with any material that will interfere with the test, are injected subcutaneously with 0.5 ml of the
398 tuberculin under test. No abnormal effects should occur within 7 days.
- 399 Tests on tuberculin for living mycobacteria may be performed either on the tuberculin immediately
400 before it is dispensed into final containers or on samples taken from the final containers themselves.
401 A sample of at least 10 ml must be taken and ~~this must be~~ injected intraperitoneally or subcutaneously
402 into at least two guinea-pigs, dividing the volume to be tested equally between the guinea-pigs. It is
403 desirable to take a larger sample, 50 ml, and to concentrate any residual mycobacteria by
404 centrifugation or membrane filtration. The guinea-pigs are observed for at least 42 days and are
405 examined macroscopically at post-mortem. Any lesions found are examined microscopically and by
406 culture. Each filled container must be inspected before it is labelled, and any showing abnormalities
407 must be discarded.
- 408 A test for the absence of toxic or irritant properties must be ~~carried out~~ conducted according to the
409 ~~specifications of the~~ European Pharmacopoeia (2000-2024) specifications or the equivalent
410 regulatory documents for each country or region.
- 411 To test for lack of sensitising effect, three guinea-pigs that have not previously been treated with any
412 material that could interfere with the test are each injected intradermally on ~~each of three occasions~~
413 with the equivalent of 500 ~~IU~~ International units – one IU is equal to the biological activity 0.02 µg of
414 PPD – of the preparation under test in a 0.1 ml volume. In the USA and Canada, the potency of the
415 tuberculin is expressed as tuberculin unit (TU) rather than IU. One TU is also defined as 0.02 µgs of
416 PPD. Each guinea-pig, together with ~~each of the~~ three control guinea-pigs that have not been injected
417 previously, is injected intradermally 15–21 days after the third injection with the same dose of ~~the~~
418 ~~same~~ tuberculin. The reactions of the two groups of guinea-pigs should not be significantly different
419 when measured 24–28 hours later.
- 420 iv) Batch potency
- 421 The potency of avian tuberculin is determined in guinea-pigs sensitised with *M. a. avium*, ~~by~~
422 ~~comparison~~ compared with a standard preparation calibrated in IU or TU.
- 423 Use no fewer than nine albino guinea-pigs, each weighing 400–600 g. Sensitise the guinea-pigs by
424 administering ~~to each, by deep intramuscular injection,~~ a suitable dose of inactivated or live
425 *M. a. avium* to each by deep intramuscular injection. The test is performed between 4 and 6 weeks
426 later ~~as follows:~~ Shave. Briefly, shave the guinea-pigs' flanks ~~so as~~ to provide space for three-to-four
427 injections on each side. Prepare at least three dilutions of the tuberculin under test and at least three
428 dilutions of the standard preparation in an isotonic buffer solution containing 0.0005% (w/v)
429 polysorbate 80 (Tween 80). Choose the dilutions so that the reactions produced have diameters of
430 not less than 8 mm and not more than 25 mm. Allocate the dilutions to the injection sites randomly
431 ~~according to~~ using a Latin square design. The dilutions correspond to 0.001, 0.0002, and 0.00004
432 mg of protein in a final dose of 0.2 ml, injected intradermally.
-

433 At 24 hours, the reactions' diameters ~~of the reactions~~ are measured, and the results are calculated
434 using standard statistical methods, taking the diameters to be directly proportional to the logarithms
435 of the concentrations of the tuberculins. The estimated potency must be not less than 75% and not
436 more than 133% of the potency stated on the label. The test is not valid unless the fiducial limits of
437 error ($p = 0.95$) are not less than 50% and not more than 200% of the estimated potency. If the batch
438 fails a potency test, the test may be repeated one or more times, provided that the final estimate of
439 potency ~~and of~~ fiducial limits is based on the combined results of all the tests.

440 It is recommended that avian tuberculin should contain the equivalent of at least 25,000 IU/ml or
441 approximately 0.5 mg protein per ml, giving a dose for practical use of 2500 IU/0.1 ml.

442 3. Requirements for authorisation/registration/licensing

443 3.1. Manufacturing process

444 The manufacturing process should follow the requirements of European Pharmacopoeia (2000–2024) or other
445 international standards.

446 3.2. Safety requirements

447 3.2.1. Target and non-target animal safety

448 Antimicrobial preservatives or other substances that may be added to a tuberculin must have been shown not
449 to impair the safety and effectiveness of the product. The maximum permitted concentrations for phenol is
450 0.5% (w/v), and for glycerol, it is 10% (v/v). The pH should be between 6.5 and 7.5.

451 3.2.2. Precautions (hazards)

452 Experience ~~both~~ in humans and animals led to the observation that appropriately diluted tuberculin injected
453 intradermally results in a localised reaction at the injection site without generalised manifestations. Even in
454 very sensitive persons, severe, generalised reactions are extremely rare and limited.

455 3.3. Stability

456 During storage, liquid avian tuberculin should be protected from the light and held at a temperature of 5°C ($\pm 3^\circ\text{C}$).
457 Freeze-dried preparations may be stored at higher temperatures (~~but not exceeding~~ 25°C) and protected from ~~the~~
458 light. During use, periods of exposure to higher temperatures or to direct sunlight should be kept at a minimum.

459 ~~Provided the tuberculins are~~ Following accepted practice, tuberculin should be stored at a temperature of between
460 2°C and 8°C and protected from light; they may be used up to the end of the following periods ~~subsequent to~~ after
461 the last satisfactory potency test: Liquid PPD tuberculins: 2 years; lyophilised PPD-A tuberculins: 8 years; HCSCM
462 (heat-concentrated synthetic-medium) tuberculins diluted: 2 years. Recent research on the temperature stability of
463 human, bovine, and avian tuberculin solutions has shown that they are stable for a year at 37°C. This should be
464 further explored as these products are used in the field in remote areas of the world where maintaining temperature
465 control is very difficult (Maes *et al.*, 2011).

466 REFERENCES

467 ANGUS R.D. (1978). Production of Reference PPD tuberculins for Veterinary use in the United States. *J. Biol. Stand.*, **6**,
468 221.

469 ARAHAL D.R., BULL C.T., BUSSE H.J., CHRISTENSEN H., CHUVOCHINA M., DEDYSH S.N., FOURNIER P.E., KONSTANTINIDIS K.T.,
470 PARKER C.T., ROSSELLO-MORA R., VENTOSA A. & GOKER M. (2023). Guidelines for interpreting the International Code of
471 Nomenclature of Prokaryotes and for preparing a Request for an Opinion. *Int. J. Syst. Evol. Microbiol.*, **73**.

472 BUCKWALTER S.P., OLSON S.L., CONNELLY B.J., LUCAS B.C., RODNING A.A., WALCHAK R.C., DEML S.M., WOHLFIEL S.L. &
473 WENGENACK N.L. (2016). Evaluation of Matrix-Assisted Laser Desorption Ionization-Time of Flight Mass Spectrometry for
474 Identification of *Mycobacterium* species, *Nocardia* species, and Other Aerobic *Actinomycetes*. *J. Clin. Microbiol.*, **54**, 376–
475 384.

476 COUSINS D., FRANCIS B. & DAWSON D. (1996). Multiplex PCR provides a low-cost alternative to DNA probe methods for rapid
477 identification of *Mycobacterium avium* and *Mycobacterium intracellulare*. *J. Clin. Microbiol.*, **34**, 2331–2333.

-
- 478 COWMAN S., VAN INGEN J., GRIFFITH D.E. & LOEBINGER M.R. (2019). Non-tuberculous mycobacterial pulmonary disease. *Eur*
479 *Respir. J.*, **54**(1).
- 480 DVORSKA L., BULL T.J., BARTOS M., MATLOVA L., SVASTOVA P., WESTON R.T., KINTR J., PARMOVA I., VAN SOOLINGEN D. & PAVLIK
481 I. (2003). A standardised restriction fragment length polymorphism (RFLP) method for typing *Mycobacterium avium* isolates
482 links IS901 with virulence for birds. *J. Microbiol. Methods*, **55**, 11–27.
- 483 DVORSKA L., MATLOVA L., AYELE W. Y., FISCHER O. A., AMEMORI T., WESTON R. T., ALVAREZ J., BERAN V., MORAVKOVA M. &
484 PAVLIK I. (2007). Avian tuberculosis in naturally infected captive water birds of the Ardeidae and Threskiornithidae families
485 studied by serotyping, IS901 RFLP typing and virulence for poultry. *Vet. Microbiol.*, **119**, 366–374.
- 486 DVORSKA L., MATLOVA L., BARTOS M., PARMOVA I., BARTL J., SVASTOVA P., BULL T. J. & PAVLIK I. (2004). Study of
487 *Mycobacterium avium* complex strains isolated from cattle in the Czech Republic between 1996 and 2000. *Vet. Microbiol.*,
488 **99**, 239–250.
- 489 DVORSKA L., PARMOVA I., LAVICKOVA M., BARTL J., VRBAS V. & PAVLIK I. (1999). Isolation of *Rhodococcus equi* and atypical
490 mycobacteria from lymph nodes of pigs and cattle in herds with the occurrence of tuberculoid gross changes in the Czech
491 Republic over the period of 1996–1998. *Veterinarni Medicina*, **44**, 321–330.
- 492 EUROPEAN PHARMACOPOEIA (2000–2024). Purified protein derivative (avian). In: European Pharmacopoeia, Eleventh Edition.
493 Editions of the Council of Europe, Strasbourg, France,
494 https://www.edqm.eu/en/d/234640?p_l_back_url=%2Fen%2Fsearch%3Fq%3Dpurified%2Bprotein%2Bderivative
- 495 GUERRERO C., BERNASCONI C., BURKI D., BODMER T. & TELENTI A. (1995). A novel insertion element from *Mycobacterium*
496 *avium*, IS1245, is a specific target for analysis of strain relatedness. *J. Clin. Microbiol.*, **33**, 304–307.
- 497 HAAGSMA J. & ANGUS R.D. (1995). Tuberculin production. In: *Mycobacterium bovis* Infections in Humans and Animals,
498 Steele J.H. & Thoen C.O., eds. Iowa State University Press, Ames, USA, 73–84.
- 499 HALL L., DOERR K.A., WOHLFIEL S.L. & ROBERTS G.D. (2003). Evaluation of the MicroSeq system for identification of
500 mycobacteria by 16S ribosomal DNA sequencing and its integration into a routine clinical mycobacteriology laboratory. *J.*
501 *Clin. Microbiol.*, **41**, 1447–1453.
- 502 HOOP R. (2002). *Mycobacterium tuberculosis* infection in a canary (*Serinus canaria* L.) and a blue-fronted Amazon parrot
503 (*Amazona amazona aestiva*). *Avian Dis.*, **46**, 502–504.
- 504 INDERLIED C.B., KEMPER C.A. & BERMUDEZ L.E.M. (1993). The *Mycobacterium avium* complex. *Clin. Microbiol. Rev.*, **6**, 266–
505 310.
- 506 KAEVSKA M., SLANA I., KRALIK P. & PAVLIK I. (2010). Examination of *Mycobacterium avium* subsp. *avium* distribution in
507 naturally infected hens by culture and triplex quantitative real time PCR. *Veterinarni Medicina*, **55**, 325–330.
- 508 KAZDA J., PAVLIK I., FALKINHAM J. & HRUSKA K. (2009). The Ecology of *Mycobacteria*: Impact on Animal's and Human's
509 Health, First Edition, Springer Science+Business Media BV, 520 pp. ISBN 978-1-4020-9412-5.
- 510 KUNZE Z.M., PORTAELS F. & MCFADDEN J.J. (1992). Biologically distinct subtypes of *Mycobacterium avium* differ in
511 possession of insertion sequence IS901. *J. Clin. Microbiol.*, **30**, 2366–2372.
- 512 KIRSCHNER P., MEIER P.A. & BOTTGER E.C. (1993). Genotypic identification and detection of mycobacteria. In: Diagnostic
513 Molecular Microbiology, Persing D.H., Smith T.F., Tenover F.C. & White T.C., eds. American Society for Microbiology,
514 Washington DC, USA, 173–190.
- 515 LANTERI G., MARINO F., REALE S., VITALE F., MACRI F. & MAZZULLO G. (2011). *Mycobacterium tuberculosis* in a red-crowned
516 parakeet (*Cyanoramphus novaezelandiae*). *J. Avian Med. Surg.*, **25**, 40–43.
- 517 MAES M., GIMÉNEZ J.F., D'ALESSANDRO A. & DE WAARD J.H. (2011). The stability of human, bovine and avian tuberculin
518 purified protein derivative (PPD). *J. Infect. Dev. Ctries*, **5**, 781–785.
- 519 MIJS W., DE HAAS P., ROSSAU R., VAN DER LAAN T., RIGOUTS L., PORTAELS F. & VAN SOOLINGEN D. (2002). Molecular evidence
520 to support a proposal to reserve the designation *Mycobacterium avium* subsp. *avium* to bird-type isolates and *M. avium*
521 subsp. *hominissuis* for the human/porcine type of *M. avium*. *Int. J. Syst. Evol. Microbiol.*, **52**, 1505–1518.
- 522 MORAVKOVA M., HLOZEK P., BERAN V., PAVLIK I., PREZIUSO S., CUTERI V. & BARTOS M. (2008). Strategy for the detection and
523 differentiation of *Mycobacterium avium* species in isolates and heavily infected tissues. *Res. Vet. Sci.*, **85**, 257–264.
-

- 524 NARSANA N., ALEJANDRA PEREZ M. & SUBRAMANIAN A. (2023). Mycobacteria in Organ Transplant Recipients. *Infect. Dis. Clin. North Am.*, S0891-5520(23)00040-5. doi: 10.1016/j.idc.2023.04.004.
- 526 PAVLIK I., MATLOVA L., DVORSKA L., BARTL J., OKTABCOVA L., DOCEKAL J. & PARMOVA I. (2003). Tuberculous lesions in pigs in the Czech Republic during 1990–1999: occurrence, causal factors and economic losses. *Veterinari Medicina*, **48**, 113–125.
- 528 PAVLIK I., MATLOVA L., DVORSKA L., SHITAYE J. E. & PARMOVA I. (2005). Mycobacterial infections in cattle and pigs caused by *Mycobacterium avium* complex members and atypical mycobacteria in the Czech Republic during 2000–2004. *Veterinari Medicina*, **50**, 281–290.
- 531 PAVLIK I., SVASTOVA P., BARTL J., DVORSKA L. & RYCHLIK I. (2000). Relationship between IS901 in the *Mycobacterium avium* complex strains isolated from birds, animals, humans, and the environment and virulence for poultry. *Clin. Diagn. Lab. Immunol.*, **7**, 212–217.
- 534 PETERS M., PRODINGER W.M., GUMMER H., HOTZEL H., MOBIUS P. & MOSER I. (2007). *Mycobacterium tuberculosis* infection in a blue-fronted amazon parrot (*Amazona aestiva aestiva*). *Vet. Microbiol.*, **122**, 381–383.
- 536 POCKNELL A.M., MILLER B.J., NEUFELD J.L. & GRAHN B.H. (1996). Conjunctival mycobacteriosis in two emus (*Dromaius novaehollandiae*). *Vet. Pathol.*, **33**, 346–348.
- 538 REALINI L., DE RIDDER K., HIRSCHEL B. & PORTAELS F. (1999). Blood and charcoal added to acidified agar media promote the growth of *Mycobacterium genavense*. *Diagn. Microbiol. Infect. Dis.*, **34**, 45–50.
- 540 RIOJAS M.A., FRANK A.M., GREENFIELD S.R., KING S.P., MEEHAN C.J., STRONG M., WATTAM A.R. & HAZBÓN M.H. (2021). Identification and Characterization of Mycobacterial Species Using Whole-Genome Sequences. *Methods Mol. Biol.*, **2314**, 399–457.
- 543 RITAGGO V., KREMER K., VAN DER LAAN T., PIJNENBURG J.E.M., DE HAAS P.E.W. & VAN SOOLINGEN D. (1998). Use of IS904 and IS1245 in RFLP typing of *Mycobacterium avium* complex: relatedness among serovar reference strains, human and animal isolates. *Int. J. Tuberculosis Lung Dis.*, **2**, 242–251.
- 546 ROZANSKA M. (1965). Preparation of antigen for whole blood rapid agglutination test and its specificity for diagnosis of avian tuberculosis. *Bull. Vet. Inst. Pulawy*, **9**, 20–25.
- 548 SAITO H., TOMIOKA H., SATO K., TASAKA H. & DAWSON D.J. (1990). Identification of various serovar strains of *Mycobacterium avium* complex by using DNA probes specific for *Mycobacterium avium* and *Mycobacterium intracellulare*. *J. Clin. Microbiol.*, **28**, 1694–1697.
- 551 SALAMATIAN I., GHANIEL A., MOSAVARI N., NOURANI H., KESHAVARZ R. & ESLAMPANAH M. (2020). Outbreak of avian mycobacteriosis in a commercial turkey breeder flock. *Avian Pathol.*, **49**, 296–304.
- 553 SATTAR A., ZAKARIA Z., ABU J., AZIZ S.A. & ROJAS-PONCE G. (2021). Isolation of *Mycobacterium avium* and other nontuberculous mycobacteria in chickens and captive birds in peninsular Malaysia. *BMC Vet. Res.*, **17**, 13.
- 555 SCHMIDT V., KOHLER H., HEENEMANN K. & MOBIUS P. (2022). Mycobacteriosis in Various Pet and Wild Birds from Germany: Pathological Findings, Coinfections, and Characterization of Causative Mycobacteria. *Microbiol. Spectr.*, **10**(4): e0045222.
- 557 SCHMIDT V., SCHNEIDER S., SCHLOMER J., KRAUTWALD-JUNGHANNS M.E. & RICHTER E. (2008). Transmission of tuberculosis between men and pet birds: a case report. *Avian Pathol.*, **37**, 589–592.
- 559 SCHMITZ A., KORBEL R., THIEL S., WORLE B., GOHL C. & RINDER M. (2018a). High prevalence of *Mycobacterium genavense* within flocks of pet birds. *Vet. Microbiol.*, **218**, 40–44.
- 561 SCHMITZ A., RINDER M., THIEL S., PESCHEL A., MOSER K., REESE S. & KORBEL R. (2018b). Retrospective Evaluation of Clinical Signs and Gross Pathologic Findings in Birds Infected With *Mycobacterium genavense*. *J. Avian Med. Surg.*, **32**, 194–204.
- 563 SHITAYE J.E., GRIMOVA V., GRYM M., HALOUZKA R., HORVATHOVA A., MORAVKOVA M., BERAN V., SVOBODOVA J., DVORSKA-BARTOSOVA L. & PAVLIK I. (2009). *Mycobacterium avium* subsp. *hominissuis* infection in a pet parrot. *Emerg. Inf. Dis.*, **15**, 617–619.
- 566 SHITAYE J.E., HALOUZKA R., SVOBODOVA J., GRIMOVA V., GRYM M., SKORIC M., FICTUM P., BERAN V., SLANY M. & PAVLIK I. (2010). First isolation of *Mycobacterium genavense* in blue headed parrot (*Pionus menstruus*) imported from Surinam (South America) to the Czech Republic: a case report. *Veterinari Medicina*, **55**, 339–347.

- 569 SHITAYE J.E., MATLOVA L., HORVATHOVA A., MORAVKOVA M., DVORSKA-BARTOSOVA L., TREML F., LAMKA J. & PAVLIK I. (2008).
570 *Mycobacterium avium* subsp. *avium* distribution studied in a naturally infected hen flock and in the environment by culture,
571 serotyping and IS901 RFLP methods. *Vet. Microbiol.*, **127**, 155–164.
- 572 SHITAYE J.E., PARMOVA I., MATLOVA L., DVORSKA L., HORVATHOVA A., VRBAS V. & PAVLIK, I. (2006). ~~Mycobacterial and~~
573 ~~Rhodococcus equi~~ infections in pigs in the Czech Republic between the years 1996 and 2004: the causal factors and
574 distribution of infections in the tissues. *Veterinarni Medicina*, **51**, 497–511. <http://www.vri.cz/docs/vetmed/51-11-497.pdf>
- 575 SLANA I., KAEVSKA M., KRALIK P., HORVATHOVA A. & PAVLIK, I. (2010). Distribution of *Mycobacterium avium* subsp. *avium* and
576 *M. a. hominissuis* in artificially infected pigs studied by culture and IS901 and IS1245 quantitative real time PCR. *Vet.*
577 *Microbiol.*, **144**, 437–443.
- 578 SOINI H., EEROLA E. & VILJANEN M.K. (1996). Genetic diversity among *Mycobacterium avium* complex Accu-Probe-positive
579 isolates. *J. Clin. Microbiol.*, **34**, 55–57.
- 580 TELL L.A., FOLEY J., NEEDHAM M.L. & WALKER R.L. (2003a). Comparison of four rapid DNA extraction techniques for
581 conventional polymerase chain reaction testing of three *Mycobacterium* spp. that affect birds. *Avian Dis.*, **47**, 1486–1490.
- 582 TELL L.A., LEUTENEGGER C.M., LARSEN R.S., AGNEW D.W., KEENER L., NEEDHAM M.L. & RIDEOUT B.A. (2003b). Real-time
583 polymerase chain reaction testing for the detection of *Mycobacterium genavense* and *Mycobacterium avium* complex
584 species in avian samples. *Avian Dis.*, **47**, 1406–1415.
- 585 TELL L.A., WOODS L. & CROMIE R.L. (2001). Mycobacteriosis in birds. *Rev. Sci. Tech.*, **20**, 180–203.
- 586 THOREL M.F., HUCHZERMAYER H. & MICHEL A.L. (2001). *Mycobacterium avium* and *M. intracellulare* infection in mammals.
587 *Rev. sci. tech. Off. int. Epiz.*, **20**, 204–218.
- 588 THOREL M.F., HUCHZERMAYER H., WEISS R. & FONTAINE J.J. (1997). *Mycobacterium avium* infections in animals. Literature
589 review. *Vet. Res.*, **28**, 439–447.
- 590 THOREL M.F., KRICHEVSKY M. & LEVY-FREBAULT V.V. (1990). Numerical taxonomy of mycobactin-dependent mycobacteria,
591 emended description of *Mycobacterium avium*, and description of *Mycobacterium avium* subsp. *avium* subsp. nov.,
592 *Mycobacterium avium* subsp. *paratuberculosis* subsp. nov., and *Mycobacterium avium* subsp. *silvaticum* subsp. nov. *Int.*
593 *J. Syst. Bacteriol.*, **40**, 254–260.
- 594 TORTOLI E., MEEHAN C.J., GROTTOLA A., FREGNI SERPINI G., FABIO A., TROVATO A., PECORARI M. & CIRILLO D.M. (2019).
595 Genome-based taxonomic revision detects a number of synonymous taxa in the genus *Mycobacterium*. *Infect. Genet.*
596 *Evol.*, **75**, 103983.
- 597 VAN INGEN J., AL HAJOJ SAM., BOERE M., AL RABIAH F., ENAIMI M., DE ZWAAN R., TORTOLI E., DEKHUIJZEN R. & VAN SOOLINGEN
598 D. (2009). *Mycobacterium riyadhense* sp. nov.; a non-tuberculous species identified as *Mycobacterium tuberculosis* by a
599 commercial line-probe assay. *Int. J. Syst. Evol. Microbiol.*, **59**, 1049–1053.
- 600 ~~VAN SOOLINGEN D., BAUER J., RITACCO V., CARDOSO LEAO S., PAVLIH., VINCENT V., RASTOGI N., GORI A., BODMER T., GARZELLI~~
601 ~~G. & GARCIA M.J. (1998). IS1245 restriction fragment length polymorphism typing of *Mycobacterium avium* isolates:~~
602 ~~proposal for standardization. *J. Clin. Microbiol.*, **36**, 3051–3054.~~
- 603 WITTE C., FOWLER J.H., PFEIFFER W., HUNGERFORD L.L., BRAUN J., BURCHELL J., PAPENDICK R. & RIDEOUT B.A. (2021). Social
604 network analysis and whole-genome sequencing to evaluate disease transmission in a large, dynamic population: A study
605 of avian mycobacteriosis in zoo birds. *PLoS One*, **16**(6): e0252152.
- 606 WOLINSKY E. & SCHAEFER W.B. (1973). Proposed numbering scheme for mycobacterial serotypes by agglutination. *Int. J.*
607 *Syst. Bacteriol.*, **23**, 182–183.
- 608 WORLD HEALTH ORGANIZATION (WHO) (1987). Requirements for Biological Substances No. 16, Annex 1: Requirement for
609 Tuberculins. Technical Report Series No. 745, WHO, Geneva, Switzerland, 31–59.
- 610 *
611 * *
- 612 **NB:** There is currently (2024) no WOA Reference Laboratory for avian tuberculosis
613 (please consult the WOA Web site for the current list:
614 <https://www.woah.org/en/what-we-offer/expertise-network/reference-laboratories/#ui-id-3><http://www.oie.int/>).
- 615 **NB:** FIRST ADOPTED IN 1989 AS TUBERCULOSIS IN BIRDS. MOST RECENT UPDATES ADOPTED IN 2014.

2 MEETING OF THE WOHAI BIOLOGICAL STANDARDS COMMISSION

3 Paris, 4–8 September 2023

4
5 SECTION 3.4.

6 BOVINAE

7 CHAPTER 3.4.1.

8 BOVINE ANAPLASMOSIS

9 SUMMARY

10 **Definition of the disease:** Bovine anaplasmosis results from infection with *Anaplasma marginale*. A second
11 species, *A. centrale*, has long been recognised and usually causes benign infections. *Anaplasma marginale*
12 is responsible for almost all outbreaks of clinical disease. *Anaplasma phagocytophilum* and *A. bovis*, which
13 infect cattle, ~~have been recently~~ are also included within the genus but they are not reported to, *Anaplasma*
14 *phagocytophilum* can cause clinical self-limiting disease in cattle. There are no reports of disease associated
15 with *A. bovis* infection. The organism is classified in the genus *Anaplasma* belonging to the family
16 Anaplasmataceae of the order Rickettsiales.

17 **Description of the disease:** Anaemia, jaundice in acute, severe cases and ~~sudden unexpected~~
18 characteristic signs of bovine anaplasmosis. Other signs include rapid loss of milk production and weight,
19 but the clinical disease can only be confirmed by identifying the organism. Once infected, cattle may remain
20 carriers for life, and identification of these animals depends on the detection of specific antibodies using
21 serological tests, or of rickettsial DNA using molecular amplification techniques. The disease is typically
22 transmitted by tick vectors, but mechanical transmission by biting insects or by needle can occur.

23 **Detection ~~Identification~~ of the agent:** Microscopic examination of blood or organ smears stained with
24 Giemsa stain is the most common method of identifying *Anaplasma* in clinically affected animals. In these
25 smears, *A. marginale* organisms appear as dense, rounded, intraerythrocytic bodies approximately 0.3–
26 1.0 µm in diameter situated on or near the margin of the erythrocyte. *Anaplasma centrale* is similar in
27 appearance, but most of the organisms are situated toward the centre of the erythrocyte. It can be difficult
28 to differentiate *A. marginale* from *A. centrale* in a stained smear, particularly with low levels of rickettsaemia.
29 Commercial stains that give very rapid staining of *Anaplasma spp.* are available in some countries.
30 *Anaplasma phagocytophilum* can only be observed in infected granulocytes, mainly neutrophils and *A. bovis*
31 can only be observed in infected monocytes infecting granulocytes, mainly neutrophils.

32 It is important that smears be well prepared and free from foreign matter. Smears from live cattle should
33 preferably be prepared from blood drawn from the jugular vein or another large vessel. For post-mortem
34 diagnosis, smears should be prepared from internal organs (including liver, kidney, heart and lungs) and

35 from blood retained in peripheral vessels. The latter are particularly ~~desirable~~ useful if post-mortem
36 decomposition is advanced.

37 **Serological tests:** A competitive enzyme-linked immunosorbent assay (C-ELISA) has ~~been demonstrated~~
38 ~~to have~~ good sensitivity in detecting carrier animals. Card agglutination is the next most frequently used
39 assay. The complement fixation test (CFT) is no longer considered a reliable test ~~for disease certification of~~
40 ~~individual animals~~ due to variable sensitivity. Cross reactivity between *Anaplasma* spp. can complicate
41 interpretation of serological tests. In general, the C-ELISA has the best specificity, with cross-reactivity
42 described between *A. marginale*, *A. centrale*, *A. phagocytophilum* and *Ehrlichia* spp. Alternatively, an
43 indirect ELISA using the CFT with modifications (I-ELISA) is a reliable test used in many laboratories and
44 can be prepared in-house for routine diagnosis of anaplasmosis. Finally, a displacement double-antigen
45 sandwich ELISA has been developed to differentiate between *A. marginale* and *A. centrale* antibodies.

46 **Nucleic-acid-based tests** ~~have been used~~ are often used in diagnostic laboratories and experimentally,
47 and are capable of detecting the presence of low-level infection in carrier cattle and tick vectors. A nested
48 conventional polymerase chain reaction (PCR) ~~reaction is necessary~~ has been used to identify low-level
49 carriers using conventional polymerase chain reaction (PCR), and although nonspecific amplification can
50 occur. ~~Recently,~~ Real-time PCR assays with have analytical sensitivity equivalent to nested conventional
51 PCR ~~have been described and are preferable in a diagnostic setting to reduce the risk of amplicon~~
52 contamination.

53 **Requirements for vaccines:** Live vaccines are used in several countries to protect cattle against
54 *A. marginale* ~~infection~~ bovine anaplasmosis. A vaccine consisting of live *A. centrale* is most widely used and
55 gives partial protection against challenge with virulent *A. marginale*. Vaccination with *A. centrale* leads to
56 infection and long-term persistence in many cattle. Vaccinated cattle are typically protected from disease
57 caused by *A. marginale*, but not infection.

58 *Anaplasma centrale* vaccine is provided in chilled or frozen forms. Quality control is very important as other
59 blood-borne agents that may be present in donor cattle can contaminate vaccines and be disseminated
60 broadly. For this reason, frozen vaccine is recommended as it allows thorough post-production quality control,
61 which limits the risk of contamination with other pathogens.

62 *Anaplasma centrale* vaccine is not entirely safe. A practical recommendation is to restrict its use, as far as
63 possible, to calves, as nonspecific immunity will minimise the risk of some vaccine reactions that may require
64 treatment with tetracycline or imidocarb. Partial immunity develops in 6–8 weeks and lasts for several years
65 after a single vaccination. In countries where *A. centrale* is exotic, it cannot be used as a vaccine against *A.*
66 *marginale*.

67 A. INTRODUCTION

68 Outbreaks of bovine anaplasmosis are due to infection with *Anaplasma marginale*. *Anaplasma centrale* ~~is capable of~~
69 ~~producing~~ can produce a moderate degree of anaemia, but clinical outbreaks in the field are extremely rare. ~~Now species~~
70 ~~of *Anaplasma*.~~ Other members of the family Anaplasmataceae that infect cattle include *A. phagocytophilum* and *A. bovis*
71 (Dumler *et al.*, 2001), ~~with a primary reservoir.~~ *Anaplasma phagocytophilum* has a broad host range and causes the
72 diseases human granulocytic anaplasmosis (HGE), equine granulocytic anaplasmosis (EGA), and canine granulocytic
73 anaplasmosis (CGA), in humans, horses, and dogs, respectively (Matei *et al.*, 2019). In northern Europe in rodents, *A.*
74 *phagocytophilum* causes tick-borne fever, primarily affecting lambs. In cattle, *A. phagocytophilum* infections have been
75 reported to infect cattle, but do not cause from many geographical regions, however the association with disease is less
76 commonly reported. Naturally occurring clinical disease as reported in Germany was characterised by fever (39.5–41.7°
77 C), sudden reduction in milk production, lower limb oedema, and stiffness with leukopenia, erythropenia, neutropenia,
78 lymphocytopenia and monocytopenia. The affected animals recovered without antibiotic treatment (Droher *et al.*, 2005;
79 Hofmann-Lehmann *et al.*, 2004; Silaghi *et al.*, 2018).

80 The most marked clinical signs of bovine anaplasmosis are anaemia and jaundice, the latter occurring in acute severe
81 cases or late in the disease. Haemoglobinaemia and haemoglobinuria are not present, and this may assist in the differential
82 diagnosis of bovine anaplasmosis from babesiosis, which is often endemic in the same regions. The disease can only be
83 confirmed, however, by identification of the organism in erythrocytes from the affected animal. Caution must be exercised
84 if using nucleic acid techniques alone to diagnose *A. marginale* in anaemic cattle. Persistent, low-level infection can be

85 detected by these techniques and may lead to a misdiagnosis of bovine anaplasmosis. Visualisation of *A. marginale* bodies
86 in erythrocytes is therefore required for confirmation.

87 *Anaplasma marginale* occurs in most tropical and subtropical countries and is widely distributed in ~~some more~~-temperate
88 regions. *Anaplasma centrale* was first described from South Africa. The organism has since been imported by other
89 countries – including Australia and some countries in South America, South-East Asia and the Middle East – for use as a
90 vaccine against *A. marginale*.

91 *Anaplasma* species ~~were, though~~ originally ~~regarded described~~ as protozoan parasites, but further research showed they
92 had no significant attributes to justify this description. Since the last major accepted revision of the are obligate intracellular
93 Gram-negative bacteria. Based on taxonomy established in 2001 (Dumler *et al.*, 2001), the Family *Anaplasmataceae*
94 (Order *Rickettsiales*) is now composed of ~~four~~ five genera, *Anaplasma*, *Ehrlichia*, *Neorickettsia*, and *Wolbachia*. ~~The genus~~
95 and *Aegyptianella* is retained within the Family *Anaplasmataceae* as genus *incertae sedis*. The revised genus, The genus
96 *Anaplasma* now contains *Anaplasma marginale* as the type species, *A. phagocytophilum* the agent of human granulocytic
97 ehrlichiosis (formerly *Ehrlichia phagocytophila* and *E. equi*), *A. platys*, and *A. bovis* (~~formerly *E. bovis*~~). ~~*Haemobartonella*~~
98 ~~and *Eperythrozoon* are now considered most closely related to the mycoplasmas.~~

99 *Anaplasma* species are transmitted either mechanically or biologically by arthropod vectors. ~~Reviews based on careful~~
100 study-Detection of reported transmission experiments list up pathogen DNA within a tick is insufficient to 19 different ticks
101 as capable of determine the ability of a particular tick species to transmit a pathogen. Studies demonstrating transmission
102 of the pathogen are critical in determining the potential role of a particular tick species in pathogen transmission-transmitting
103 *A. marginale* (Kocan *et al.*, 2004). These are: *Argas persicus*, *Ornithodoros lahorensis*, Many studies have demonstrated
104 the transmission ability of *Dermcentor albipictus*, *D. andersoni*, *D. hunteri*, *D. occidentalis*, *D. variabilis*,
105 *Hyalomma excavatum*, *H. rufipes*, *Ixodes ricinus*, *I. scapularis*, and *D. albipictus*. Additionally, transmission by multiple
106 *Rhipicephalus* species is well recognised including *R. annulatus* (formerly *Boophilus annulatus*), *R. bursa*, *R. calcaratus*,
107 *R. decoloratus*, *R. evertsi*, *R. microplus*, *R. sanguineus* and *R. simus*. However, the classification of several ticks in these
108 reports has been questioned, and *R. sanguineus*. Other species of *Rhipicephalus* also likely serve as biological vectors
109 of *A. marginale*. *Anaplasma marginale* DNA has been widely reported in *Hyalomma* species, and transmission has been
110 demonstrated with *H. excavatum*. It is likely that multiple *Hyalomma* species also serve as vectors of *A. marginale* (Shkap
111 *et al.*, 2009).

112 Intrastadial or transstadial transmission ~~is the usual mode can occur~~, even in the one-host, *Rhipicephalus* species. Male
113 ticks may be particularly important as vectors, as they can become persistently infected and serve as a reservoir are most
114 likely to move between cattle searching for infection-female ticks. Experimental demonstration of vector competence does
115 not necessarily imply a role in transmission in the field. However, *Rhipicephalus* species are clearly important vectors of
116 anaplasmosis in countries such as Australia and countries in, many regions of Africa, and Latin America, and some species
117 of, *Dermacentor* spp. are efficient vectors in the United States of America (USA).

118 Various other biting arthropods have been implicated as mechanical vectors, particularly in the USA. Experimental
119 transmission has been demonstrated with a number of species of *Tabanus* (horseflies), and with mosquitoes of the genus
120 *Psorophora* (Kocan *et al.*, 2004). The importance of biting insects in the natural transmission of anaplasmosis appears to
121 vary greatly from region to region. *Anaplasma marginale* also can be readily transmitted during vaccination against other
122 diseases unless a fresh or sterilised needle is used for injecting each animal. Similar transmission by means of unsterilised
123 surgical instruments has been described (Reinbold *et al.*, 2010a).

124 The main-only known biological vectors of *A. centrale* appear to be multihost ticks is *R. simus*, endemic in Africa, including
125 *R. simus*. The. Though multiple transmission studies have been done, there is no evidence that the common cattle tick
126 (*R. microplus*) has not been shown to be can serve as a vector for *A. centrale*. This is of relevance-relevant where
127 *A. centrale* is used as a vaccine in *R. microplus*-infested regions.

128 *Anaplasma marginale* infection has not been reported in humans. ~~Thus, There is no minimal risk of field or laboratory~~
129 transmission to workers and-from laboratories working with *A. marginale* may operate at the lowest biosafety level,
130 equivalent to BSL-1. Nevertheless the agent should be handled with appropriate biosafety and containment procedures as
131 determined by biorisk analysis (see Chapter 1.1.4 Biosafety and biosecurity: Standard for managing biological risk in the
132 veterinary laboratory and animal facilities).

B. DIAGNOSTIC TECHNIQUES

Table 1. Test methods available for the diagnosis of bovine anaplasmosis and their purpose

Method	Purpose					
	Population freedom from infection	Individual animal freedom from infection prior to movement	Contribute to eradication policies	Confirmation of clinical cases	Prevalence of infection – surveillance	Immune status in individual animals or populations (post-vaccination)
Microscopic examination	–	± _≡	–	+++	–	–
Detection of the agent^(a)						
PCR	–	++ ±	–	+++	–	–
Detection of immune response						
CAT ^(b)	–	–	–	–	+	+
C-ELISA ^(b)	+++	+++	+++	–	+++	+++
IFAT ^(b)	+	–	–	–	++	++
CFT	–	–	–	–	±	–
<u>ddasELISA</u>	≡	≡	≡	≡	≡	≡

Key: +++ = recommended for this purpose; ++ recommended but has limitations;

+ = suitable in very limited circumstances; – = not appropriate for this purpose.

Agent id. = agent identification; CAT = card agglutination test; CFT = complement fixation test;

C-ELISA = competitive enzyme-linked immunosorbent assay; ddasELISA = displacement double-antigen, sandwich ELISA;

IFAT = indirect fluorescent antibody test; PCR = polymerase chain reaction.

^(a)A combination of agent identification methods applied on the same clinical sample is recommended.

^(b)These tests do not distinguish infected from vaccinated animals.

1. Detection of the agent

1.1. Microscopic examination

Samples from live cattle should include thin blood smears and blood collected into an anticoagulant. Air-dried thin blood smears can be kept satisfactorily at room temperature for at least 1 week. The blood sample in anticoagulant should be held and transferred at 4°C, unless it can reach the laboratory within a few hours. This sample is useful for preparing fresh smears if those submitted are not satisfactory. In addition, a low packed cell volume and/or erythrocyte count can help to substantiate the involvement of *A. marginale* when only small numbers of the parasites are detected in smears, ~~for example particularly~~ during the recovery stage of the disease.

In contrast to *Babesia bovis*, *A. marginale* ~~does not~~ does not accumulate in capillaries, so blood drawn from the jugular or other large vessel is satisfactory. Anaplasma marginale replicate in the erythrocytes to form small membrane-bound colonies, also termed inclusion bodies or initial bodies. Because of the rather indistinctive morphology of Anaplasma. These initial bodies can be visualised on a blood smear, but are small and easily confused with debris or stain precipitate (see Figure 1). Thus it is essential that smears are well prepared and, including ensuring slides are free from foreign matter, as specks of debris can confuse diagnosis and stain is recently filtered (Watman #1 filter paper). Thick blood films as are used sometimes for the diagnosis of babesiosis are not appropriate for the diagnosis of anaplasmosis, as Anaplasma A. marginale are difficult to identify once they become dissociated from erythrocytes.

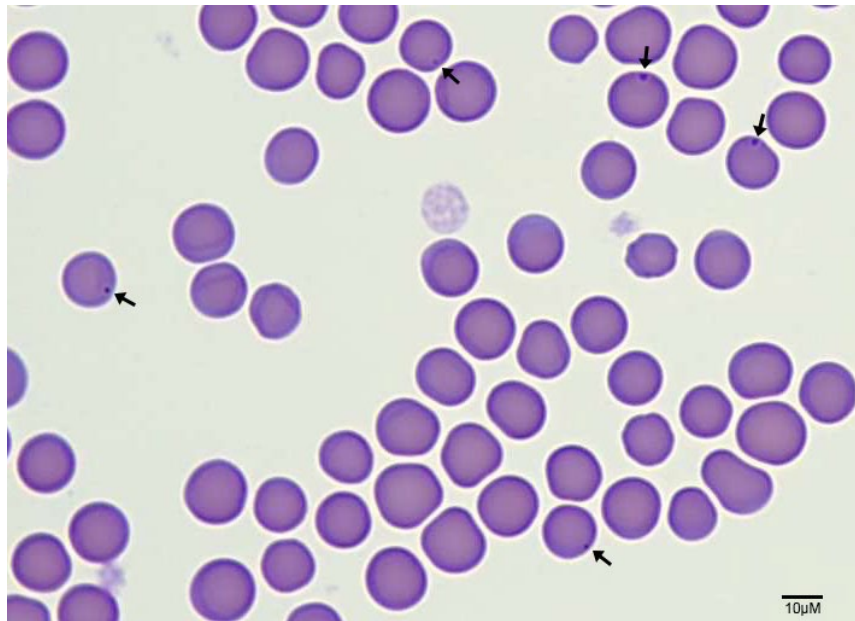


Figure 1. *Anaplasma marginale* initial bodies. A Diff-Quick stained blood smear from a bovine experimentally infected with *A. marginale*. Arrows point to the *A. marginale* initial bodies. Photo from S. Noh.

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162 Samples from dead animals should include air-dried thin smears from the liver, kidney, heart and lungs and from a
163 peripheral blood vessel. The latter is particularly recommended should there be a significant delay before post-
164 mortem examination because, under these circumstances, bacterial contamination of organ smears often makes
165 identification of *Anaplasma A. marginale* equivocal. Brain smears, which are useful for the diagnosis of some forms
166 of babesiosis, are of no direct value for diagnosing anaplasmosis, but should be included for differential diagnosis
167 where appropriate.

168 Blood from organs, rather than organ tissues *per se*, is required for smear preparation, as the aim is to be able to
169 examine microscopically intact erythrocytes for the presence of *Anaplasma A. marginale colonies*. Organ-derived
170 blood smears can be stored satisfactorily at room temperature for several days.

171 Both blood and organ smears can be stained in 10% Giemsa stain for approximately 30 minutes after fixation in
172 absolute methanol for 1 minute. After staining, the smears are rinsed three or four times with tap water to remove
173 excess stain and are then air-dried. Conditions for Giemsa staining vary from laboratory to laboratory, but distilled
174 water is not recommended for dilution of Giemsa stock. Water should be pH 7.2–7.4 to attain best resolution with
175 Giemsa stain. Commercial stains that give very rapid staining of *Anaplasma A. marginale* are available in some
176 countries. Smears ~~are~~ must be examined under oil immersion at a magnification of ×700–1000.

177 *Anaplasma marginale* ~~appear as dense, initial bodies are~~ rounded and deeply stained intraerythrocytic bodies, and
178 approximately 0.3–1.0 µm in diameter. Most of these bodies are located on or near the margin of the erythrocyte.
179 This feature distinguishes *A. marginale* from *A. centrale*, as in the latter most of the organisms have a more central
180 location in the erythrocyte. However, particularly at low levels of rickettsaemia, differentiation of these two species in
181 smears can be difficult. Appendages associated with the *Anaplasma* ~~body~~ initial body have been described in some
182 isolates of *A. marginale* (Krojer & Ristic, 1963; Stich *et al.*, 2004).

183 The percentage of infected erythrocytes varies with the stage and severity of the disease. Maximum rickettsaemias
184 in excess of 50% may occur with *A. marginale*. Multiple infections of individual erythrocytes are common during
185 periods of high rickettsaemias.

186 The infection becomes visible microscopically 2–6 weeks following transmission. During the course of clinical
187 disease, the rickettsaemia approximately doubles each day for up to about 10 days, and then decreases at a similar
188 rate. Severe anaemia may persist for some weeks after the parasites have become virtually undetectable in blood
189 smears. Following recovery from initial infection, cattle remain latently infected for life.

1.2. Polymerase chain reaction

191 Nucleic-acid-based tests to detect *A. marginale* infection in carrier-infected cattle have been developed although not
 192 yet fully validated. The analytical sensitivity of polymerase chain reaction (PCR)-based methods has been estimated
 193 at 0.0001% infected erythrocytes, but at this level, only a proportion of carrier cattle would be detected. A nested PCR
 194 has been used to identify *A. marginale* carrier cattle with a capability of identifying as few as 30 infected erythrocytes
 195 per ml of blood, well below the lowest levels in carriers. However, nested PCR is time consuming as it requires two
 196 full PCR reactions, and poses significant quality control and specificity problems for routine use (Torioni De Echaide
 197 *et al.*, 1998). Real-time PCR assays are reported to achieve a level of analytical sensitivity equivalent to nested PCR
 198 has also been described for identification of *A. marginale* and should be considered instead of the nested PCR (Carelli
 199 *et al.*, 2007; Decaro *et al.*, 2008; Reinbold *et al.*, 2010b). Two Advantages of this technique the real-time PCR, which
 200 uses a single closed tube for amplification and analysis, are reduced opportunity for amplicon contamination and a
 201 semi-quantitative assay result. Equipment and reagents needed for real-time PCR is are expensive, requires
 202 preventive maintenance, and may be beyond the capabilities of some laboratories. Real-time PCR assays may target
 203 one of several genes (Carelli *et al.*, 2007; Decaro *et al.*, 2008), or 16S rRNA (Reinbold *et al.*, 2010b), and are reported
 204 to achieve a level of analytical sensitivity equivalent to nested conventional PCR (Carelli *et al.*, 2007; Decaro *et al.*,
 205 2008; Reinbold *et al.*, 2010b).

206 The most widely cited assays for the detection *A. marginale* in individual animals use a probe for increased specificity
 207 and are designed to detect *msp1b* (Carelli *et al.*, 2007) or *msp5* (Futse *et al.*, 2003) in genomic DNA extracted from
 208 whole blood. The assay based on detection of *msp1b* has been partially validated to detect the pathogen in individual
 209 animals and was used to define samples for the validation of a C-ELISA (Carelli *et al.*, 2007; Chung *et al.*, 2014). The
 210 analytical test performance of this assay is robust, and exclusivity testing confirmed other bacterial and protozoal tick-
 211 borne pathogens of cattle were not detected. The assay, evaluated using 51 blood samples from 18 cattle herds in
 212 three regions of southern Italy, had 100% concordance with nested PCR.

213 *Msp1b* is a multigene family. Based on the annotation of the St. Maries strain of *A. marginale*, the designed primers
 214 and probe will amplify multiple members of this gene family, including *msp1b-1*, *msp1b-2*, and *msp1-pg3*. This may
 215 help increase diagnostic sensitivity, but may pose challenges if quantification of the pathogen is desired. Additionally,
 216 some *A. marginale* strains have single nucleotide polymorphisms in *msp1b* within the primer and probe binding
 217 regions. Thus, if *msp1b* is used as a diagnostic target, primer and probe design should consider local *A. marginale*
 218 strains. *Msp1b* has the advantage as a target in that orthologs of this gene family are absent in the related *A.*
 219 *phagocytophilum* and *Ehrlichia* spp., including *E. ruminantium*, thus helping ensure specificity of the test.

220 *Msp5* has also been used as a target to detect *A. marginale* in cattle in field samples and more frequently in
 221 experimental samples (Futse *et al.*, 2003). *Msp5* is highly conserved among *A. marginale* strains and is a single copy
 222 gene, thus providing some advantages as a target for ensuring detection of widely variant strains of *A. marginale*.
 223 However, the related *Anaplasma* spp. and *Ehrlichia* spp. all have *msp5* orthologs with 50% identity to an *E.*
 224 *ruminantium* gene (NCBI accession: L07385.1), thus specificity must be determined in laboratory and field samples.
 225 Additionally, little work has been done to validate an *msp5*-based real-time PCR test for diagnostic purposes.

226 A third primer-probe set is designed to detect *A. marginale* using real-time, reverse transcriptase PCR. The primers
 227 amplify a 16sRNA gene segment from *A. marginale* and *A. phagocytophilum*, while the probe differentiates between
 228 the two species (Reinbold *et al.*, 2010b). The analytical performance of this assay is robust. However, the diagnostic
 229 sensitivity, specificity, and of particular importance with 16sRNA sequence-based tests, exclusivity for other tick-
 230 borne pathogens of cattle have not been evaluated. Additionally, this assay is designed for use following RNA
 231 extraction and reverse transcription, which is more laborious and expensive than DNA extraction. Bacterial RNA is
 232 rapidly degraded, and this may ultimately reduce diagnostic sensitivity of this assay.

233 In regions that use *A. centrale* as a vaccine, it may be useful to differentiate between *A. marginale* and *A. centrale*
 234 infected/vaccinated animals. PCR is best suited for this task. The real-time PCR assay developed by Carelli *et al.*
 235 can also be used in a duplex reaction to detect and differentiate between *A. centrale* and *A. marginale* (Decaro *et al.*,
 236 2008). Primers and probe have been designed to specifically amplify a region of *A. centrale groEL*, but not *A.*
 237 *marginale groEL*, despite 97% sequence identity between the two genes. The *A. marginale*-specific primers and
 238 probes perform similarly in the single and duplex PCR (Carelli *et al.*, 2007). Using the same 51 field samples from
 239 cattle in Italy, the *A. centrale* assay had less analytical sensitivity compared with nested PCR and discordance in 4
 240 of 51 samples between an *A. centrale* reverse line blot test and the duplex PCR assay.

Table 1. Oligonucleotides used in PCR assays to detect *A. marginale* and *A. centrale*

<u>Assay</u>	<u>Reference</u>	<u>Oligonucleotides^(a)</u>	<u>Sequence 5'–3'^(b)</u>	<u>Amplicon size (bp)</u>	<u>NCBI accession number</u>
Real-time PCR	Carelli <i>et al.</i> , 2007	<i>Am_msp1b_F</i>	<u>TTG-GCA-AGG-CAG-CAG-CTT</u>	95	M59845
		<i>Am_msp1b_R</i>	<u>TTC-CGC-GAG-CAT-GTG-CAT</u>		
		<i>Am_msp1b_PB</i>	<u>TCG-GTC-TAA-CAT-CTC-CAG-GCT-TTC-AT</u>		
Real-time PCR	Futse <i>et al.</i> , 2003	<i>Am_msp5_F</i>	<u>GCC-AAG-TGA-TGG-TGA-TAT-CGA</u>	151	M93392
		<i>Am_msp5_R</i>	<u>AGA-ATT-AAG-CAT-GTG-ACC-GCT-G</u>		
		<i>Am_msp5_PB</i>	<u>AAC-GTT-CAT-GTA-CCT-CAT-CAA</u>		
Reverse-transcription real-time PCR	Reinbold <i>et al.</i> , 2010	<i>16S rRNA_F^(c)</i>	<u>CTC-AGA-ACG-AAC-GCT-GG</u>	142	M60313
		<i>16S rRNA_R^(c)</i>	<u>CAT-TTC-TAG-TGG-CTA-TCC-C</u>		
		<i>Am_16S rRNA_PB^(d)</i>	<u>CGC-AGC-TTG-CTG-CGT-GTA-TGG-T</u>		
Real-time PCR ^(d)	Decaro <i>et al.</i> , 2008	<i>Ac_groEL_F^(e, f)</i>	<u>CTA-TAC-ACG-CTT-GCA-TCT-C</u>	77	CP001759.1
		<i>Ac_groEL_R^(e, f)</i>	<u>CGC-TTT-ATG-ATG-TTG-ATG-C</u>		
		<i>Ac_groEL_PB^(e, f)</i>	<u>TCA-TCA-TTC-TTC-CCC-TTT-ACC-TCG-T</u>		

^(a)*Am* denotes *A. marginale*, *Ac* denotes *A. centrale*, *Pb* denotes probe sequence.

^(b)Fluorophores and quenchers not included in probe sequences.

^(c)Amplifies *A. phagocytophilum* and *A. marginale* 16S rRNA gene.

^(d)Probe is specific for *A. marginale* 16S rRNA gene.

^(e)Can be used as a duplex PCR with *msp1b* primers and probe based on Carelli *et al.*, 2007.

^(f)Primers and probe amplify *A. centrale groEL*.

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248 2. Serological tests

249 In general, unless animals have been treated or are at a very early stage of infection (<14 days), serology using the
250 competitive enzyme-linked immunosorbent assay (C-ELISA), indirect ELISA (I-ELISA) or card agglutination test (CAT)
251 (see below) may be the preferred methods of identifying infected animals in most laboratories. *Anaplasma marginale*
252 infections usually persist for the life of the animal. However, except for occasional small recrudescences, *Anaplasma*
253 *A. marginale* initial bodies cannot readily be detected in blood smears after acute rickettsaemia and, even end-point PCR
254 may not detect the presence of *Anaplasma* the pathogen in blood samples from asymptomatic carriers. Thus, a number of
255 serological tests have been developed with the aim of detecting persistently infected animals.

256 A feature of the serological diagnosis of anaplasmosis is the highly variable results with regard to both sensitivity and
257 specificity reported for many of the tests from different laboratories. This is due at least in part to inadequate evaluation
258 validation of the tests using significant numbers of known positive and negative animals. Importantly, the capacity of several
259 assays to detect known infections of long-standing duration has been inadequately addressed. An exception is a C-ELISA
260 (see below), which has been initially validated using true positive and negative animals defined by nested PCR (Torioni
261 De Echaide *et al.*, 1998), and the card agglutination assay, for which relative sensitivity and specificity in comparison with
262 the C-ELISA has been evaluated (Molloy *et al.*, 1999). And updated in 2014 (Chung *et al.*, 2014). Therefore, while most of
263 the tests described in this section are useful for obtaining broad-based epidemiological data, caution is advised on their
264 use for disease certification. The C-ELISA, I-ELISA and CAT are described in detail below.

265 It should be noted that there is a high degree of cross-reactivity between *A. marginale* and *A. centrale*, as well as cross-
266 reactivity with both *A. phagocytophilum* and *Ehrlichia* spp. in serological tests (Al-Adhami *et al.*, 2011; Dreher *et al.*, 2005).
267 While the infecting species can sometimes be identified using antigens from homologous and heterologous species,
268 equivocal results are obtained on many occasions. Efforts have been made to develop tests that differentiate between
269 naturally acquired immunity to *A. marginale* and vaccine acquired immunity due to immunisation with *A. centrale* (Bellezze
270 *et al.*, 2023; Sarli *et al.*, 2020).

271 2.1. Competitive enzyme-linked immunosorbent assay

272 A C-ELISA using a recombinant antigen termed Major surface protein 5 (MSP5) is an immunodominant protein
273 expressed by *A. marginale*, *A. ovis*, and *A. centrale*. In *A. marginale* the gene is highly conserved making it a useful
274 target across broad geographical regions with high *A. marginale* strain diversity (Knowles *et al.*, 1996; Torioni De

275 Echaide et al., 1998). Thus, a C-ELISA based on recombinantly expressed (rMSP5 and MSP5-) in combination with
276 an MSP5-specific monoclonal antibody (mAb) has proven very sensitive and specific for detection of Anaplasma-
277 infected animals (Hofmann-Lehmann et al., 2004; Molloy et al., 1999; Reinbold et al., 2010b; Strik et al., 2007). All
278 A. marginale strains tested, along with Additionally, A. ovis and A. centrale, express the MSP5 antigen and induce
279 infected animals produce antibodies against the immunodominant epitope recognised by the MSP5-specific mAb. A
280 recent report mAb used in the C-ELISA. This C-ELISA was updated in 2014 to improve performance by using
281 glutathione S-transferase (GST) instead of maltose binding protein (MBP) as the tag on the rMSP5 (Chung et al.,
282 2014). This assay no longer requires adsorption to remove the antibodies directed against MBP, thus it is faster and
283 easier than the previous version of the C-ELISA. The diagnostic sensitivity is 100% and the diagnostic specificity is
284 99.7% using a cut-off of 30% inhibition as determined by receiver operating characteristic (ROC) plot (Chung et al.,
285 2014). For this validation, 385 sera defined as negative were from dairy cattle maintained in tick-free facilities from
286 farms with no clinical history of bovine anaplasmosis. The 135 positive sera were from cattle positive for A. marginale
287 using nested PCR and serology.

288 One study suggested that antibodies from cattle experimentally infected with A. phagocytophilum will test positive in
289 the C-ELISA (Dreher et al., 2005). However, in another study no cross-reactivity could be demonstrated, and the mAb
290 used in the assay did not react with A. phagocytophilum MSP5 in direct binding assays (Strik et al., 2007). Cross
291 reactivity has been demonstrated between A. marginale and Ehrlichia spp, in naturally and experimentally infected
292 cattle (Al-Adhami et al., 2011). Earlier studies had shown that the C-ELISA was 100% specific using 261 known
293 negative sera from a non-endemic region, detecting acutely infected cattle as early as 16 days after experimental tick
294 or blood inoculation, and was demonstrated to detect cattle that have been experimentally infected as long as 6 years
295 previously (Knowles et al., 1996). In detecting persistently infected cattle from an anaplasmosis endemic region that
296 were defined as true positive or negative using a nested PCR procedure, the rMSP5 C-ELISA had a sensitivity of
297 96% and a specificity of 95% (Torioni De Echaide et al., 1998). A. marginale and Ehrlichia sp. BOV2010 isolated in
298 Canada, in naturally and experimentally infected cattle (Al-Adhami et al., 2011).

299 Test results using the rMSP5 C-ELISA are available in less than 2.5-hours. A test kit is available commercially that
300 contains specific instructions. Users should follow the manufacturer's instructions. In general, however, it is conducted
301 as follows.

302 **2.1.1. Kit reagents**

- 303 A 96-well microtitre plate coated with rMSP5 antigen,
- 304 A 96-well coated adsorption/transfer plate for serum adsorption to reduce background binding,
- 305 100×Mab peroxidase conjugate,
- 306 40× wash solution and ready-to-use conjugate diluting buffer,
- 307 Ready to use substrate and stop solutions,
- 308 Positive and negative controls

309 **2.1.2. Test procedure**

- 310 i) Add 70 µl of undiluted serum sample to the coated adsorption/transfer plate and incubate at
311 room temperature for 30 minutes.
- 312 ii) Transfer 50 µl per well of the adsorbed undiluted serum to the rMSP5-coated plate and incubate
313 at room temperature for 60 minutes.
- 314 iii) Discard the serum and wash the plate twice using diluted wash solution.
- 315 iv) Add 50 µl per well of the 1× diluted MAb peroxidase conjugate to the rMSP5-coated plate wells,
316 and incubate at room temperature for 20 minutes.
- 317 v) Discard the 1×diluted MAb peroxidase conjugate and wash the plate four times using diluted
318 wash solution.
- 319 vi) Add 50 µl per well of the substrate solution, cover the plate with foil, and incubate for 20 minutes
320 at room temperature.
- 321 vii) Add 50 µl per well of stop solution to the substrate solution already in the wells and gently tap
322 the sides of the plate to mix the wells.
- 323 viii) Immediately read the plate in the plate reader at 620, 630 or 650 nm.

324

2.1.3. Test validation

325

The mean average optical density (OD) of the negative control must range from 0.40 to 2.10. The average per cent inhibition of the positive control must be $\geq 30\%$.

326

327

2.1.4. Interpretation of the results

328

The % inhibition is calculated as follows:

$$100 - \frac{\text{Sample OD} \times 100}{\text{Mean negative control OD}} = \text{Per cent inhibition}$$

329

$$\% \text{ inhibition} = 100[1 - (\text{Sample OD} \div \text{Negative Control OD})]$$

330

Samples with $< 30\%$ inhibition are negative. Samples with $\geq 30\%$ inhibition are positive.

331

Specificity of the MSP5 C-ELISA may be increased by using a higher percentage inhibition cut-off value (Bradway *et al.*, 2001); however the effect of this change on sensitivity has not been thoroughly evaluated.

332

333

Recently, an improved MSP5 C-ELISA was developed by replacing rMBP-MSP5 with rGST-MSP5 in addition to an improvement in the antigen coating method by using a specific catcher system. The new rMSP5-GST C-ELISA was faster, simpler, had a higher specificity and an improved resolution compared with the rMSP5-MBP C-ELISA with MBP adsorption (Chung *et al.*, 2014).

334

335

336

337

2.2. Indirect enzyme-linked immunosorbent assay

338

An I-ELISA was first developed using the CAT antigen, which is a crude *A. marginale* lysate (see below), and it The test can be implemented where the commercial C-ELISA is not available. Unlike the C-ELISA, most reagents, such as buffers and ready-to dissolve substrates, are available commercially in many countries. Any laboratory can prepare the antigen using local strains of *A. marginale*, though standardised methods have not been developed. I-ELISA uses small amounts of serum and antigen that and the sensitivity and specificity of the test standardised with true positive and negative sera is as good as for the C-ELISA. As it can be prepared in each laboratory, Only the general procedure is described here (Barry *et al.*, 1986). For commercial kits, the manufacturer's instructions should be followed. In the case of in-house I-ELISA The sensitivity and specificity of the test was 87.3% and 98.4–99.6% respectively, though this varied by laboratory (Nielsen *et al.*, 1996). For general methods, refer to Barry *et al.* (1986). Initial bodies and membranes are obtained as for the complement fixation test (Rogers *et al.*, 1964). This antigen is treated with 0.1% sodium dodecyl sulphate for 30 minutes prior to fixing the antigen to the microtitre plate. For each laboratory, the specific amount of antigen has to must be adjusted optimised to obtain the best reading and the least expenditure.

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Alternatively, rMSP5 can be used as the antigen in this test. This eliminates the need for preparation and standardisation of antigen derived from splenectomised, *A. marginale* infected animals (Silva *et al.*, 2006). In a comparison between I-ELISA using the CAT antigen and rMSP with a histidine tag (rMSP5-HIS), these two I-ELISAs performed identically. In this comparison, IFAT was used as the gold standard test (Silva *et al.*, 2006).

351

352

353

354

Test results using the I-ELISA are available in about 4 to 5 hours. It is generally conducted as follows:

355

2.2.1. Test reagents

356

A 96-well microtitre plate coated with ~~crude~~ *A. marginale* antigen,

357

PBS/Tween buffer, (PBS 0.1 M, pH 7.2, Tween 20 0.05%),

358

Blocking reagent (e.g. commercial dried skim milk)

359

Tris buffer 0.1 M, MgCl₂, 0.1 M, NaCl, 0.05 M, pH 9.8

360

Substrate *p*-Nitrophenyl phosphate disodium hexahydrate

361

Positive and negative controls.

-
- 362 **2.2.2. Test procedure (this test is run in triplicate)**
- 363 i) Plates can be prepared ahead of time and kept under airtight conditions at -20°C .
- 364 ii) Carefully remove the plastic packaging before using plates, being careful not to touch the bottom
- 365 of them as this can distort the optical density reading.
- 366 iii) Remove the lid and deposit 200 μl PBST20 solution in each well and incubate for 5 minutes at
- 367 room temperature (RT).
- 368 iv) For one plate, dissolve 1.1 g of skim milk (blocking agent) in 22 ml of PBST20.
- 369 v) Remove the plate contents and deposit in each well 200 μl of blocking solution, put the lid on
- 370 and incubate for 60 minutes at 37°C .
- 371 vi) Wash the plate three times for 5 minutes with PBST20.
- 372 vii) Dilute all serum samples including controls 1/100 in PBST20 solution.
- 373 viii) Remove the contents of the plate and deposit 200 μl of diluted serum in each of the three wells
- 374 for each dilution, starting with the positive and negative and blank controls.
- 375 ix) Incubate plate at 37°C covered for 60 minutes.
- 376 x) Wash three times as described in subsection vi.
- 377 xi) Dilute 1/1000 anti-IgG bovine alkaline phosphatase conjugate in PBST20 solution. Add 200 μl
- 378 of the diluted conjugate per well. Incubate the covered plate at 37°C for 60 minutes.
- 379 xii) Remove the lid and wash three times as described in point vi above ~~make three washes with~~
- 380 ~~PBST20.~~
- 381 xiii) Remove the contents of the plate and deposit 195 μl of 0.075% *p*-Nitrophenyl phosphate
- 382 disodium hexahydrate in Tris buffer in each well and incubate for 60 minutes at 37°C .
- 383 xiv) The reaction is quantified by a microplate reader spectrophotometer, adjusted to 405 nm
- 384 wavelength. The data are expressed in optical density (OD).

385 **2.2.3. Data analysis**

386 Analysis of results should take into account the following parameters.

- 387 i) The mean value of the blank wells.
- 388 ii) The mean value of the positive wells with their respective standard deviations.
- 389 iii) The mean value of negative wells with their respective standard deviations.
- 390 iv) The mean value of the blank wells is subtracted from the mean of all the other samples if not
- 391 automatically subtracted by the ELISA reader.
- 392 v) Control sera are titrated to give optical density values ranging from 0.90 to 1.50 for the positive
- 393 and, 0.15 to 0.30 for the negative control.

394 Positive values are those above the cut-off calculated value which is the sum of the average of the

395 negative and two times the standard deviation.

396 ~~For purposes of assessing the consistency of the test operator, the error "E" must also be estimated;~~

397 ~~this is calculated by determining the percentage represented by the standard deviation of any against~~

398 ~~their mean serum.~~

399 As with all diagnostic tests, it is important to measure reproducibility. For more details see Chapter

400 2.2.4 Measurement uncertainty.

401 **2.3. Displacement double-antigen sandwich ELISA to differentiate between *A. marginale* and**

402 ***A. centrale* antibodies**

403 In regions where vaccination with *A. centrale* is used to control bovine anaplasmosis, differentiation between

404 *A. centrale*-vaccinated and *A. marginale*-infected animals may be useful. Because there is often high amino acid

405 identity between *A. marginale* and *A. centrale* surface proteins, identifying unique targets for serological assays for

406 this purpose is difficult. Epitopes from MSP5 (aa28-210, without the transmembrane region) that are not shared

407 between *A. marginale* and *A. centrale* were used to develop a displacement double-antigen sandwich ELISA

408 (ddasELISA) (Bellezze *et al.*, 2023; Sarli *et al.*, 2020). The recombinant MSP5 epitopes from *A. marginale* or *A.*
409 *centrale* are expressed in *E. coli* with a histidine tag and purified. The ELISA plates are then coated with either the
410 recombinant *A. marginale* MSP5 epitope, or the *A. centrale* MSP5 epitope and blocked. Serum is added to the wells
411 and allowed to incubate. Following washing, a combination of biotinylated and non-biotinylated recombinant proteins
412 are added to improve specificity of the reaction (see below for specifics). The protein–biotin binding to the serum
413 antibody is detected with a peroxidase-streptavidin based detection system. The optical density for the *A. marginale*
414 MSP5-coated well (ODAm) and the OD for the *A. centrale* MSP5 (ODAc) coated well for each animal is measured. If
415 the OD for either target is <0.2, the sample is excluded from the analysis. For the remaining samples, the ratio
416 between the OD values (ODAm/ODAc) is calculated. If the ratio is >0.38 the sample is considered positive for anti-
417 *A. marginale* antibodies, and a ratio ≤ 0.38 is classified as vaccinated with *A. centrale*.

418 For the detection of *A. marginale* the test has a diagnostic specificity of 98% and a diagnostic sensitivity of 98.9%.
419 For 702 field samples evaluated, 131 (19%) had an OD <0.2 in the ddasELISA and thus were excluded from the
420 analysis. Of those animals, 52% were nested PCR positive for *A. marginale*, 23% were nested PCR positive for *A.*
421 *centrale*, 4.6% were nested PCR positive for *A. marginale* and *A. centrale*, 20% were nested PCR negative for both,
422 suggesting the ddasELISA may lack sensitivity.

423 Of the 571 ddasELISA positive field samples, the agreement between the ddasELISA and nested PCR was 84% and
424 the kappa coefficient was 0.70 (95% CI: 0.635–0.754), indicating substantial agreement between tests. There was
425 agreement between the ddasELISA and nested PCR for 93% of the *A. marginale* ddasELISA positive samples and
426 86% of the *A. centrale* ddasELISA positive samples. Additionally, 36 nested PCR negative samples tested positive
427 for antibodies against *A. marginale* (n=28) or *A. centrale* (n=8) by ddasELISA. This test could not identify animals
428 with co-infections, meaning animals vaccinated with *A. centrale* that are then infected with *A. marginale*, which is not
429 uncommon.

430 Test results using the ddasELISA are available in 5–6 hours. It is conducted as outlined below, see Bellezze *et al.*,
431 2023 for more details.

432 2.3.1. Test reagents

- 433 i) A 96-well microtitre plate coated with either *A. marginale* or *A. centrale* recombinant protein
- 434 ii) PBS/Tween buffer (PBS (50mM sodium phosphate, 150 mM NaCl, pH 7.2) with 0.05% Tween-
435 20)
- 436 iii) Blocking reagent (PBS with 10% commercial dried skim milk)
- 437 iv) Purified recombinant *A. marginale* MSP5 epitopes and *A. centrale* epitopes
- 438 v) Biotinylated recombinant *A. marginale* MSP5 epitopes and *A. centrale* epitopes
- 439 vi) Streptavidin-horse radish peroxidase (HRP) detection system
- 440 vii) Chromogenic substrate (1 mM 2,2'-Azinobis [3-ethylbenzothiazoline-6-sulfonic acid]-
441 diammonium salt in 0.05 M sodium citrate, pH 4.5, 0.0025% V/V H₂O₂ (100 µl/well).
- 442 viii) ELISA plate reader (405 nm reading)
- 443 ix) Positive and negative control sera for *A. marginale* and *A. centrale*

444 2.3.2. Test procedure

- 445 i) Plates are coated overnight.
- 446 ii) Block with blocking buffer for 1 hour at room temperature and wash three times with PBS/Tween
447 buffer.
- 448 iii) Add undiluted serum 100 µl/well and incubate for 1 hour at 25°C at 100 rpm.
- 449 iv) Wash three times with PBS/Tween buffer.
- 450 v) Add 100 µl of *A. marginale* MSP5-biotin (1 µg/ml) plus *A. centrale* MSP5 (10 µg/ml) to
451 *A. marginale* test wells. Add *A. centrale* MSP5-biotin (1 µg/ml) plus *A. marginale* MSP5
452 (10 µg/ml) in PBS/Tween buffer + 10% fat-free dried milk to *A. centrale* test wells.
- 453 vi) Incubate 1 hour at 25°C, 100 rpm and wash the plate five times with PBS/Tween buffer.
- 454 vii) To detect the bound protein–biotin complex, add streptavidin-HRP diluted in 1/500 in
455 PBS/Tween buffer with 10% dried milk for 1 hour at 25°C, 100 rpm.
- 456 viii) Wash five times with PBS/Tween buffer.

-
- 457 ix) Add chromogenic substrate based on manufacturer's instructions.
- 458 x) The reaction is measured by microplate reader spectrophotometer at 405 nm wavelength. The
459 data are expressed in optical density (OD).
- 460 xi) OD_{405nm} <0.2 is considered negative.
- 461 xii) Results are expressed as the ratio between antibodies specific for *A. marginale* MSP5 and for
462 *A. centrale* MSP5 (ODAm/ODAc). If the ratio is >0.38 the sample is considered positive for anti-
463 *A. marginale* antibodies, and a ratio ≤ 0.38 is classified as vaccinated with *A. centrale*.

464 2.4. Card agglutination test

465 ~~The advantages of the CAT are that it is sensitive.~~ The sensitivity of the CAT is from 84% to 98% (Gonzalez *et al.*,
466 1978; Molloy *et al.*, 1999) and the specificity is 98.6% (Molloy *et al.*, 1999). Though sometimes giving variable results,
467 the CAT can be useful under certain circumstances, as it may be undertaken either in the laboratory or in the field,
468 and it gives a result within a few minutes. Nonspecific reactions may be a problem, and subjectivity in interpreting
469 assay reactions can result in variability in test interpretation. In addition, the CAT antigen, which is a ~~suspension~~
470 lysate of *A. marginale* particles isolated from erythrocytes, can be difficult to prepare and can vary from batch to batch
471 and laboratory to laboratory. To obtain the antigen, splenectomised calves are infected by intravenous inoculation
472 with blood containing ~~Anaplasma~~ *A. marginale*-infected erythrocytes. When the rickettsaemia exceeds 50%, the
473 animal is exsanguinated, the infected erythrocytes are washed, lysed, and the erythrocyte ghosts and ~~Anaplasma~~
474 particles *A. marginale* are pelleted. The pellets are sonicated, washed, and then resuspended in a stain solution to
475 produce the antigen suspension.

476 A test procedure that has been slightly modified from that originally described (Amerault & Roby, 1968; Amerault *et*
477 *al.*, 1972) is as follows, and is based on controlled conditions in a laboratory setting:

478 2.4.1. Test procedure

- 479 i) Ensure all test components are at a temperature of 25–26°C before use (this constant
480 temperature is critical for the test).
- 481 ii) On each circle of the test card (a clear perspex/plastic or glass plate marked with circles that
482 are 18 mm in diameter), place next to each other, but not touching, 10 µl of bovine serum factor
483 (BSF), 10 µl of test serum, and 5 µl of CAT antigen³⁹. Negative and low positive control sera
484 must be tested on each card.
- 485 iii) BSF is serum from a selected animal with high known conglutinin level. If the conglutinin level
486 is unknown, fresh serum from a healthy animal known to be free from *Anaplasma* can be used.
487 The BSF must be stored at –70°C in small aliquots, a fresh aliquot being used each time the
488 tests are performed. The inclusion of BSF improves the sensitivity of the test.
- 489 iv) Mix well with a glass stirrer. After mixing each test, wipe the stirrer with clean tissue to prevent
490 cross-contamination.
- 491 v) Place the test card in a humid chamber and rock at 100–110 rpm for 7 minutes.
- 492 vi) Read immediately against a backlight. Characteristic clumping of the antigen (graded from +1
493 to +3) is considered to be a positive result. The test is considered to give a negative result when
494 there is no characteristic clumping.

495 A latex card agglutination test, a relatively simple and rapid test platform, has been partially validated.
496 This test uses rMSP5-HIS rather than *A. marginale* lysate and does not require BSF. The
497 performance of this test was compared with that of the I-ELISA using rMSP5-HIS as the antigen. The
498 relative sensitivity was 95.2% and relative specificity was 91.86% (Ramos *et al.*, 2014).

39 The test as conducted in the USA and Mexico uses larger volumes of reagents: antigen (15 µl), serum (30 µl), and bovine serum factor (30 µl), and a 4-minute reaction time (see step iv).

499

2.4. Complement fixation test

500 The complement fixation (CF) test has been used extensively for many years; however, it shows variable sensitivity
501 (ranging from 20 to 60%), possibly reflecting differences in techniques for antigen production, and poor reproducibility.
502 In addition, it has been demonstrated that the CF assay fails to detect a significant proportion of carrier cattle (Bradway
503 *et al.*, 2001). It is also uncertain as to whether or not the CF test can identify antibodies in acutely infected animals
504 prior to other assays (Coetzee *et al.*, 2007; Molloy *et al.*, 1999). Therefore, the CF test is no longer recommended as
505 a reliable assay for detecting infected animals.

506

2.5. Indirect fluorescent antibody test

507 Because of the limitations on the number of indirect fluorescent antibody (IFA) tests that can be performed daily by
508 one operator, other serological tests are generally preferred to the IFA test. The IFA test is performed as described
509 for bovine babesiosis in chapter 3.4.2, except that *A. marginale* infected blood is used for the preparation of antigen
510 smears. A serious problem encountered with the test is nonspecific fluorescence. The reported sensitivity is 97.6%
511 and specificity 89.6% (Gonzalez *et al.*, 1978). Antigen made from blood collected as soon as adequate rickettsaemia
512 (5–10%) occurs is most likely to be suitable. Nonspecific fluorescence due to antibodies adhering to infected
513 erythrocytes can be reduced by washing the erythrocytes in an acidic glycine buffer before antigen smears are
514 prepared. Infected erythrocytes are washed twice in 0.1 M glycine buffer (pH 3.0, centrifuged at 1000 *g* for 15 minutes
515 at 4°C) and then once in PBS, pH 7.4. Recently published data show that the IFA, like the C-ELISA, can cross react
516 with other members of the *Anaplasmataceae* family, and specifically an *Ehrlichia* spp. identified as BOV2010 (Al-
517 Adhami *et al.*, 2011).

518

2.6. Complement fixation test

519 The complement fixation test (CFT) was used extensively for many years; however, it has variable sensitivity (ranging
520 from 20 to 60%), possibly reflecting differences in techniques for antigen production, and poor reproducibility. In
521 addition, the CF assay fails to detect a significant proportion of carrier cattle (Bradway *et al.*, 2001). It is also uncertain
522 as to whether or not the CF test can identify antibodies in acutely infected animals prior to other assays (Coetzee *et*
523 *al.*, 2007; Molloy *et al.*, 1999). Therefore, the CF test is no longer recommended as a reliable assay for detecting
524 infected animals.

525

C. REQUIREMENTS FOR VACCINES

526

1. Background

527 Several immunisation methods have been used to protect cattle against anaplasmosis in countries where the disease is
528 endemic, but none is ideal to date (McHardy, 1984). A review of *A. marginale* vaccines and antigens has been published
529 (Kocan *et al.*, 2003–2010; Noh *et al.*, 2012). Use of the less pathogenic *A. centrale*, which gives partial cross-protection
530 against *A. marginale*, is the most widely accepted method, although not used in many countries ~~where the disease is~~
531 ~~exotic~~, including north America.

532 In this section, the production of live *A. centrale* vaccine is described. It involves infection of a susceptible, splenectomised
533 calf and the use of its blood as a vaccine. Detailed accounts of the production procedure are available and reference should
534 be made to these publications for details of the procedures outlined here (Bock *et al.*, 2004; de Vos & Jorgensen, 1992;
535 Pipano, 1995).

536 Guidelines for the production of veterinary vaccines are given in Chapter 1.1.8 *Principles of veterinary vaccine production*.
537 The guidelines given here and in Chapter 1.1.8 are intended to be general in nature and may be supplemented by national
538 and regional requirements.

539 *Anaplasma centrale* vaccine can be provided in either frozen or chilled form depending on demand, transport networks,
540 and the availability of liquid nitrogen or dry ice supplies. Frozen vaccine is recommended in most instances, as it allows
541 for thorough post-production quality control of each batch. It is, however, more costly to produce and more difficult to
542 transport than chilled vaccine. The risk of contamination makes post-production control essential, but may be prohibitively
543 expensive.

544 2. Outline of production and minimum requirements for conventional vaccines

545 2.1. Characteristics of the seed

546 2.1.1. Biological characteristics

547 *Anaplasma centrale* was isolated in 1911 in South Africa and has been used as a vaccine in South
548 America, Australia, Africa, the Middle East, and South-East Asia. It affords only partial, but adequate,
549 protection in regions where the challenging-circulating strains are of moderate virulence (e.g.
550 Australia) (Bock & de Vos, 2001). In the humid tropics where *A. marginale* ~~appears to~~ may be a very
551 more virulent rickettsia, the protection afforded by *A. centrale* may be inadequate to prevent disease
552 in some animals.

553 *Anaplasma centrale* usually causes benign infections, especially if used in calves under 9 months of
554 age. Severe reactions following vaccination have been reported when adult cattle are inoculated. The
555 suitability of an isolate of *A. centrale* as a vaccine can be determined by inoculating susceptible cattle,
556 monitoring the subsequent reactions, and then challenging the animals and susceptible controls with
557 a virulent local strain of *A. marginale*. Both safety and efficacy can be judged by monitoring
558 rickettsaemias in stained blood films and the depression of packed cell volumes of inoculated cattle
559 during the vaccination and challenge reaction periods.

560 Infective material for preparing the vaccine is readily stored as frozen stabilates of infected blood in
561 liquid nitrogen or dry ice. Dimethyl sulphoxide (DMSO) ~~and~~ or polyvinylpyrrolidone M.W. 40,000
562 (Bock *et al.*, 2004) are the recommended cryopreservatives, as they allow for intravenous
563 administration after thawing of the stabilate. A detailed account of the freezing technique using DMSO
564 is reported elsewhere (Mellors *et al.*, 1982), but briefly involves the following: infected blood is
565 collected, chilled to 4°C, and cold cryoprotectant (4 M DMSO in PBS) is added slowly with stirring to
566 a final blood:protectant ratio of 1:1, to give a final concentration of 2 M DMSO. The entire dilution
567 procedure is carried out in an ice bath and the diluted blood is dispensed into suitable containers
568 (e.g. 5 ml cryovials), and frozen, as soon as possible, in the vapour phase of a liquid nitrogen
569 container.

570 2.1.2. Quality criteria

571 Evidence of purity of the *A. centrale* isolate can be determined by serological testing of paired sera
572 from the cattle used in the safety test for possible ~~contaminants~~ pathogens that may be present (Bock
573 *et al.*, 2004; Pipano, 1997). Donor calves used to expand the seed for vaccine production should be
574 examined for all blood-borne infections prevalent in the vaccine-producing country, including
575 *Babesia*, *Anaplasma*, *Ehrlichia*, *Theileria* and *Trypanosoma*. This can be done by routine examination
576 of stained blood films after splenectomy, PCR, and preferably also by serology. Any calves showing
577 evidence of natural infections of any of these agents should be rejected. The absence of other
578 infective agents should also be confirmed. These may include the agents of enzootic bovine leukosis,
579 mucosal disease, infectious bovine rhinotracheitis, ephemeral fever, Akabane disease, bluetongue,
580 and foot and mouth disease, ~~and rinderpest~~. The testing procedures will depend on the diseases
581 prevalent in the country and the availability of tests but should involve serology of paired sera at the
582 very least and, in some cases, virus isolation, antigen, or DNA/RNA detection (Bock *et al.*, 2004;
583 Pipano, 1981; 1997).

584 2.2. Method of manufacture

585 2.2.1. Procedure

586 i) Production of frozen vaccine

587 Quantities of the frozen stabilate (5–10 ml) are thawed by immersing the vials in water preheated to
588 40°C. The thawed material is kept on ice and used as soon as possible (within 30 minutes) to infect
589 a susceptible, splenectomised calf by intravenous inoculation.

590 The rickettsaemia of ~~the~~ this donor calf is monitored daily by examining stained films of jugular blood,
591 and the blood is collected for vaccine production when suitable rickettsaemias are reached. A
592 rickettsaemia of 1×10^8 /ml (approximately 2% rickettsaemia in jugular blood) is the minimum required
593 for production of vaccine as this is the dose to vaccinate a bovine. If a suitable rickettsaemia is not
594 obtained, passage of the strain by subinoculation of 100–200 ml of blood to a second splenectomised
595 calf may be necessary.

596 Blood from the donor is collected by aseptic jugular or carotid cannulation using heparin as an
597 anticoagulant (5 International Units [IU] heparin/ml blood). The use of blood collection units for human
598 use are also suitable and guarantee sterility and obviate the need to prepare glass flasks that make
599 the procedure more cumbersome.

600 In the laboratory, the infective blood is mixed in equal volumes with 3 M glycerol in PBS supplemented
601 with 5 mM glucose at 37°C (final concentration of glycerol 1.5 M). The mixture is then equilibrated at
602 37°C for 30 minutes and dispensed into suitable containers (e.g. 5 ml cryovials). The vials are cooled
603 at approximately 10°C/minute in the vapour phase of liquid nitrogen and, when frozen, stored in the
604 liquid phase (Bock *et al.*, 2004).

605 DMSO can be used as a cryoprotectant in the place of glycerol. This is done in the same way as
606 outlined for the preparation of seed stabilate (Mellors *et al.*, 1982; Pipano, 1981).

607 If glycerolised vaccine is to be diluted, the diluent should consist of PBS with 1.5 M glycerol and 5 mM
608 glucose (Jorgensen *et al.*, 1989). Vaccine cryopreserved with DMSO should be diluted with diluent
609 containing the same concentration of DMSO as in the original cryopreserved blood (Pipano *et al.*,
610 1986).

611 ii) Production of chilled vaccine

612 Infective material for chilled vaccine is prepared in the same way as for frozen vaccine, but it must
613 be issued and used as soon as possible after collection. The infective blood can be diluted to provide
614 1×10^7 parasites per dose of vaccine. A suitable diluent is 10% sterile bovine serum in a
615 glucose/balanced salt solution containing the following quantities per litre: NaCl (7.00 g), MgCl₂.6H₂O
616 (0.34 g), glucose (1.00 g), Na₂HPO₄(2.52 g), KH₂PO₄(0.90 g), and NaHCO₃(0.52 g).

617 If diluent is not available, acid citrate dextrose (20% [v/v]) or citrate phosphate dextrose (20% [v/v])
618 should be used as anticoagulant to provide the glucose necessary for survival of the organisms.

619 iii) Use of vaccine

620 In the case of frozen vaccine, vials should be thawed by immersion in water, preheated to 37°C to
621 40°C, and the contents mixed with suitable diluent to the required dilution. If glycerolised vaccine is
622 prepared, it should be kept cool and used within 8 hours (Bock *et al.*, 2004). If DMSO is used as a
623 cryoprotectant, the prepared vaccine should be kept on ice and used within 15–30 minutes (Pipano,
624 1981). The vaccine is most commonly administered subcutaneously.

625 iv) Chilled vaccine should be kept refrigerated and used within 4–7 days of preparation.

626 The strain of *A. centrale* used in the vaccine is of reduced virulence, but is not entirely safe. A practical
627 recommendation is, therefore, to limit the use of vaccine to calves, where nonspecific immunity will
628 minimise the risk of vaccine reactions. When older animals have to be vaccinated, there is a risk of
629 severe reactions. These reactions occur infrequently, but valuable breeding stock or pregnant
630 animals obviously warrant close attention, –and should be observed daily for 3 weeks post-
631 vaccination. Clinically sick animals should be treated with oxytetracycline or imidocarb at dosages
632 recommended by the manufacturers. Protective immunity develops in 6–8 weeks and usually lasts
633 for several years.

634 Anaplasmosis and babesiosis vaccines are often used concurrently, but it is not advisable to use any
635 other vaccines at the same time (Bock *et al.*, 2004).

636 2.2.2. Requirements for substrates and media

637 *Anaplasma centrale* ~~cannot~~ can be cultured in vitro ~~in~~ *Rhipicephalus appendiculatus* and *Dermacentor variabilis*
638 ~~cells lines, though antigen expression and immunogenicity of the cultured *A. centrale* need to be tested (Bell-~~
639 ~~Sakyi *et al.*, 2015).~~ No substrates or media other than buffers and diluents are used in vaccine production.
640 DMSO or glycerol should be purchased from reputable companies.

641 2.2.3. In-process controls

642 i) Source and maintenance of vaccine donors

643 A source of calves free from natural infections of ~~*Anaplasma*~~ *A. marginale* and other tick-borne
644 diseases should be identified. If a suitable source is not available, it may be necessary to breed the
645 calves under tick-free conditions specifically for the purpose of vaccine production.

646 The calves should be maintained under conditions that will prevent exposure to infectious diseases
647 and to ticks and biting insects. In the absence of suitable facilities, the risk of contamination with the
648 agents of infectious diseases present in the country involved should be estimated, and the benefits
649 of local production of vaccine weighed against the possible adverse consequences of spreading
650 disease (Bock *et al.*, 2004).

651 ii) Surgery

652 Donor calves should be splenectomised to allow maximum yield of organisms for production of
653 vaccine. This is best carried out in young calves and under general anaesthesia.

654 iii) Screening of vaccine donors before inoculation

655 As for preparation of seed stabilate, donor calves for vaccine production should be examined for all
656 blood-borne infections prevalent in the vaccine-producing country, including *Babesia*, *Anaplasma*,
657 *Ehrlichia*, *Theileria* and *Trypanosoma*. This can be done by routine examination of stained blood films
658 after splenectomy, and preferably also by serology. Any calves showing evidence of natural infections
659 of any of these agents should be rejected. The absence of other infective agents should also be
660 confirmed. These may include the agents of enzootic bovine leukosis, bovine viral diarrhoea,
661 infectious bovine rhinotracheitis, ephemeral fever, Akabane disease, bluetongue, and foot and mouth
662 disease. The testing procedures will depend on the diseases prevalent in the country and the
663 availability of tests, but should involve serology of paired sera at the very least and, in some cases,
664 virus isolation, antigen, or DNA/RNA detection (Bock *et al.*, 2004; Pipano, 1981; 1997).

665 iv) Monitoring of rickettsaemias following inoculation

666 It is necessary to determine the concentration of rickettsia in blood being collected for vaccine. The
667 rickettsial concentration can be estimated from the erythrocyte count and the rickettsaemia
668 (percentage of infected erythrocytes).

669 v) Collection of blood for vaccine

670 All equipment should be sterilised before use (e.g. by autoclaving). Once the required rickettsaemia
671 is reached, the blood is collected in heparin using strict aseptic techniques. This is best done if the
672 calf is sedated and with the use of a closed-circuit collection system.

673 Up to 3 litres of heavily infected blood can be collected from a 6-month-old calf. If the calf is to live,
674 the transfusion of a similar amount of blood from a suitable donor is indicated. Alternatively, the calf
675 should be killed immediately after collection of the blood.

676 vi) Dispensing of vaccine

677 All procedures are performed in a suitable environment, such as a laminar flow cabinet, using
678 standard sterile techniques. Use of a mechanical or magnetic stirrer will ensure thorough mixing of
679 blood and diluent throughout the dispensing process. Penicillin (500,000 IU/litre) and streptomycin
680 (370,000 µg/litre) are added to the vaccine at the time of dispensing.

681 **2.2.4. Final product batch tests**

682 The potency, safety and sterility of vaccine batches cannot be determined in the case of chilled vaccine, and
683 specifications for frozen vaccine depend on the country involved. The following are the specifications for frozen
684 vaccine produced in Australia.

685 i) Sterility and purity

686 Standard tests for sterility are employed for each batch of vaccine and diluent (see Chapter 1.1.9
687 *Tests for sterility and freedom from contamination of biological materials intended for veterinary use*).

688 The absence of contaminants is determined by doing appropriate serological testing of donor cattle,
689 by inoculating donor lymphocytes into sheep and then monitoring them for evidence of viral infection,
690 and by inoculating cattle and monitoring them serologically for infectious agents that could potentially
691 contaminate the vaccine. Cattle inoculated during the test for potency (see Section C.2.2.4.iii) are
692 suitable for the purpose. Depending on the country of origin of the vaccine, these agents include the
693 causative organisms of enzootic bovine leukosis, infectious bovine rhinotracheitis, bovine viral
694 diarrhoea, ephemeral fever, Akabane disease, Aino virus, bluetongue, parainfluenza, foot and mouth
695 disease, lumpy skin disease, rabies, Rift Valley fever, contagious bovine pleuropneumonia,
696 Jembrana disease, heartwater, pathogenic *Theileria* and *Trypanosoma spp.*, *Brucella abortus*,

697 *Coxiella*, and *Leptospira* (Bock *et al.*, 2004; Pipano, 1981; 1997). Other pathogens to consider include
698 the causal agents of bovine tuberculosis and brucellosis as they may spread through contaminated
699 blood used for vaccine production. Most of these agents can be tested by means of specific PCR and
700 there are many publications describing primers, and assay conditions for any particular disease.

701 ii) Safety

702 Vaccine reactions of the cattle inoculated in the test for potency (see Chapter 1.1.8 *Principles of*
703 *veterinary vaccine production*) are monitored by measuring rickettsaemia and depression of packed
704 cell volume. Only batches with pathogenicity levels equal to or lower than a predetermined standard
705 are released for use.

706 iii) Potency

707 Vaccine is thawed and diluted 1/5 with a suitable diluent (Bock *et al.*, 2004). The diluted vaccine is
708 then incubated for 8 hours at 4°C, and five cattle are inoculated subcutaneously with 2 ml doses. The
709 inoculated cattle are monitored for the presence of infections by examination of stained blood smears.
710 All should become infected for a batch to be accepted. A batch proving to be infective is
711 recommended for use at a dilution of 1/5 with isotonic diluent.

712 **2.3. Requirements for authorisation**

713 **2.3.1. Safety**

714 The strain of *A. centrale* used in vaccine is of reduced virulence but is not entirely safe. A practical
715 recommendation is, therefore, to limit the use of vaccine to calves, where nonspecific immunity will
716 minimise the risk of vaccine reactions. When older animals have to be vaccinated, there is a risk of
717 severe reactions. These reactions occur infrequently, but valuable breeding stock or pregnant
718 animals obviously warrant close attention, and should be observed daily for 3 weeks post-
719 vaccination. Clinically sick animals should be treated with oxytetracycline or imidocarb at dosages
720 recommended by the manufacturers.

721 *Anaplasma centrale* is not infective to other species, and the vaccine is not considered to have other
722 adverse environmental effects. The vaccine is not infective for humans. When the product is stored
723 in liquid nitrogen, the usual precautions pertaining to the storage, transportation and handling of deep-
724 frozen material applies.

725 **2.3.2. Efficacy requirements**

726 ~~Partial but long-lasting immunity results from one inoculation. There is no evidence that repeated~~
727 ~~vaccination will have a boosting effect. Immunisation with live *A. centrale* results in long-term infection~~
728 ~~of the vaccinee, thus repeated vaccination is unnecessary. Infection with *A. centrale* does not prevent~~
729 ~~subsequent infection with *A. marginale*, but does at least result in protection from disease (Shkap *et*~~
730 ~~*al.*, 2009).~~ The vaccine is used for control of clinical anaplasmosis in endemic areas. It will not provide
731 sterile immunity, and should not be used for eradication of *A. marginale*.

732 **2.3.3. Stability**

733 The vaccine can be kept for 5 years when stored in liquid nitrogen. Once thawed, it rapidly loses its
734 potency. Thawed vaccine cannot be refrozen.

735 **3. Vaccines based on biotechnology**

736 There are no vaccines based on biotechnology available for anaplasmosis.

737 **REFERENCES**

738 AL-ADHAMI B., SCANDRETT W.B., LOVANOV V.A. & GAJADHAR A.A. (2011). Serological cross reactivity between *Anaplasma*
739 *marginale* and *Ehrlichia* species in naturally and experimentally infected cattle. *J. Vet. Diagn. Invest.*, **23**, 1181–1188.

740 AMERAULT T.E. & ROBY T.O. (1968). A rapid card agglutination test for bovine anaplasmosis. *J. Am. Vet. Med. Assoc.*, **153**,
741 1828–1834.

-
- 742 AMERAULT T.E., ROSE J.E. & ROBY T.O. (1972). Modified card agglutination test for bovine anaplasmosis: evaluation with
743 serum and plasma from experimental and natural cases of anaplasmosis. *Proc. U.S. Anim. Health Assoc.*, **76**, 736–744.
- 744 BARRY D.N., PARKER R.J., DE VOS A.J., DUNSTER P. & RODWELL B.J. (1986). A microplate enzyme-linked immunosorbent
745 assay for measuring antibody to *Anaplasma marginale* in cattle serum. *Aust. Vet. J.*, **63**, 76–79.
- 746 BELL-SAKYI L., PALOMAR A.M., BRADFORD E.L. & SHKAP V. (2015). Propagation of the Israeli vaccine strain of *Anaplasma*
747 *centrale* in tick cell lines. *Vet. Microbiol.*, **179**, 270–276.
- 748 BELLEZZE J., THOMPSON C.S., BOSIO A.S., TORIONI S.M. & PRIMO M.E. (2023). Development and field evaluation of an ELISA
749 to differentiate *Anaplasma marginale*-infected from *A. centrale*-vaccinated cattle. *J. Vet. Diagn. Invest.*, **35**, 204–208.
- 750 BOCK R., JACKSON L., DE VOS A. & JORGENSEN W. (2004). Babesiosis of cattle. *Parasitology*, **129**, Suppl, S247–269.
- 751 BOCK R.E. & DE VOS A.J. (2001). Immunity following use of Australian tick fever vaccine: a review of the evidence. *Aust.*
752 *Vet. J.*, **79**, 832–839.
- 753 BRADWAY D.S., TORIONI DE ECHAIDE S., KNOWLES D.P., HENNAGER S.G. & MCELWAIN T.F. (2001). Sensitivity and specificity of
754 the complement fixation test for detection of cattle persistently infected with *Anaplasma marginale*. *J. Vet. Diagn. Invest.*,
755 **13**, 79–81.
- 756 CARELLI G., DECARO N., LORUSSO A., ELIA G., LORUSSO E., MARI V., CECI L. & BUONAVOGLIA C. (2007). Detection and
757 quantification of *Anaplasma marginale* DNA in blood samples of cattle by real-time PCR. *Vet. Microbiol.*, **124**, 107–114.
- 758 COETZEE J.F., SCHMIDT P.L., APLEY M.D., REINBOLD J.B. & KOCAN K.M. (2007). Comparison of the complement fixation test
759 and competitive ELISA for serodiagnosis of *Anaplasma marginale* infection in experimentally infected steers. *Am. J. Vet.*
760 *Res.*, **68**, 872–878.
- 761 CHUNG C., WILSON C., BANDARANAYAKA-MUDIYANSELAGE C.-B., KANG E., ADAMS D.S., KAPPMAYER L.S., KNOWLES D.P.,
762 MCELWAIN T.F., EVERMANN J.F., UETI M.W., SCOLES G.A., LEE S.S. & MCGUIRE T.C. (2014). Improved diagnostic performance
763 of a commercial *Anaplasma* antibody competitive enzyme-linked immunosorbent assay using recombinant major surface
764 protein 5-glutathione S-transferase fusion protein as antigen. *J. Vet. Diagn. Invest.*, **26**, 61–71.
- 765 DECARO N., CARELLI G., LORUSSO E., LUCENTE M.S., GRECO G., LORUSSO A., RADOGNA A., CECI L. & BUONAVOGLIA C. (2008).
766 Duplex real-time polymerase chain reaction for simultaneous detection and quantification of *Anaplasma marginale* and
767 *Anaplasma centrale*. *J. Vet. Diagn. Invest.*, **20**, 606–611.
- 768 DE VOS A.J. & JORGENSEN W.K. (1992). Protection of cattle against babesiosis in tropical and subtropical countries with a
769 live, frozen vaccine. *In: Tick Vector Biology, Medical and Veterinary Aspects*, Fivaz B.H., Petney T.N. & Horak I.G., eds.
770 Springer Verlag, Berlin, Germany, 159–174.
- 771 DREHER U.M., DE LA FUENTE J., HOFMANN-LEHMANN R., MELI M.K., PUSTERIA N., KOCAN K.M., WOLDEHIWET A., REGULA G. &
772 STAERK K.D.C. (2005). Serologic cross reactivity between *Anaplasma marginale* and *Anaplasma phagocytophilum*. *Clin.*
773 *Vaccine. Immunol.*, **12**, 1177–1183.
- 774 DUMLER J.S., BARBET A.F., BEKKER C.P., DASCH G.A., PALMER G.H., RAY S.C., RIKIHISA Y. & RURANGIRWA F.R. (2001).
775 Reorganization of genera in the Families Rickettsiaceae and Anaplasmataceae in the order Rickettsiales: unification of
776 some species of *Ehrlichia* with *Anaplasma*, *Cowdria* with *Ehrlichia*, and *Ehrlichia* with *Neorickettsia*, descriptions of five
777 new species combinations and designation of *Ehrlichia equi* and 'HGE agent' as subjective synonyms of *Ehrlichia*
778 *phagocytophila*. *Int. J. Syst. Evol. Microbiol.*, **51**, 2145–2165.
- 779 FUTSE J.E., UETI M.W., KNOWLES D.P. JR. & PALMER G.H. (2003). Transmission of *Anaplasma marginale* by *Boophilus*
780 *microplus*: retention of vector competence in the absence of vector-pathogen interaction. *J. Clin. Microbiol.* **41**, 3829–
781 3834.
- 782 GONZALEZ, E. F., LONG R. F. & TODOROVIC R. A. (1978). Comparisons of the complement-fixation, indirect fluorescent
783 antibody, and card agglutination tests for the diagnosis of bovine anaplasmosis. *Am. J. Vet. Res.*, **39**, 1538-1541.
- 784 HOFMANN-LEHMANN R., MELI M.L., DREHER U.M., GÖNCZI E., DEPLAZES P., BRAUN U., ENGELS M., SCHÜPBACH J., JÖRGER K.,
785 THOMA R., GRIOT C., STÄRCK K.D.C., WILLI B., SCHMIDT J., KOCAN K.M. & LUTZ H. (2004). Concurrent infections with vector-
-

-
- 786 borne pathogens associated with fatal haemolytic anemia in a cattle herd in Switzerland. *J. Clin. Microbiol.*, **42**, 3775–
787 3780.
- 788 JORGENSEN W.K., DE VOS A.J. & DALGLIESH R.J. (1989). Infectivity of cryopreserved *Babesia bovis*, *Babesia bigemina* and
789 *Anaplasma centrale* for cattle after thawing, dilution and incubation at 30°C. *Vet. Parasitol.*, **31**, 243–251.
- 790 KOCAN K.M., DE LA FUENTE J., BLOUIN E.F. & GARCIA GARCIA J.C. (2004). *Anaplasma marginale* (Rickettsiales:
791 Anaplasmataceae): recent advances in defining host-pathogen adaptations of a tick-borne rickettsia. *Parasitology*, **129**,
792 S285–S300.
- 793 KOCAN K.M., DE LA FUENTE J., GUGLIELMONE A.A. & MELENDEZ R.D. (2003). Antigens and alternatives for control of
794 *Anaplasma marginale* infection in cattle. *Clin. Microbiol. Rev.*, **16**, 698–712.
- 795 KOCAN K. M., J. DE LA FUENTE, BLOUIN E. F., COETZEE J. F. & EWING S. A. (2010). The natural history of *Anaplasma marginale*.
796 *Vet. Parasitol.*, **167**, 95–107.
- 797 KNOWLES D., TORIONI DE ECHAIDE S., PALMER G., MCGUIRE T., STILLER D. & MCELWAIN T. (1996). Antibody against an
798 *Anaplasma marginale* MSP5 epitope common to tick and erythrocyte stages identifies persistently infected cattle. *J. Clin.*
799 *Microbiol.*, **34**, 2225–2230.
- 800 KREIER J.P. & RISTIC M. (1963). Anaplasmosis. X Morphological characteristics of the parasites present in the blood of
801 calves infected with the Oregon strain of *Anaplasma marginale*. *Am. J. Vet. Res.*, **24**, 676–687.
- 802 MCHARDY N. (1984). Immunization against anaplasmosis: a review. *Prev. Vet. Med.*, **2**, 135–146.
- 803 MATEI I.A., ESTRADA-PENA A., CUTLER S.J., VAYSSIER-TAUSSAT M., VARELA-CASTRO L., POTKONJAK A., ZELLER H. & MIHALCA
804 A.D. (2019). A review on the eco-epidemiology and clinical management of human granulocytic anaplasmosis and its agent
805 in Europe. *Parasit. Vectors*, **12**, 599.
- 806 MELLORS L.T., DALGLIESH R.J., TIMMS P., RODWELL B.J. & CALLOW L.L. (1982). Preparation and laboratory testing of a frozen
807 vaccine containing *Babesia bovis*, *Babesi abigemina* and *Anaplasma centrale*. *Res. Vet. Sci.*, **32**, 194–197.
- 808 MOLLOY J.B., BOWLES P.M., KNOWLES D.P., MCELWAIN T.F., BOCK R.E., KINGSTON T.G., BLIGHT G.W. & DALGLIESH R.J. (1999).
809 Comparison of a competitive inhibition ELISA and the card agglutination test for detection of antibodies to *Anaplasma*
810 *marginale* and *Anaplasma centrale* in cattle. *Aust. Vet. J.*, **77**, 245–249.
- 811 NIELSEN K., SMITH P., GALL D., DE ESHAIDE S. T, WAGNER G. & DAJER A. (1996). Development and validation of an indirect
812 enzyme immunoassay for detection of antibody to *Anaplasma marginale* in bovine sera. *Vet. Parasitol.*, **67**, 133–142.
- 813 NOH S. M. & BROWN W.C. (2012). Adaptive immune responses to infection and opportunities for vaccine development
814 (Anaplasmataceae). *Intracellular Pathogens II: Rickettsiales*. G. H. Palmer. Washington, DC, USA, ASM Press. II: 330–
815 365.
- 816 PIPANO E. (1981). Frozen vaccine against tick fevers of cattle. In: XI International Congress on Diseases of Cattle, Haifa,
817 Israel. Mayer E., ed. Bregman Press, Haifa, Israel, 678–681.
- 818 PIPANO E. (1995). Live vaccines against hemoparasitic diseases in livestock. *Vet. Parasitol.*, **57**, 213–231.
- 819 PIPANO E. (1997). Vaccines against hemoparasitic diseases in Israel with special reference to quality assurance. *Trop.*
820 *Anim. Health Prod.*, **29** (Suppl. 4), 86S–90S.
- 821 PIPANO E., KRIGEL Y., FRANK M., MARKOVICS A. & MAYER E. (1986). Frozen *Anaplasma centrale* vaccine against
822 anaplasmosis in cattle. *Br. Vet. J.*, **142**, 553–556.
- 823 RAMOS C.A., ARAUJO F.R., SANTOS R.C., MELO E.S., SOUSA L.C., VIDAL C.E., GUERRA N.R. & RAMOS R.A. (2014).
824 Development and assessment of a latex agglutination test based on recombinant MSP5 to detect antibodies against
825 *Anaplasma marginale* in cattle. *Braz. J. Microbiol.*, **45**, 199–204.
-

- 826 REINBOLD J.B., COETZEE J.F., HOLLIS L.C., NICKELL J.S., RIEGEL C.M., CHRISTOPHER J.A. & GANTA R.R. (2010a). Comparison
827 of iatrogenic transmission of *Anaplasma marginale* in Holstein steers via needle and needle-free injection techniques. *Am.*
828 *J. Vet. Res.*, **71**, 1178–1188.
- 829 REINBOLD J.B., COETZEE J.F., SIRIGIREDDY K.R. & GANTA R.R. (2010b). Detection of *Anaplasma marginale* and
830 *A. phagocytophilum* in bovine peripheral blood samples by duplex real-time reverse transcriptase PCR assay. *J. Clin.*
831 *Microbiol.*, **48**, 2424–2432.
- 832 ~~ROGERS T.E., HIDALGO R.J. & DIMOPOULLOS G.T. (1964). Immunology and serology of *Anaplasma marginale*. I.
833 Fractionation of the complement fixing antigen. *J. Bacteriol.*, **88**, 81–86.~~
- 834 SARLI M., THOMPSON C.S., NOVOA M., VALENTINI B.S., MASTROPAOLO M., ECHAIDE I.E., DE ECHAIDE S.T. & PRIMO M.E. (2020).
835 Development and evaluation of a double-antigen sandwich ELISA to identify *Anaplasma marginale*-infected and
836 *A. centrale*-vaccinated cattle. *J. Vet. Diagn. Invest.*, **32**, 70–76.
- 837 SHKAP V., KOCAN K., MOLAD T., MAZUZ M., LEIBOVICH B., KRIGEL Y., MICHAYTCHENKO A., BLOUIN E., DE LA FUENTE J., SAMISH
838 M., MTSHALI M., ZWEYGARTH E., FLEIDEROVICH E.L. & FISH L. (2009). Experimental transmission of field *Anaplasma marginale*
839 and the *A. centrale* vaccine strain by *Hyalomma excavatum*, *Rhipicephalus sanguineus* and *Rhipicephalus (Boophilus)*
840 annulatus ticks. *Vet. Microbiol.*, **134**, 254–260.
- 841 SILAGHI C., NIEDER M., SAUTER-LOUIS C., KNUBBEN-SCHWEIZER G., PFISTER K. & PFEFFER M. (2018). Epidemiology, genetic
842 variants and clinical course of natural infections with *Anaplasma phagocytophilum* in a dairy cattle herd. *Parasit. Vectors*,
843 **11**, 20.
- 844 STICH R.W., OLAH G.A., BRAYTON K.A., BROWN W.C., FECHHEIMER M., GREEN CHURCH K., JITTAPALAPONG S., KOCAN K.M.,
845 MCGUIRE T.C., RURANGIRWA F.R. & PALMER G.H. (2004). Identification of a novel *Anaplasma marginale* appendage-
846 associated protein that localizes with actin filaments during intraerythrocytic infection. *Infect Immun.*, **72**, 7257–7264.
- 847 SILVA V.M., ARAUJO F.R., MADRUGA C.R., SOARES C.O., KESSLER R.H., ALMEIDA M.A., FRAGOSO S.P., SANTOS L.R., RAMOS
848 C.A., BACANELLI G. & TORRES R.A. (2006). Comparison between indirect enzyme-linked immunosorbent assays for
849 *Anaplasma marginale* antibodies with recombinant Major Surface Protein 5 and initial body antigens. *Mem. Inst. Oswaldo*
850 *Cruz.*, **101**, 511–516.
- 851 STRIK N.I., ALLEMAN A.R., BARBET A.F., SORENSON H.L., ~~WANSLEY~~ WAMSLEY H.L., GASCHEN F.P., LUCKSCHANDER N., WONG S.,
852 CHU F., FOLEY J.E., BJOERSDORFF A., STUEN S. & KNOWLES D.P. (2007). Characterization of *Anaplasma phagocytophilum*
853 major surface protein 5 and the extent of its cross-reactivity with *A. marginale*. *Clin. Vaccine Immunol.*, **14**, 262–268.
- 854 TORIONI DE ECHAIDE S., KNOWLES D.P., MCGUIRE T.C., PALMER G.H., SUAREZ C.E. & McELWAIN T.F. (1998). Detection of
855 cattle naturally infected with *Anaplasma marginale* in a region of endemicity by nested PCR and a competitive enzyme-
856 linked immunosorbent assay using recombinant major surface protein 5. *J. Clin. Microbiol.*, **36**, 777–782.

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859 **NB:** There is a WOAHP Reference Laboratory for anaplasmosis (please consult the WOAHP Web site:
860 <https://www.woah.org/en/what-we-offer/expertise-network/reference-laboratories/#ui-id-3>)
861 Please contact the WOAHP Reference Laboratory for any further information on
862 diagnostic tests, reagents and vaccines for bovine anaplasmosis

863 **NB:** FIRST ADOPTED IN 1991. MOST RECENT UPDATES ADOPTED IN 2015.

41 concurrently in the same assay. Enzyme-linked immunosorbent assays and the virus neutralisation test are
42 the most widely used.

43 **Requirements for vaccines:** There is no standard vaccine for BVD, but a number of commercial
44 preparations are available. An ideal vaccine should be able to prevent transplacental infection in pregnant
45 cows. Modified live virus vaccine should not be administered to pregnant cattle (or to their sucking calves)
46 due to the risk of transplacental infection. Live vaccines that contain cytopathic strains of BVDV present a
47 risk of inducing mucosal disease in PI animals. Inactivated viral vaccines are safe and can be given to any
48 class of animal but generally require booster vaccinations. BVDV is a particularly important hazard to the
49 manufacture of vaccines and biological products for other diseases due to the high frequency of
50 contamination of batches of fetal calf serum used as a culture medium supplement.

51 A. INTRODUCTION

52 1. Impact of the disease

53 Cattle of all ages are susceptible to infection with bovine viral diarrhoea viruses (BVDV). Distribution of the virus is world-
54 wide although some countries have recently eradicated the virus. BVDV infection results in a wide variety of clinical
55 manifestations, including enteric and respiratory disease in any class of cattle or reproductive and fetal disease following
56 infection of a susceptible breeding female. Infection may be subclinical or extend to severe fatal disease. Clinical
57 presentations and severity of disease may vary with different strains of virus. BVDV viruses also cause immune
58 suppression, which can render infected animals more susceptible to infection with other viruses and bacteria. The clinical
59 impact may be more apparent in intensively managed livestock. Animals that survive *in-utero* infection in the first trimester
60 of gestation are almost always persistently infected (PI). PI animals provide the main reservoir of the virus in a population
61 and excrete large amounts of virus in urine, faeces, discharges, milk and semen. The virus spreads mainly by close contact
62 between PI animals and other cattle. Virus shedding by acutely infected animals is usually less important. This virus may
63 also persist in the environment for short periods or be transmitted ~~with~~via contaminated reproductive materials. Vertical
64 transmission plays an important role in its epidemiology and pathogenesis.

65 Infections of the breeding female may result in conception failure or embryonic and fetal infection which results in abortions,
66 stillbirths, teratogenic abnormalities or the birth of PI calves. Persistently viraemic animals may be born as weak, unthrifty
67 calves or may appear as normal healthy calves and be unrecognised clinically for a long time. However, PI animals have
68 a markedly reduced life expectancy, with a high proportion dying before reaching maturity. Infrequently, some of these
69 animals may later develop mucosal disease with anorexia, gastrointestinal erosions, and profuse diarrhoea, invariably
70 leading to death. Mucosal disease can arise only in PI animals. It is important to avoid the trade of viraemic animals. It is
71 generally considered that serologically positive, non-viraemic cattle are 'safe', providing that they are not pregnant.
72 However, a small proportion of persistently viraemic animals may produce antibodies to some of the viral proteins if they
73 are exposed to another strain of BVDV that is antigenically different to the persisting virus. Consequently, seropositivity
74 cannot be completely equated with 'safety'. Detection of PI animals must be specifically directed at detection of the virus
75 or its components (RNA or antigens). Latent infections generally do not occur following recovery from acute infection.
76 However, semen collected from bulls during an acute infection is likely to contain virus during the viraemic period and often
77 for a short time afterwards. Although extremely rare, some recovered bulls may have a persistent testicular infection and
78 excrete virus in semen, perhaps indefinitely.

79 While BVDV strains are predominantly pathogens of cattle, interspecies transmission can occur following close contact
80 with sheep, goats or pigs. Infection of pregnant small ruminants or pigs with BVDV can result in reproductive loss and the
81 birth of PI animals. BVDV infections have been reported in both New World and Old World camelids. Additionally, strains
82 of border disease virus (BDV) have infected cattle, resulting in clinical presentations indistinguishable from BVDV infection.
83 The birth of cattle PI with BDV and the subsequent development of mucosal disease have also been described. Whilst
84 BVDV and BDV have been reported as natural infections in pigs, the related virus of classical swine fever does not naturally
85 infect ruminants.

86 Although ubiquitous, control of BVDV can be achieved at the herd level, and even at the national level, as evidenced by
87 the progress towards eradication made in many European countries (Moennig *et al.*, 2005; Schweizer *et al.*, 2021).

88 2. The causal agent

89 Bovine viral diarrhoea virus (BVDV) is a single linear positive-stranded RNA virus in the genus *Pestivirus* of the family
90 *Flaviviridae*. The genus contains a number of species including ~~the two genotypes of bovine viral diarrhoea virus (BVDV)~~
91 (types 1 [*Pestivirus bovis*], and 2 [*Pestivirus tauri*] and 3 [*Pestivirus brazilense*]) and the closely related classical swine
92 fever (*Pestivirus suis*) and ovine border disease viruses (*Pestivirus ovis*). Viruses in these ~~genotypes~~ pestivirus species
93 show considerable antigenic difference from each other and, within the ~~type 1 and type 2~~ species *Pestivirus bovis* and

94 tauri, BVDV isolates exhibit considerable biological and antigenic diversity. Within the ~~two BVDV genotypes species~~
95 *Pestivirus bovis* and *tauri*, further subdivisions are discernible by genetic analysis (Vilcek *et al.*, 2001). The two ~~genotypes~~
96 species may be differentiated from each other, and from other pestiviruses, by monoclonal antibodies (MAbs) directed
97 against the major glycoproteins E2 and ERNs or by genetic analysis. Reverse-transcription polymerase chain reaction (RT-
98 PCR) assays enable virus typing direct from blood samples (Letellier & Kerkhofs, 2003; McGoldrick *et al.*, 1999). Type 1
99 viruses are generally more common although the prevalence of type 2 strains can be high in North America. BVDV of both
100 ~~genotypes species~~ (*Pestivirus bovis* and *tauri*) may occur in non-cytopathic and cytopathic forms (biotypes), classified
101 according to whether or not microscopically apparent cytopathology is induced during infection of cell cultures. Usually, it
102 is the non-cytopathic biotype that circulates freely in cattle populations. Non-cytopathic strains are most frequently
103 responsible for disease in cattle and are associated with enteric and respiratory disease in any class of cattle or
104 reproductive and fetal disease following infection of a susceptible breeding female. Infection may be subclinical or extend
105 to severe fatal disease (Brownlie, 1985). Cytopathic viruses are encountered in cases of mucosal disease, a clinical
106 syndrome that is relatively uncommon and involves the 'super-infection' of an animal that is PI with a non-cytopathic virus
107 by a closely related cytopathic strain. The two virus biotypes found in a mucosal disease case are usually antigenically
108 closely related if not identical. Type 2 viruses are usually non-cytopathic and have been associated with outbreaks of
109 severe acute infection and a haemorrhagic syndrome. However some type 2 viruses have also been associated with a
110 disease indistinguishable from that seen with the more frequently isolated type 1 viruses. Further, some type 1 isolates
111 have been associated with particularly severe and fatal disease outbreaks in adult cattle. Clinically mild and inapparent
112 infections are common following infection of non-pregnant animals with either ~~genotype-virus species~~.

113 ~~There is an increasing awareness of an "atypical" or "HoBi-like" pestivirus—a putative BVDV type 3 *Pestivirus H* strains~~
114 are also associated with clinical disease in cattle, but they appear mainly restricted to South American and Asian cattle
115 populations, in cattle, also associated with clinical disease (Bauermann *et al.*, 2013; Chen *et al.*, 2021), but its distribution
116 ~~is presently unclear~~. These viruses are readily detected by proven pan-reactive assays such as real-time RT-PCR. Some
117 commercial antigen ELISAs (enzyme-linked immunosorbent assays) have been shown to detect these strains (Bauermann
118 *et al.*, 2012); generally virus isolation, etc., follows the same principles as for BVDV 1 (*Pestivirus bovis*) and 2 (*Pestivirus*
119 *tauri*). It should be noted however, that antibody ELISAs vary in their ability to detect antibody to BVDV type 3 (*Pestivirus*
120 *brazilense*) and vaccines designed to protect against BVDV 1 and 2 may not confer full protection against infection with
121 these ~~novel~~ pestiviruses (Bauermann *et al.*, 2012; 2013).

122 3. Pathogenesis

123 3.1. Acute infections

124 Acute infections with BVDV are encountered more frequently in young animals, and may be clinically inapparent or
125 associated with fever, diarrhoea (Baker 1995), respiratory disease and sometimes sudden death. The severity of disease
126 may vary with virus strain and the involvement of other pathogens (Brownlie, 1990). In particular, outbreaks of a severe
127 form of acute disease with haemorrhagic lesions, thrombocytopenia and high mortality have been reported sporadically
128 from some countries (Baker, 1995; Bolin & Ridpath, 1992). Infection with type 2 viruses (*Pestivirus tauri*) in particular
129 has been demonstrated to cause altered platelet function. During acute infections there is a brief viraemia for 7–10 days
130 and shedding of virus can be detected in nasal and ocular discharges. There may also be a transient leukopenia,
131 thrombocytopenia or temperature response, but these can vary greatly among animals. Affected animals may be
132 predisposed to secondary infections with other viruses and bacteria. Although BVDV may cause a primary respiratory
133 disease on its own, the immunosuppressive effects of the virus exacerbate the impact of this virus. BVDV is one of the
134 major pathogens of the bovine respiratory disease complex in feedlot cattle and in other intensive management systems
135 such as calf raising units.

136 Infection of breeding females immediately prior to ovulation and in the first few days after insemination can result in
137 conception failure and early embryonic loss (McGowan & Kirkland, 1995). Cows may also suffer from infertility,
138 associated with changes in ovarian function and secretions of gonadotropin and progesterone (Fray *et al.*, 2002).
139 Bulls may excrete virus in semen for a short period during and immediately after infection and may suffer a temporary
140 reduction of fertility. Although the virus level in this semen is generally low it can result in reduced conception rates
141 and be a potential source of introduction of virus into a naive herd (McGowan & Kirkland, 1995).

142 3.2. *In-utero* infections

143 Infection of a breeding female can result in a range of different outcomes, depending on the stage of gestation at
144 which infection occurred. Before about 25 days of gestation, infection of the developing conceptus will usually result
145 in embryo-fetal death, although abortion may be delayed for a considerable time (McGowan & Kirkland, 1995).
146 Surviving fetuses are normal and uninfected. However, infection of the female between about 30–90 days will
147 invariably result in fetal infection, with all surviving progeny PI and seronegative. Infection at later stages and up to
148 about day 150 can result in a range of congenital defects including hydranencephaly, cerebellar hypoplasia, optic
149 defects, skeletal defects such as arthrogyposis and hypotrichosis. Growth retardation may also occur, perhaps as a
150 result of pituitary dysfunction. Fetal infection can result in abortion, stillbirth or the delivery of weak calves that may
151 die soon after birth (Baker, 1995; Brownlie, 1990; Duffell & Harkness, 1985; Moennig & Liess, 1995). Some PI calves

152 may appear to be normal at birth but fail to grow normally thrive. They remain PI for life and are usually seronegative,
153 exceptions may be young calves that ingested colostrum containing antibodies. The onset of the fetal immune
154 response and production of antibodies occurs between approximately day 90–120, with an increasing proportion of
155 infected calves having detectable antibodies while the proportion in which virus may be detected declines rapidly.
156 Infection of the bovine fetus after day 180 usually results in the birth of a normal seropositive calf.

157 3.3. Persistent infections

158 Persistently viraemic animals are a continual source of infective virus to other cattle and are the main reservoir of
159 BVDV in a population. In a population without a rigorous BVDV control programme, approximately 1–2% of cattle are
160 PI. During outbreaks in a naive herd or breeding group, if exposure has occurred in the first trimester of pregnancy,
161 a very high proportion of surviving calves will be PI. If a PI animal dies, there are no pathognomonic lesions due to
162 BVDV and the pathology is often complicated by secondary infections with other agents. Some PI animals will survive
163 to sexual maturity and may breed successfully but their progeny of female PI animals will also always be PI. Animals
164 being traded or used for artificial breeding should first be screened to ensure that they are not PI.

165 3.4. Mucosal disease

166 Persistently viraemic animals may later succumb to mucosal disease (Brownlie, 1985). However, cases are rare. This
167 syndrome has been shown to be the outcome of the infection of a PI animal with an antigenically similar cytopathic
168 virus, which can arise either through superinfection, recombination between non-cytopathic biotypes, or mutation of
169 the persistent biotype (Brownlie, 1990). There is usually little need to specifically confirm that a PI animal has
170 succumbed to mucosal disease as this is largely a scientific curiosity and of little practical significance, other than
171 that the animal is PI with BVDV. However, cases of mucosal disease may be the first indication in a herd that BVDV
172 infection is present, and should lead to more in depth investigation and intervention.

173 3.5. Semen and embryos

174 Bulls that are PI usually have poor quality, highly infective semen and reduced fertility (McGowan & Kirkland, 1995).
175 All bulls used for natural or artificial insemination should be screened for both acute and persistent BVDV infection.
176 A rare event, possibly brought about by acute infection during pubescence, can result in persistent infection of the
177 testes and thus strongly seropositive bulls that intermittently excrete virus in semen (Voges *et al.*, 1998). This
178 phenomenon has also been observed following vaccination with an attenuated virus (Givens *et al.*, 2007). Embryo
179 donor cows that are PI with BVDV also represent a potential source of infection, particularly as there are extremely
180 high concentrations of BVDV in uterine and vaginal fluids. While oocysts without an intact zona pellucida have been
181 shown to be susceptible to infection *in vitro*, the majority of oocysts remain uninfected with BVDV. Normal uninfected
182 progeny have also been 'rescued' from PI animals by the use of extensive washing of embryos and *in-vitro* fertilisation.
183 Female cattle used as embryo recipients should always be screened to confirm that they are not PI, and ideally, are
184 seropositive or were vaccinated at least 4 weeks before first use.

185 Biological materials used for *in-vitro* fertilisation techniques (bovine serum, bovine cell cultures) have a high risk of
186 contamination and should be screened for BVDV. Incidents of apparent introduction of virus via such techniques have
187 highlighted this risk. It is considered essential that serum supplements used in media should be free of contaminants
188 as detailed in Chapter 1.1.9 *Tests for sterility and freedom from contamination of biological materials intended for*
189 *veterinary use*, using techniques described in Section B.3-1.1 of this chapter.

190 4. Approaches to diagnosis and sample collection

191 The diagnosis of BVDV infection can sometimes be complex because of the delay between infection and clinical
192 expression. While detection of PI animals should be readily accomplished using current diagnostic methods, the recognition
193 of acute infections and detection of BVDV in reproductive materials can be more difficult.

194 4.1. Acute infections

195 Unlike PI animals, acutely infected animals excrete relatively low levels of virus and for a short period of time (usually
196 about 7–10 days) but the clinical signs may occur during the later stages of viraemia, reducing the time to detect the
197 virus even further. In cases of respiratory or enteric disease, samples should be collected from a number of affected
198 animals, preferentially selecting the most recently affected. Swabs should be collected from the nares and conjunctiva
199 of animals with respiratory disease or from rectum and faeces if there are enteric signs. Lung and spleen are preferred
200 from dead animals. Viral RNA may be detected by real-time RT-PCR assays and have the advantages of high
201 sensitivity and being able to detect genome from non-infectious virus. As the virus levels are very low, it is not usually
202 practical to undertake virus isolation unless there is a need to characterise the strain of BVDV involved. Serology
203 undertaken on paired acute and convalescent sera (collected at least 21 days after the acute sample and from 8–10
204 animals) is worthwhile and gives a high probability of incriminating or excluding BVDV infection.

205 Confirmation that an abortion, stillbirth or perinatal death is caused by BVDV is often difficult to establish because
206 there can be a long delay between initial infection and death or expulsion of the fetus. Sampling should take into
207 consideration the need to detect either viral components or antibodies. Spleen and lung are preferred samples for
208 virus detection while pericardial or pleural fluids are ideal samples for serology. The stomach of newborn calves
209 should be checked to confirm that sucking has not occurred. While virus may be isolated from fetal tissue in some
210 cases, emphasis should be placed on the detection of viral antigen by ELISA or RNA by real-time RT-PCR. For
211 serology, both ELISAs and virus neutralisation test (VNT) are suitable though sample quality and bacterial
212 contamination may compromise the ability to detect antibodies by VNT. Maternal serology, especially on a group of
213 animals, can be of value, with the aim of determining whether there has been recent infection in the group. A high
214 antibody titre (>1/1000) to BVDV in maternal serum is suggestive of fetal infection and is probably due to the fetus
215 providing the dam with an extended exposure to virus.

216 **4.2. Persistent infections**

217 In the past, identification of PI animals relied heavily on the use of virus isolation in cell cultures. However, antigen
218 detection ELISAs and real-time RT-PCR assays, each with relatively high sensitivity, are widely used for the detection
219 of viral antigens or RNA in both live and dead animals. Virus isolation aimed at the detection of non-cytopathic BVDV
220 in blood is also used, while in some countries, the virus has been identified by immunohistochemistry (IHC). Skin
221 samples have been collected from live animals while a wide range of tissues from dead animals are suitable. Both
222 virus isolation and IHC are labour intensive and costly and can be technically demanding. Virus isolation from blood
223 can be confounded by the presence of maternal antibody to BVDV in calves less than 4–5 months of age (diagnostic
224 gap). Also for antigen detection ELISAs and flow cytometry from blood or blood leukocytes, there are restrictions that
225 limit when animals that ingested colostrum that contains antibodies against BVDV can be reliably tested. In older
226 animals with persistent viraemia infection, low levels of antibody may be present due to their ability to seroconvert to
227 strains of BVDV (including vaccines) antigenically different to the persisting virus (Brownlie, 1990). Bulk (tank) or
228 individual milk samples have been used to monitor dairy herds for the presence of a PI animal. Antigen ELISA, real-
229 time PCR and virus isolation have all been used. To confirm a diagnosis of persistent infection, animals should be
230 retested after an interval of at least 3 weeks by testing of blood samples for the presence of the virus and for evidence
231 absence of seroconversion. Care should be taken with retesting of skin samples as it has been shown that, in some
232 acute cases, viral antigen may persist for many weeks in skin (Cornish *et al.*, 2005).

233 **4.3. Mucosal disease**

234 Although not undertaken for routine diagnostic purposes, for laboratory confirmation of a diagnosis of mucosal
235 disease it is necessary to isolate the cytopathic virus. This biotype may sometimes be isolated from blood, but it can
236 be recovered more consistently from a variety of other tissues, in particular spleen, intestine and Peyer's patch tissue.
237 Virus isolation is readily accomplished from spleen which is easy to collect and is seldom toxic for cell culture.

238 **4.4. Reproductive materials**

239 Semen donor bulls should be sampled for testing for freedom from BVDV infection prior to collection of semen, in
240 accordance with the *Terrestrial Animal Health Code*. It is necessary to confirm that these bulls are not PI, are not
241 undergoing an acute infection and to establish their serological status. This initial testing should be carried out on
242 whole blood or serum samples. To establish that a seropositive bull does not have a persistent testicular infection
243 (PTI), samples of semen should be collected on at least three separate occasions at intervals of not less than 7 days
244 due to the possibility of intermittent low level virus excretion, especially during the early stages of infection. There is
245 also a need to submit a number of straws from each collection, or an appropriate volume of raw semen. Particular
246 care should be taken to ensure that sample transport recommendations are adhered to and that the laboratory
247 documents the condition of the samples on arrival at the laboratory. Further details of collection, transport and test
248 requirements are provided in sections that follow.

B. DIAGNOSTIC TECHNIQUES

Table 1. Test methods available for diagnosis of bovine viral diarrhoea and their purpose

Method	Purpose					
	<u>Population freedom from infection</u>	<u>Individual animal freedom from infection prior to movement</u>	<u>Contribute to eradication policies</u>	<u>Confirmation of clinical cases</u>	<u>Prevalence of infection – surveillance</u>	<u>Immune status in individual animals or populations (post-vaccination)</u>
Detection of the agent^(a)						
Virus isolation	+	++ ±	++	++ ±	–	–
Antigen detection by ELISA	+++	+++	+++	+++	+++	–
Antigen detection by IHC	–	–	–	++	–	–
NA detection by real-time RT-PCR	+++	+++	+++	+++	+++	–
Detection of immune response						
ELISA	+++	++	+++	– <u>+(a)</u>	+++	+++
VN	+	++ ±	++	–	+	+++

Key: +++ = recommended for this purpose; ++ recommended but has limitations;

+ = suitable in very limited circumstances; – = not appropriate for this purpose.

ELISA = enzyme-linked immunosorbent assay; IHC = immunohistochemistry method; NA = nucleic acid; RT-PCR = reverse-transcription polymerase chain reaction; ISH = *in-situ* hybridisation; VN = virus neutralisation.

^(a)A combination of agent detection methods applied on the same clinical sample is recommended.

1. Detection of the agent

To prevent the shipment of either animals or animal derivatives (especially semen and embryos) that are infected with BVDV, it is necessary to test for the presence of the infectious virus (virus isolation), viral antigens (antigen detection ELISA) or RNA (real-time RT-PCR) in the blood of the animal being shipped, or the donor of the germplasm (semen or embryos). The exception is for seropositive bulls where semen must be tested rather than the donor bull. Serology only plays a role for establishing that seronegative animals are not undergoing an acute infection or, to establish the serological status of donor bulls. Due to their variable sensitivity without prior virus amplification, procedures such as IHC or *in-situ* hybridisation (ISH) directly on tissues are not considered to be suitable for certification for freedom from BVDV for international trade purposes. In contrast, immune-staining is an essential component of virus isolation in cell culture to detect the presence of non-cytopathic strains of BVDV which predominate in field infections.

All test methods must be extensively validated by testing on known uninfected and infected populations of cattle, including animals with low- and high-titre viraemias. Methods based on polyclonal or MAb-binding assays (ELISA or IHC), immune labelling (VI) or on nucleic acid recognition (PCR) must be shown to detect the full range of antigenic and genetic diversity found among BVD viruses. There are ~~three~~ designated WOAHP Reference Laboratories for BVDV that can assist with relevant information; the reference laboratories for classical swine fever could also be approached to offer some advice.

1.1. Virus isolation

When performed to a high standard, BVDV isolation is very reliable. However, it does have very exacting requirements to ensure that the cell cultures and medium components give a system that is very sensitive and are not compromised by the presence of either low levels of BVDV specific antibody or virus. Virus isolation only has the capacity to detect infectious virus which imposes certain limits on sample quality. Further, to detect low levels of virus that may be present in some samples, particularly semen, it may be necessary to examine larger volumes of specimen than is usual. Some of these limitations can be overcome by the use of antigen detection ELISAs with proven high analytical sensitivity, or the use of real-time RT-PCR.

279 The virus may be isolated in a number of bovine monolayer cell cultures (e.g. kidney, lung, testis or turbinate). In
280 some instances, ovine cells are also suitable. Primary or secondary cultures can be frozen as cell suspensions in
281 liquid nitrogen. These can then be tested over a series of passages, or seeded to other susceptible cells and checked
282 for freedom from contaminants and to evaluate their sensitivity compared to an approved batch of cells before routine
283 use. Such problems may be reduced by the use of continuous cell lines, which can be obtained BVD-free, however,
284 their BVDV-free status and susceptibility must be monitored regularly. Continuous cells should be used under a 'seed
285 lot' system where they are only used over a limited passage range, within which they have been shown to have
286 acceptable sensitivity to BVDV infection. Although particular continuous cell lines are considered to be appropriate
287 for use for BVDV isolation, there can be significant variation in batches of cells from different sources due to differing
288 passage histories so their suitability must still be confirmed before routine use.

289 Non-cytopathic BVDV is a common contaminant of bovine tissues and cell cultures must be checked for freedom
290 from adventitious virus by regular testing. Cells must be grown in proven cell culture medium components and a large
291 area of cells must be examined. It is not appropriate to screen a few wells of a 96 well plate – examining all wells of
292 a 96 well plate will be more convincing evidence of freedom. The fetal bovine serum that is selected for use in cell
293 culture must also be free not only from virus, but also and of equal or perhaps even greater importance, from BVDV
294 neutralising antibody. Heat treatment (56°C for 30–45 minutes) is inadequate for the destruction of BVDV in
295 contaminated serum; irradiation with a dose of at least 25 kiloGrays (2.5 Mrad) is more certain. Commercial batches
296 of fetal bovine serum mostly test positive by real-time RT-PCR even after the virus has been inactivated by irradiation.
297 Further, most commercially collected batches of fetal bovine serum contain antibodies to pestiviruses, sometimes at
298 levels that are barely detectable but sufficient to inhibit virus isolation. To overcome this, serum can be obtained from
299 BVD virus and antibody free donor animals and used with confidence. Testing of donors for both virus and antibody
300 occurs on an individual animal basis. Although horse serum has been substituted for bovine fetal serum, it is often
301 found to have poorer cell-growth-promoting characteristics. Further there has sometimes been cross contamination
302 with fetal bovine serum during processing, negating the objective of obtaining a BVDV-free product.

303 Buffy coat cells, whole blood, washed leukocytes or serum are suitable for isolation of the virus from live animals.
304 Maternal antibody may interfere with isolation from serum in young calves. Tissue suspensions from post-mortem
305 cases should be prepared by standard methods. Confirmation that a bull is not PI with BVDV is most readily achieved
306 by testing of a blood sample. However, persistent testicular infections (PTI) have been detected in some bulls that
307 have recovered from acute infection, are no longer viraemic and are now seropositive (Voges *et al.*, 1998). Virus may
308 be detected in most but not all collections of semen from these bulls. Although still considered to be uncommon, to
309 exclude the potential for a PTI it is essential to screen semen from all seropositive bulls. To be confident that a bull
310 does not have a PTI, batches of semen collected over several weeks should be screened. Once a series of collections
311 have been screened, further testing of semen from a seropositive bull is not warranted. Raw semen, and occasionally
312 extended semen, is cytotoxic and must be diluted in culture medium. For these reasons, it is important to monitor the
313 health of the cells by microscopic examination at intervals during the incubation. These problems are largely
314 overcome by the use of real-time RT-PCR which has several advantages over virus isolation, including higher
315 sensitivity and the potential to be completed within a few hours rather than weeks for virus isolation.

316 There are many variations of procedure in use for virus isolation. All should be optimised to give maximum sensitivity
317 of detection of a standard virus preparation. All biological components used for cell culture should be screened and
318 shown to be free of both BVDV and antibodies to BVDV. Cell cultures (whether primary or continuous lines) should
319 be regularly checked to confirm that they maintain maximum susceptibility to virus infection. Depending on the
320 specimen type and purpose for testing, virus isolation is likely to require one or more passages in cell cultures. While
321 PI animals can be readily identified by screening blood or serum with one passage, semen should be routinely
322 cultured for three passages and biological products such as fetal bovine serum up to five times (original inoculation
323 plus four passages). Conventional methods for virus isolation are used, with the addition of a final immune-staining
324 step (immunofluorescence or, more frequently, peroxidase staining) to detect growth of non-cytopathic virus. Thus
325 tube cultures should include flying cover-slips, while microplate cultures can be fixed and labelled directly in the plate.
326 Examples are given below. Alternatively, culture supernatant from the final passage can be screened by real-time
327 RT-PCR (see below).

328 **1.1.1. Microplate immunoperoxidase method for mass screening for virus detection in serum** 329 **samples (Meyling, 1984)**

- 330 i) 10–25 µl of the serum sample is placed into each of four wells of a 96-well tissue-culture grade
331 microplate. This is repeated for each sample. Known positive and negative controls are
332 included.
- 333 ii) 100 µl of a cell suspension at the appropriate concentration (usually about 150,000 cells/ml) in
334 medium without fetal calf serum (FCS) is added to all wells. *Note:* the sample itself acts as the
335 cell-growth supplement. If testing samples other than serum, use medium with 10% FCS that is
336 free of antibodies to ruminant pestiviruses.

-
- 337
338
- iii) The plate is incubated at 37°C for 4 days, either in a 5% CO₂ atmosphere or with the plate sealed.
- 339
340
- iv) Each well is examined microscopically for evidence of cytopathology (cytopathic effect or CPE), or signs of cytotoxicity.
- 341
342
- v) The cultures are frozen briefly at approximately –80°C and 50 µl of the culture supernatant is passaged to new cell cultures, repeating steps 31.1.1.i to iv above.
- 343
- vi) The cells are then fixed and stained by one of two methods:
- 344
- **Paraformaldehyde**
- 345
346
- a) Add 200 µl of a 1/10 dilution of formaldehyde solution (approximately 3% concentration) to the plate and leave at room temperature for 10 minutes.
- 347
- b) The contents of the plate are then discarded and the plate is washed.
- 348
349
- c) Wash plates 5 times with 0.05% Tween 20 in water (an automatic microplate washer can be used with a low pressure and speed setting).
- 350
351
352
- d) To each well add 50 µl of an antiviral antibody at the appropriate dilution (prepared in phosphate buffered saline/ PBS containing 1% gelatin) and incubate for 60–90 minutes at 37°C in a humidified chamber.
- 353
- e) Wash plates five times as in step c).
- 354
355
356
357
- f) Dilute the appropriate peroxidase conjugated antiserum to the optimum dilution in 1% gelatin/PBS (e.g. peroxidase conjugated rabbit anti-mouse immunoglobulin when the antiviral antibody is a mouse monoclonal). The optimum concentration should be determined for each batch of conjugate by “checkerboard” titration against reference positive and negative controls.
- 358
359
- g) To each well of the microplate add 50 µl of the diluted peroxidase conjugate and incubate for 90 minutes at 37°C in a humidified chamber.
- 360
- h) Wash plates five times as in step c).
- 361
362
- i) “Develop” the plate by adding 3-amino-9-ethyl carbazole (AEC) substrate (100 µl/well) and allowing to react for 30 minutes at room temperature.
- 363
- j) Add 100 µl of PBS to each well and add a lid to each plate.
- 364
365
366
- k) Examine the wells by light microscopy, starting with the negative and positive control wells. There should be no or minimal staining apparent in the cells that were uninfected (negative control). The infected (positive control) cells should show a reddish- brown colour in the cytoplasm.
- 367
- **Acetone**
- 368
- a) The plate is emptied by gentle inversion and rinsed in PBS.
- 369
370
371
372
373
- b) The cells are fixed as follows: the plate is dipped into a bath of 20% acetone in PBS, emptied immediately and then transferred to a fresh bath of 20% acetone in PBS for 10 minutes. The plate is drained thoroughly and as much fluid as possible is removed by tapping and blotting. The plate is dried thoroughly for at least 3 hours at a temperature of 25–30°C (e.g. using radiant heat from a bench lamp). *Note:* the drying is part of the fixation process.
- 374
- c) The fixed cells are rinsed by adding PBS to all wells.
- 375
376
377
- d) The wells are drained and the BVD antibody (50 µl) is added to all wells at a predetermined dilution in PBS containing 1% Tween 80 (PBST) and 5% horse serum or 1% gelatin. (Horse serum or gelatin may be added to reduce nonspecific staining.)
- 378
- e) Incubate at 37°C for 15 minutes.
- 379
- f) Empty the plate and wash three times in PBST.
- 380
381
- g) Drain and add the appropriate anti-species serum conjugated to peroxidase at a predetermined dilution in PBST (50 µl per well) for 15 minutes at 37°C.
- 382
- h) Empty the plate and wash three times in PBST.
- 383
- i) Rinse the plate in distilled water. Ensure all fluid is tapped out from the plate.
- 384
385
- j) Add freshly prepared hydrogen peroxide substrate with a suitable chromogen, e.g. 3-amino-9-ethyl carbazole (AEC).
-

386 An alternative substrate can be made, consisting of 9 mg diaminobenzidine tetrahydrochloride
387 and 6 mg sodium perborate tetrahydrate dissolved in 15 ml of PBS. Though the staining is not
388 quite so intense, these chemicals have the advantage that they can be shipped by air.

389 k) The plate is examined microscopically. Virus-positive cells show red-brown cytoplasmic
390 staining.

391 Alternative methods for fixation of the cells may be used and include the use of heat (see Chapter
392 3.8.3 *Classical swine fever*, Section B.2.2.1.viii). These should be first evaluated to ensure that the
393 capacity to detect viral antigen is not compromised.

394 1.1.2. Tube method for tissue or buffy coat suspensions

395 *Note:* this method can also be conveniently adapted to 24-well plastic dishes. *Note:* a minimum of 2 and
396 preferably 3 passages (including primary inoculation) is required.

397 i) Tissue samples are ground up and a 10% suspension in culture medium is made. This is then
398 centrifuged to remove the debris.

399 ii) Test tube cultures with newly confluent or subconfluent monolayers of susceptible bovine cells are
400 inoculated with 0.1 ml of the sample. The culture is left to adsorb for 1 hour at 37°C.

401 iii) The culture is washed with 1 ml of medium; this is then discarded and 1 ml of culture maintenance
402 medium is added.

403 iv) The culture is incubated for 4–5 days at 37°C, and examined microscopically for evidence of CPE
404 or signs of cytotoxicity.

405 v) The culture should then be frozen and thawed for passage to fresh cultures for one or preferably
406 two more passages (including the culture inoculated for the final immunostaining). At the final
407 passage, after freeze–thaw the tissue culture fluid is harvested and passaged on to microtitre plates
408 for culture and staining by the immunoperoxidase method (see section B.3.1.1.1 above) or by the
409 immunofluorescent method. For immunofluorescence, cover-slips are included in the tubes and
410 used to support cultured cells. At the end of the culture period, the cover slips are removed, fixed
411 in 100% acetone and stained with an immunofluorescent conjugate to BVDV. Examine the cover
412 slips under a fluorescent microscope for diffuse, cytoplasmic fluorescence characteristic of
413 pestiviruses. Alternatively, culture supernatant from the final passage can be screened by real-time
414 RT-PCR (see below).

415 1.1.3. Virus isolation from semen

416 The samples used for the test are, typically, extended bovine semen or occasionally raw semen.
417 Semen samples should be transported to the laboratory in liquid nitrogen, or on dry ice. The samples
418 should be stored in liquid nitrogen or at lower than –70°C (for long-term storage) or 4°C (for short-
419 term storage of not more than 1–2 days). The receiving laboratory should document the condition
420 under which samples are received. Raw semen is generally cytotoxic and should be prediluted (e.g.
421 1/10 in BVDV free bovine serum) before being added to cell cultures. At least 0.1 ml of raw semen
422 should be tested with three passages in cell culture. Toxicity may also be encountered with extended
423 semen. For extended semen, an approximation should be made to ensure that the equivalent of a
424 minimum of 0.1 ml raw semen is examined (e.g. a minimum of 1.0 ml extended semen). If toxicity is
425 encountered, multiple diluted samples may need to be tested to reach a volume equivalent to 0.1 ml
426 raw semen (e.g. 5 × 1 ml of a sample of extended semen that has been diluted 1/5 to reduce toxicity).
427 A suggested method is as follows:

428 i) Dilute 200 µl fresh semen in 1.8 ml bovine serum containing antibiotics. This can be the same
429 serum as is being used for supplementing the cell cultures, and must be shown to be free from
430 antibodies against BVDV.

431 ii) Mix vigorously and leave for 30 minutes at room temperature.

432 iii) Inoculate 1 ml of the semen/serum mixture into a monolayer of susceptible cells (see virus
433 isolation from tissue above) in cell culture tubes or a six-well tissue culture plate.

434 iv) Incubate the cultures for 1 hour at 37°C.

435 v) Remove the mixture, wash the monolayer several times with maintenance medium and then
436 add new maintenance medium to the cultures.

-
- 437 vi) Include BVDV negative and positive controls in the test. Special caution must be taken to avoid
438 accidental contamination of test wells by the positive control, for example always handling the
439 positive control last.
- 440 vii) Observe plates microscopically to ensure freedom from contamination and cytotoxicity. No
441 cytopathology is expected as a result of BVDV infection but other viruses such as BHV-1 could
442 be inadvertently isolated.
- 443 viii) After 5–7 days, the cultures are frozen at or below approximately –70°C and thawed, clarified
444 by centrifugation, and the supernatant used to inoculate fresh monolayers.
- 445 ix) At the end of the second passage, the supernatant from the freeze-thaw preparation should be
446 passaged onto cultures in a suitable system for immunoperoxidase staining or other antigen
447 detection or by real-time RT-PCR after 5 days of culture. This is most readily achieved in 96
448 well microplates. The sample is considered to be negative, if there is no evidence of viral antigen
449 or BVDV RNA detected.

450 1.2. Nucleic acid detection

451 Conventional gel based RT-PCR has in the past been used for the detection of BVD viral RNA for diagnostic
452 purposes. A multiplex RT-PCR has been used for the simultaneous amplification and typing of virus from cell culture,
453 or direct from blood samples. However, gel based RT-PCR has the disadvantage that it is relatively labour intensive,
454 expensive and prone to cross contamination. These problems had been markedly reduced following the introduction
455 of probe-based real-time or quantitative RT-PCR methods. Nevertheless, stringent precautions should still be taken
456 to avoid nucleic acid contamination in the test system and general laboratory areas where samples are handled and
457 prepared (see Chapter 1.1.6 *Principles and methods of validation of diagnostic assays for infectious diseases* and
458 Chapter 2.2.3 *Development and optimisation of nucleic acid assays*). These assays have even higher sensitivity than
459 gel based RT-PCR and can be completed in a few hours. They are in widespread use for the diagnosis of infectious
460 diseases, allowing the direct detection of viral RNA from a wide range of specimens including serum, whole blood,
461 tissues, milk and semen. The high analytical sensitivity allows the adoption of strategies to screen pools of individual
462 samples or testing of bulk tank milk. By using this approach the presence of one or more PI animals can be identified
463 in herds containing several hundred cows. However, it is not appropriate to pool blood samples taken from calves
464 between day 7 and 40 of life, when colostrum that contains antibodies against BVDV was ingested. During this time
465 the sensitivity of PCR can be reduced and infected animals escape detection. In contrast, the detection of viral RNA
466 in skin biopsy samples remains unaffected (Fux & Wolf, 2012). Although slightly more expensive than immunostaining
467 methods, real-time RT-PCR is a quick and reliable method that can also be used to screen culture supernatant from
468 the final passage of cell cultures. While real-time RT-PCR has very high sensitivity and can be applied to the screening
469 of biological materials used for vaccine manufacture, caution is needed in the interpretation of results, as the detection
470 of viral RNA does not imply *per se* that infective virus is present. Real-time RT-PCR assays based on fluorescent-
471 labelled DNA probes can also be used to differentiate pestiviruses (e.g. McGoldrick *et al.*, 1999).

472 Primers for the assay should be selected in highly conserved regions of the genome, ideally the 5'-noncoding region,
473 or the NS3 (p80 gene). There are published assays that are broadly reactive across the pestivirus genus, detecting
474 all BVDV types (*Pestivirus bovis*, *tauri* and *brazilense*), CSFV (*Pestivirus suis*), some strains of BDV (*Pestivirus ovis*)
475 and most of the several 'atypical' pestiviruses (e.g. Hoffman *et al.*, 2006). A sensitive broadly reactive assay is
476 recommended for diagnostic applications because interspecies transfer of different pestiviruses is occasionally
477 encountered. When further identification of the specific virus is required, pestivirus species-specific assays can
478 be applied to further type the virus. It is important to thoroughly optimise all aspects of the real-time RT-PCR assay,
479 including the nucleic acid extraction and purification. Optimal concentrations of Mg²⁺, primers, probe and polymerase,
480 and the cycling parameters need to be determined. However, fully formulated and optimised 'ready to use'
481 'mastermixes' are now available commercially and only require addition of optimised concentrations of primers and
482 probe. Optimised cycling conditions are often recommended for a particular mastermix.

483 A variety of commercially available nucleic acid purification systems are available in kit form and several can be semi-
484 automated. Systems based on the capture and purification of RNA using magnetic beads are in widespread use and
485 allow rapid processing of large numbers of samples. Specific products should be evaluated to determine the optimal
486 kit for a particular sample type and whether any preliminary sample processing is required. For whole blood samples,
487 the type of anticoagulant and volume of blood in a specimen tube is important. More problems with inhibitors of the
488 PCR reaction are encountered with samples collected into heparin treated blood than EDTA. These differences are
489 also exacerbated if the tube does not contain the recommended volume of blood, thereby increasing the concentration
490 of anticoagulant in the sample. To identify possible false-negative results, it is recommended to spike an exogenous
491 ('internal control') RNA template into the specimen prior to RNA extraction (e.g. Hoffman *et al.*, 2006). By the inclusion
492 of PCR primers and probe specific to the exogenous sequence, the efficiency of both the RNA extraction and also
493 the presence of any PCR inhibitors can be monitored. While valuable for all sample types, the inclusion of an internal
494 control is particularly desirable when testing semen and whole blood. When using an internal control, extensive testing

495 is necessary to ensure that PCR amplification of the internal control does not compete with the diagnostic PCR and
496 thus lower the analytical sensitivity (see also chapter 1.1.6).

497 When it is suspected that a sample may contain substances that are adversely affecting either the efficiency of RNA
498 extraction or the real-time RT-PCR assay, modest dilution of the sample in saline, cell culture medium or a buffer
499 solution (e.g. phosphate buffered gelatin saline [PBGS]) will usually overcome the problem. Dilution of a semen
500 sample by 1/4 and whole unclotted blood at 1/10 is usually adequate. As the real-time RT-PCR has extremely high
501 analytical sensitivity, dilution of the sample rarely has a significant impact on the capacity of the assay to detect viral
502 RNA when present.

503 1.2.1. Real-time polymerase chain reaction for BVDV detection in semen

504 Real-time RT-PCR has been shown to be extremely useful to screen semen samples to demonstrate
505 freedom from BVDV and, apart from speed, often gives superior results to virus isolation in cell
506 culture, especially when low virus levels are present, such as may be found in bulls with a PTI. The
507 real-time RT-PCR described here uses a pair of sequence-specific primers for amplification of target
508 D-RNA and a 5'-nuclease oligoprobe for the detection of amplified products. The oligoprobe is a
509 single, sequence-specific oligonucleotide, labelled with two different fluorophores. The primers and
510 probe are available commercially and several different fluorophores options are available. This pan-
511 pestivirus real-time RT-PCR assay is designed to detect viral D-RNA of all strains of BVDV types 1
512 (*Pestivirus bovis*) and BVDV₂ (*Pestivirus tauri*) and 3 (*Pestivirus brazilense*) as well as BDV, CSFV
513 (*Pestivirus suis*), some strains of BDV (*Pestivirus ovis*) and most atypical pestiviruses. The assay
514 selectively amplifies a 208 base pair sequence of the 5' non-translated region (5' NTR) of the
515 pestivirus genome. Details of the primers and probes are given in the protocol outlined below.

516 i) Sample preparation, equipment and reagents

517 a) The samples used for the test are, typically, extended bovine semen or occasionally raw
518 semen. If the samples are only being tested by real-time RT-PCR, it is acceptable for them
519 to be submitted chilled but they must still be cold when they reach the laboratory.
520 Otherwise, if a cold chain cannot be assured or if virus isolation is being undertaken, the
521 semen samples should be transported to the laboratory in liquid nitrogen or on dry ice. At
522 the laboratory, the samples should be stored in liquid nitrogen or at lower than -70°C (for
523 long-term storage) or 4°C (for short-term storage of up to 7 days). *Note:* samples for virus
524 isolation should not be stored at 4°C for more than 1–2 days.

525 b) Due to the very high analytical sensitivity of real-time RT-PCR, much smaller volumes of
526 semen may be used. However, at least three straws (minimum 250 μl each) from each
527 collection batch of semen should be processed. The semen in the three straws should be
528 pooled and mixed thoroughly before taking a sample for nucleic acid extraction.

529 c) A real-time PCR detection system, and the associated data analysis software, is required
530 to perform the assay. A number of real-time PCR detection systems are available from
531 various manufacturers. ~~Other equipment required for the test includes a micro-centrifuge,~~
532 ~~a chilling block, a micro-vortex, and micropipettes.~~ As real-time RT-PCR assays are able
533 to detect very small amounts of target nucleic acid molecules, appropriate measures are
534 required to avoid contamination, ~~including dedicated and physically separated 'clean'~~
535 ~~areas for reagent preparation (where no samples or materials used for PCR are handled),~~
536 ~~a dedicated sample processing area and an isolated area for the PCR thermocycler and~~
537 ~~associated equipment. Each area should have dedicated reagents and equipment.~~
538 Furthermore, a minimum of one negative sample should be processed in parallel to
539 monitor the possibility of low level contamination. Sources of contamination may include
540 product carry-over from positive samples or, more commonly, from cross contamination
541 by PCR products from earlier work.

542 d) The real-time RT-PCR assay involves two separate procedures.

543 1) Firstly, BVDV RNA is extracted from semen using an appropriate validated nucleic
544 acid extraction method. Systems using magnetic beads for the capture and
545 purification of the nucleic acid are recommended. It is also preferable that the beads
546 are handled by a semi-automated magnetic particle handling system.

547 2) The second procedure is the RT-PCR analysis of the extracted RNA template in a
548 real-time RT-PCR system.

549 ii) Extraction of RNA

550 RNA or total nucleic acid is extracted from the pooled (three straws collected at the same time
551 from the same animal) semen sample. Use of a commercially available magnetic bead based
552 extraction kit is recommended. However, the preferred kit should be one that has been
553 evaluated to ensure optimal extraction of difficult samples (semen and whole blood). Some
554 systems and kit protocols are sufficiently refined that it is not necessary to remove cells from
555 the semen sample. Prior to extraction dilute the pooled semen sample 1/4 in phosphate buffered
556 gelatin saline (PBGS) or a similar buffered solution. Complete the RNA extraction by taking 50
557 µl of the diluted, pooled sample and add it to the sample lysis buffer. Some commercial
558 extraction kits may require the use of a larger volume. It has also been found that satisfactory
559 results are obtained by adding 25 µl of undiluted pooled sample to sample lysis buffer. Complete
560 the extraction by following the kit manufacturer's instructions.

561 iii) Real-time RT-PCR assay procedure

562 a) Reaction mixture: There are a number of commercial real-time PCR amplification kits
563 available from various sources and the particular kits selected need to be compatible with
564 the real-time PCR platform selected. The required primers and probes can be synthesised
565 by various commercial companies. The WOAHP Reference Laboratories for BVDV can
566 provide information on suitable suppliers.

567 b) Supply and storage of reagents: The real-time PCR reaction mixture is normally provided
568 as a 2 × concentration ready for use. The manufacturer's instructions should be followed
569 for application and storage. Working stock solutions for primers and probe are made with
570 nuclease-free water at the concentration of 20 µM and 3 µM, respectively. The stock
571 solutions are stored at -20°C and the probe solution should be kept in the dark. Single-
572 use or limited use aliquots can be prepared to limit freeze-thawing of primers and probes
573 and extend their shelf life.

574 c) Primers and probe sequences

575 Selection of the primers and probe are outlined in Hoffmann *et al.* (2006) and summarised
576 below.

577 *Forward:* BVD 190-F 5'-GRA-GTC-GTC-ART-GGT-TCG-AC

578 *Reverse:* V326 5'-TCA-ACT-CCA-TGT-GCC-ATG-TAC

579 *Probe:* TQ-pesti 5'-FAM-TGC-YAY-GTG-GAC-GAG-GGC-ATG-C-TAMRA-3'

580 d) Preparation of reaction mixtures

581 The PCR reaction mixtures are prepared in a separate room that is isolated from other
582 PCR activities and sample handling. For each PCR test, appropriate controls should be
583 included. As a minimum, a no template control (NTC), appropriate negative control (NC)
584 and two positive controls (PC1, PC2) should be included. The positive and negative
585 controls are included in all steps of the assay from extraction onwards while the NTC is
586 added after completion of the extraction. The PCR amplifications are carried out in a
587 volume of 25 µl. The protocol described is based on use of a 96 well microplate based
588 system but other options using microtubes are also suitable. Each well of the PCR plate
589 should contain 20 µl of reaction mix and 5 µl of sample as follows:

590	12.5 µl	2× RT buffer – from a commercial kit.
591	1 µl	BVD 190-F Forward primer (20 µM)
592	1 µl	V326 Reverse primer (20 µM)
593	1 µl	TQ-pesti Probe (3 µM)
594	2 µl	tRNA (40 ng/µl)
595	1.5 µl	<u>nuclease free</u> water
596	1 µl	25× enzyme mix
597	5 µl	sample (or controls – NTC, NC, PC1, PC2)

-
- 598 e) Selection of controls
- 599 NTC: usually consists of nuclease free water or tRNA in nuclease free water that is added
- 600 in place of a sample when the PCR reaction is set up.
- 601 NC: In practice, many laboratories use PBGS or a similar buffer. Ideally the controls for
- 602 testing of semen samples should be negative semen, from seronegative bulls. However,
- 603 as a minimum, the assay in use should have been extensively validated with negative and
- 604 positive samples to confirm that it gives reliable extraction and amplification with semen.
- 605 PCs: There are two positive controls (PC1=moderate – [Ct 29-32] and PC2=weak [Ct 32–
- 606 35] positive). Positive semen from naturally infected bulls is preferable as a positive
- 607 control. However, this is likely to be difficult to obtain. Further, semen from a PI bull is not
- 608 considered suitable because the virus loads are usually very high and would not give a
- 609 reliable indication of any moderate reduction in extraction or assay performance. Negative
- 610 semen spiked with defined quantities of BVDV virus could be used as an alternative. If
- 611 other samples are used as a routine PC, as a minimum the entire extraction process and
- 612 PCR assay in use must have been extensively validated using known positive semen from
- 613 bulls with a PTI or from bulls undergoing an acute infection. If these samples are not
- 614 available and spiked samples are used for validation purposes, a number of samples
- 615 spiked with very low levels of virus should be included. On a day to day basis, the inclusion
- 616 of an exogenous control with each test sample will largely compensate for not using
- 617 positive semen as a control and will give additional benefits by monitoring the efficiency of
- 618 the assay on each individual sample. Positive control samples should be prepared
- 619 carefully to avoid cross contamination from high titred virus stocks and should be prepared
- 620 in advance and frozen at a 'ready to use' concentration and ideally 'single use' volume.
- 621 f) Extracted samples are added to the PCR mix in a separate room. The controls should be
- 622 added last, in a consistent sequence in the following order: NTC, negative and then the
- 623 two positive controls.
- 624 g) Real-time polymerase chain reaction
- 625 The PCR plate or tubes are placed in the real-time PCR detection system in a separate,
- 626 designated PCR room. Some mastermixes have uniform reaction conditions that are
- 627 suitable for many different assays. As an example, the PCR detection system is
- 628 programmed for the test as follows:
- 629 1× 48°C 10 minutes
- 630 1× 95°C 10 minutes
- 631 45 × (95°C 15 seconds, 60°C 1 minute)
- 632 h) Analysis of real-time PCR data
- 633 The software program is usually set to automatically adjust results by compensating for any
- 634 background signal and the threshold level is usually set according to the manufacturer's
- 635 instructions for the selected analysis software used. In this instance, a threshold is set at 0.05.
- 636 i) Interpretation of results
- 637 a) Test controls – all controls should give the expected results with positive controls (PC1
- 638 and PC2) falling within the designated range and both the negative control (NC) and no
- 639 template control (NTC) should have no Ct values.
- 640 b) Test samples
- 641 1) Positive result: Any sample that has a cycle threshold (Ct) value less than 40 is
- 642 regarded as positive.
- 643 2) Negative result: Any sample that shows no Ct value is regarded as negative. However,
- 644 before reporting a negative result for a sample, the performance of the exogenous
- 645 internal control should be checked and shown to give a result within the accepted range
- 646 for that control (for example, a Ct value no more than 2–3 Ct units higher than the
- 647 NTC).
-

648 **1.3. Enzyme-linked immunosorbent assay for antigen detection**

649 Antigen detection by ELISA has become a widely adopted method for the detection of individual PI animals. These
650 assays are not intended for the detection of acutely infected animals (though from time to time this may be achieved).
651 Importantly, these assays are not designed for screening of semen or biological materials used in assays or vaccine
652 manufacture. Several methods for the ELISA for antigen detection have been published and a number of commercial
653 kits are available. Most are based on the sandwich ELISA principle, with a capture antibody bound to the solid phase,
654 and a detector antibody conjugated to a signal system, such as peroxidase. Amplification steps such as the use of
655 biotin and streptavidin in the detection system are sometimes used to increase assay sensitivity. Both monoclonal-
656 and polyclonal-based systems are described. The test measures BVD antigen (NS2-3 or ERNS) in lysates of peripheral
657 blood leukocytes; the new generation of antigen-capture ELISAs (ERNS capture ELISAs) are able to detect BVD
658 antigen in blood as well as in plasma or serum samples. The best of the methods gives a sensitivity similar to virus
659 isolation, and may be preferred in those rare cases where persistent infection is combined with seropositivity. Due to
660 transient viraemia, the antigen ELISA is less useful for virus detection in acute BVD infections.

661 The NS2-3 antigen detection ELISAs may be less effective in young calves that have had colostrum due to the
662 presence of BVDV maternal antibodies, especially when blood samples or blood leucocytes are tested (Fux & Wolf,
663 2012). Blood or blood leucocytes should not be tested in the first month (ERNS capture ELISA) or the first 3 months
664 (NS2-3 ELISA) of life due to the inhibitory effect of maternal antibodies. The real-time RT-PCR is probably the most
665 sensitive detection method for this circumstance, but the ERNS ELISA has also been shown to be a sensitive and
666 reliable test, particularly when used with skin biopsy (ear-notch) samples (Cornish *et al.*, 2005).

667 **1.4. Immunohistochemistry**

668 Enzyme-labelled methods are useful to detect BVDV antigen in tissue sections, particularly where suitable MAbs are
669 available. However, these assays are not appropriate to certify animals for international trade and use should be
670 limited to diagnostic investigations. It is important that the reagents and procedures used be fully validated, and that
671 nonspecific reactivity be eliminated. For PI cattle almost any tissue can be used, but particularly good success has
672 been found with lymph nodes, thyroid gland, skin, brain, abomasum and placenta. Skin biopsies, such as ear-notch
673 samples, have shown to be useful for *in-vivo* diagnosis of persistent BVDV infection.

674 **2. Serological tests**

675 Antibody to BVDV can be detected in cattle sera by a standard VNT or by ELISA, using one of several published methods
676 or with commercial kits (e.g. Edwards, 1990). Serology is used to identify levels of herd immunity, for the detection of the
677 presence of PI animals in a herd, to assist with investigation of reproductive disease and possible involvement of BVDV
678 and to establish the serological status of bulls being used for semen collection and to identify whether there has been a
679 recent infection. ELISA for antibody in bulk milk samples can give a useful indication of the BVD status of a herd (Niskanen,
680 1993). High ELISA values (0.8 or more absorbance units) in an unvaccinated herd indicates a high probability of the herd
681 having been exposed to BVDV in the recent past, most likely through one or more persistently viraemic animals being
682 present. In contrast, a very low or negative values (≤0.2) indicates that it is unlikely that persistently viraemic animals are
683 present. However, ELISA values are not always a reliable indicator of the presence of PI animals on farms, due to differing
684 husbandry (Zimmer *et al.*, 2002), recent administration of vaccine and also due to the presence of viral antigen in bulk milk,
685 which may interfere with the antibody assay itself. Determination of the antibody status of a small number of young stock
686 (9–18 months) has also been utilised as an indicator of recent transmission of BVDV in the herd (Houe *et al.*, 1995), but
687 this approach is also dependent on the degree of contact between different groups of animals in the herd and the potential
688 for exposure from neighbouring herds. VN tests are more frequently used for regulatory purposes (e.g. testing of semen
689 donors) while ELISAs (usually in the form of commercially prepared kits) are commonly used for diagnostic applications.
690 Whether ELISA or VNT, control positive and negative standard sera must be included in every test. These should give
691 results within predetermined limits for the test to be considered valid. In the VNT, a 'serum control' to monitor sample
692 toxicity should also be included for each test sample.

693 **2.1. Virus neutralisation test**

694 Selection of the virus strain to include in a VNT is very important. No single strain is likely to be ideal for all
695 circumstances, but in practice one should be selected that detects the highest proportion of serological reactions in
696 the local cattle population. Low levels of antibody to BVD type 2 virus (*Pestivirus tauri*) may not be detectable by a
697 neutralisation test that uses type 1 strain of the virus, and vice versa (Fulton *et al.*, 1997). It is important that BVD
698 type 1 and BVD type 2 (*Pestivirus bovis* and *tauri*) be used in the test and not just the one that the diagnostician
699 thinks is present, as this can lead to under reporting. Because it makes the test easier to read, most laboratories use
700 highly cytopathic, laboratory-adapted strains of BVDV for VN tests. Two widely used cytopathic strains are 'Oregon
701 C24V' and 'NADL'. However immune-labelling techniques are now available that allow simple detection of the growth

702 or neutralisation of non-cytopathic strains where this is considered desirable, especially to support the inclusion of a
703 locally relevant virus strain. An outline protocol for a microtitre VN test is given below (Edwards, 1990):

704 **2.1.1. Test procedure**

- 705 i) The test sera are heat-inactivated for 30 minutes at 56°C.
- 706 ii) From a starting dilution of 1/4, serial twofold dilutions of the test sera are made in a cell-culture
707 grade flat-bottomed 96-well microtitre plate, using cell culture medium as diluent. For each
708 sample, three or four wells are used at each dilution depending on the degree of precision
709 required. At each dilution of serum, for each sample one well is left without virus to monitor for
710 evidence of sample toxicity that could mimic viral cytopathology or interfere with virus
711 replication. Control positive and negative sera should also be included in each batch of tests.
- 712 iii) An equal volume (e.g. 50 µl) of a stock of cytopathic strain of BVDV containing 100 TCID₅₀ (50%
713 tissue culture infective dose) is added to each well. A back titration of virus stock is also done
714 in some spare wells to check the potency of the virus (acceptance limits 30–300 TCID₅₀).
- 715 iv) The plate is incubated for 1 hour at 37°C.
- 716 v) A flask of suitable cells (e.g. bovine turbinate, bovine testis) is trypsinised and the cell
717 concentration is adjusted to 1.5 × 10⁹/ml. 100 µl of the cell suspension is added to each well of
718 the microtitre plate.
- 719 vi) The plate is incubated at 37°C for 4–5 days, either in a 5% CO₂ atmosphere or with the plate
720 sealed.
- 721 vii) The wells are examined microscopically for CPE or fixed and stained by immunoperoxidase
722 staining using an appropriate monoclonal antibody. The VN titre for each serum is the dilution
723 at which the virus is neutralised in 50% of the wells. This can be calculated by the Spearman–
724 Kärber or Reed Muench methods. A seronegative animal will show no neutralisation at the
725 lowest dilution (1/4), equivalent to a final dilution of 1/8. For accurate comparison of antibody
726 titres, and particularly to demonstrate significant (more than fourfold) changes in titre, samples
727 should be tested in parallel in the same test.

728 **2.2. Enzyme-linked immunosorbent assay**

729 Both indirect and blocking types of test can be used. A number of commercial kits are available. As with the virus
730 neutralisation test, ELISAs configured using antigen from one ~~genotype-species~~ of BVDV may not efficiently detect
731 antibody induced by another ~~genotype-virus species~~. Tests should therefore be selected for their ability to detect
732 antibody to the spectrum of types and strains circulating in the country where the test is to be performed.

733 The chief difficulty in setting up the test lies in the preparation of a viral antigen of sufficient potency. The virus must
734 be grown under optimal culture conditions using a highly permissive cell type. Any serum used in the medium must
735 not inhibit growth of BVDV. The optimal time for harvest should be determined experimentally for the individual culture
736 system. The virus can be concentrated and purified by density gradient centrifugation. Alternatively, a potent antigen
737 can be prepared by treatment of infected cell cultures with detergents, such as Nonidet P40, N-decanoyl-N-
738 methylglucamine (Mega 10), Triton X-100 or 1-octylbeta-D-glucopyranoside (OGP). Some workers have used fixed,
739 infected whole cells as antigen. ~~In the future,~~ Increasing use ~~may be is~~ made of artificial antigens manufactured by
740 expressing specific viral genes in bacterial or eukaryotic systems. Such systems should be validated by testing sera
741 specific to a wide range of different virus strains. In the future, this technology should enable the production of
742 serological tests complementary to subunit or marker vaccines, thus enabling differentiation between vaccinated and
743 naturally infected cattle. An example outline protocol for an indirect ELISA is given below (Edwards, 1990).

744 **2.2.1. Test procedure**

- 745 i) Roller cultures of secondary calf testis cells with a high multiplicity of infection (about one), are
746 inoculated with BVDV strain Oregon C24V, overlaid with serum-free medium and incubated for
747 24 hours at 37°C.
- 748 ii) The cells are scraped off and pelleted. The supernatant medium is discarded. The pellet is
749 treated with two volumes of 2% OGP in PBS for 15 minutes at 4°C, and centrifuged to remove
750 the cell debris. The supernatant antigen is stored in small aliquots at –70°C, or freeze-dried.
751 Non-infected cells are processed in parallel to make a control antigen.
- 752 iii) The antigen is diluted to a predetermined dilution in 0.05 M bicarbonate buffer, pH 9.6. Alternate
753 rows of an ELISA-grade microtitre plate are coated with virus and control antigens overnight at

- 754 4°C. The plates are then washed in PBS with 0.05% Tween 20 or Tween 80 (PBST) before use
755 in the test.
- 756 iv) Test sera are diluted 1/50 in serum diluent (0.5 M NaCl; 0.01 M phosphate buffer; 0.05% Tween
757 20; 0.001 M ethylene diamine tetra-acetic acid; 1% polyvinyl pyrrolidone, pH 7.2) and added to
758 virus- and control-coated wells for 1 hour at 37°C. The plates are then washed five times in
759 PBST.
- 760 v) Rabbit anti-bovine IgG peroxidase conjugate is added at a predetermined dilution (in serum
761 diluent) for 1 hour at 37°C, then the plates are again washed five times in PBST.
- 762 vi) A suitable enzyme substrate is added, such as hydrogen peroxide/tetramethyl benzidine. After
763 colour development, the reaction is stopped with sulphuric acid and the absorbance is read on
764 an ELISA plate reader. The value obtained with control antigen is subtracted from the test
765 reaction to give a net absorbance value for each serum.
- 766 vii) It is recommended to convert net absorbance values to sample:positive ratio (or percentage
767 positivity) by dividing net absorbance by the net absorbance on that test of a standard positive
768 serum that has a net absorbance of about 1.0. This normalisation procedure leads to more
769 consistent and reproducible results.

770 C. REQUIREMENTS FOR VACCINES

771 1. Background

772 BVDV vaccines are used primarily for disease control purposes. Although they can convey production advantages
773 especially in intensively managed cattle such as in feedlots. In some countries where BVDV eradication is being
774 undertaken, PI animals are removed and remaining cattle are vaccinated to maintain a high level of infection-antibody
775 positivity and prevent the generation of further PI animals. Vaccination to control BVDV infections can be challenging due
776 in part to the antigenic variability of the virus and the occurrence of persistent infections that arise as a result of fetal
777 infection. Ongoing maintenance of the virus in nature is predominantly sustained by PI animals that are the product of *in-*
778 *utero* infection. The goal for a vaccine should be to prevent systemic viraemia and the virus crossing the placenta. If this
779 is successfully achieved it is likely that the vaccine will prevent the wide range of other clinical manifestations, including
780 reproductive, respiratory and enteric diseases and immunosuppression with its secondary sequelae. There are many
781 different vaccines available in different countries. Traditionally, BVD vaccines fall into two classes: modified live virus or
782 inactivated vaccines. Experimental recombinant subunit vaccines based on BVD viral glycoprotein E2 expressed with
783 baculovirus, ~~or~~ transgenic plants or heterologous viruses and BVDV E2 DNA vaccines have been described but few, if
784 any, are in commercial production. They offer a future prospect of 'marker vaccines' when used in connection with a
785 complementary serological test.

786 1.1. Characteristics of a target product profile

787 Traditionally, BVD vaccines fall into two classes: modified live or inactivated virus vaccines. The essential requirement
788 for both types is to ~~afford~~ provide a high level of fetal infection-protection. Many of the live vaccines have been based
789 on a cytopathic strain of the virus which is considered to be unable to cross the placenta. However, it is important to
790 ensure that the vaccine virus does not cause fetal infection. In general, vaccination of breeding animals should be
791 completed well before insemination to ensure optimal protection and avoid any risk of fetal infection. Live virus vaccine
792 may also be immunosuppressive and precipitate other infections. On the other hand, modified live virus vaccines may
793 only require a single dose. Use of a live product containing a cytopathic strain of BVDV may precipitate mucosal
794 disease by superinfection of persistently viraemic animals. Properly formulated inactivated vaccines are very safe to
795 use but, to obtain satisfactory levels of immunity, they usually require booster vaccinations, which may be
796 inconvenient. A combined vaccination protocol using inactivated followed by live vaccine may reduce the risk of
797 adverse reaction to the live strain. Whether live or inactivated, because of the propensity for antigenic variability, the
798 vaccine should contain strains of BVDV that are closely matched to viruses found in the area in which they are used.
799 For example, in countries where strains of BVDV type 2 (*Pestivirus tauri*) are found, it is important for the vaccine to
800 contain a suitable type 2 strain. For optimal immunity against type 1 strains (*Pestivirus bovis*), antigens from the
801 dominant subtypes (e.g. 1a and 1b) should be included. Due to the need to customise vaccines for the most commonly
802 encountered strains within a country or region, it is not feasible to produce a vaccine antigen bank that can be drawn
803 upon globally.

804 Guidance for the production of veterinary vaccines is given in Chapter 1.1.8 *Principles of veterinary vaccine*
805 *production*. The guidelines given here and in chapter 1.1.8 are intended to be general in nature and may be
806 supplemented by national and regional requirements.

807 2. Outline of production and minimum requirements for vaccines

808 2.1. Characteristics of the seed

809 For optimal efficacy, it is considered that there should be a close antigenic match between viruses included in a
810 vaccine and those circulating in the target population. BVDV type 2 strains (*Pestivirus tauri*) should be included as
811 appropriate. Due to the regional variations in ~~genotypes-species~~ and subtypes of BVDV, many vaccines contain more
812 than one strain of BVDV to give acceptable protection. A good appreciation of the antigenic characteristics of
813 individual strains can be obtained by screening with panels of MAbs (Paton *et al.*, 1995).

814 2.1.1. Biological characteristics of the master seed

815 Isolates of cytopathic virus are often mixed with the noncytopathic biotype. The separation and
816 purification of the two biotypes from an initial mixed culture is important to maintain the expected
817 characteristics of the ~~seed~~ seed and depends on several cycles of a limiting dilution technique for the
818 noncytopathic virus, or plaque selection for the cytopathic virus. Purity of the cytopathic virus should
819 be confirmed by at least one additional passage at limiting dilution. When isolates have been cloned,
820 their identity and key antigenic characteristics should be confirmed. The identity of the seed virus
821 should be confirmed by sequencing. Where there are multiple isolates included in the vaccine, each
822 has to be prepared separately.

823 While retaining the desirable antigenic characteristics, the strains selected for the seed should not
824 show any signs of disease when susceptible animals are vaccinated. Live attenuated vaccines should
825 not be transmissible to unvaccinated 'in-contact' animals and should not be able to infect the fetus.
826 Ideally seeds prepared for the production of inactivated vaccines should grow to high titre to minimise
827 the need to concentrate the antigens and there should be a minimal amount of protein from the cell
828 cultures incorporated into the final product. Master stocks for either live or inactivated vaccines should
829 be prepared under a seed lot system involving master and working stocks that can be used for
830 production in such a manner that the number of passages can be limited and minimise antigenic drift.
831 While there are no absolute criteria for this purpose, as a general guide, the seed used for production
832 should not be passaged more than 20 times beyond the master seed and the master seed should be
833 of the lowest passage from the original isolate as is practical.

834 2.1.2. Quality criteria (sterility, purity, freedom from extraneous agents)

835 It is crucial to ensure that all materials used in the preparation of the bulk antigens have been
836 extensively screened to ensure freedom from extraneous agents. This should include master and
837 working seeds, the cell cultures and all medium supplements such as bovine serum. It is particularly
838 important to ensure that any serum used that is of bovine origin is free of both adventitious BVDV of
839 all ~~genotypes~~ and antibodies against BVDV strains because low levels of either virus or antibody can
840 mask the presence of the other. Materials and vaccine seeds should be tested for sterility and
841 freedom from contamination with other agents, especially viruses as described in the chapter 1.1.8
842 and chapter 1.1.9.

843 2.1.3. Validation as a vaccine strain

844 All vaccines should pass standard tests for efficacy. Tests should include as a minimum the
845 demonstration of a neutralising antibody response following vaccination, a reduction in virus shedding
846 after challenge in vaccinated cattle and ideally a prevention of viraemia. Efficacy tests of BVD
847 vaccines by assessing clinical parameters in non-pregnant cattle can be limited by the difficulty of
848 consistently establishing clinical signs but, when employed, clinical parameters such as a reduction
849 in the rectal temperature response and leukopenia should be monitored. Although it can be difficult
850 by using virus isolation in cell culture to consistently demonstrate the low levels of viraemia associated
851 with an acute infection, real-time PCR could be considered as an alternative method to establish the
852 levels of circulating virus.

853 If a vaccine passes basic tests, the efficacy of vaccination should ultimately be measured by the
854 capacity to prevent transplacental transmission. If there is a substantial reduction and ideally
855 complete prevention of fetal infection, a vaccine would be expected to be highly effective in other
856 situations (for example prevention of respiratory disease). A suitable challenge system can be
857 established by intranasal inoculation of noncytopathic virus into pregnant cows between 60 and 90
858 days of gestation (Brownlie *et al.*, 1995). Usually this system will reliably produce persistently viraemic
859 offspring in non-immune cows. In countries where BVDV type 2 viruses (*Pestivirus tauri*) are
860 commonly encountered, efficacy in protecting against BVDV type 2 infections should be measured.

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2.2. Method of manufacture

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2.2.1. Procedure

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Both cytopathic and noncytopathic biotypes will grow in a variety of cell cultures of bovine origin. Standard procedures may be used, with the expectation for harvesting noncytopathic virus on days 4–7 and cytopathic virus on days 2–4. The optimal yield of infectious virus will depend on several factors, including the cell culture, isolate used and the initial seeding rate of virus. These factors should be taken into consideration and virus replication kinetics investigated to establish the optimal conditions for large scale virus production. Whether a live or inactivated vaccine, the essential aim will be to produce a high-titred virus stock. This bulk antigen preparation can subsequently be prepared according to the type of vaccine being considered.

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2.2.2. Requirements for ingredients

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Most BVDV vaccines are grown in cell cultures of bovine origin that are frequently supplemented with medium components of animal origin. The material of greatest concern is bovine serum due to the potential for contamination with BVD viruses and antibodies to these viruses. These adventitious contaminants not only affect the efficiency of production but also may mask the presence of low levels of infectious BVDV that may have undesirable characteristics. In addition to the virus seeds, all materials should be tested for sterility and freedom from contamination with other agents, especially viruses as described in chapters 1.1.8 and 1.1.9. Further, materials of bovine or ovine origin should originate from a country with negligible risk for transmissible spongiform encephalopathies [TSEs] (see chapter 1.1.9).

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2.2.3. In-process controls

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In-process controls are part of the manufacturing process. Cultures should be inspected regularly to ensure that they remain free from contamination, and to monitor the health of the cells and the development or absence of CPE, as appropriate. While the basic requirement for efficacy is the capacity to induce an acceptable neutralising antibody response, during production, target concentrations of antigen required to achieve an acceptable response may be monitored indirectly by assessment of the quantity of infectious virus or antigen mass that is produced. Rapid diagnostic assays such as the ELISA are useful to monitor BVDV antigen production. Alternatively, the quality of a batch of antigen may be determined by titration of the quantity of infectious virus present, although this may underestimate the quantity of antigen. For inactivated vaccines, infectivity is evaluated before inactivation. For inactivated vaccines the inactivation kinetics should be established so that a suitable safety margin can be determined and incorporated into the routine production processes. At the end of production, *in-vitro* cell culture assays should be undertaken to confirm that inactivation has been complete. These innocuity tests should include a sufficient number of passages and volume of inoculum to ensure that very low levels of infectious virus would be detected if present.

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2.2.4. Final product batch tests

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i) Sterility

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Tests for sterility and freedom from contamination of biological materials intended for veterinary use may be found in Chapter 1.1.9.

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ii) Identity

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Identity tests should demonstrate that no other strain of BVDV is present when several strains are propagated in a facility producing multivalent vaccines.

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iii) Safety

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Safety tests shall consist of detecting any abnormal local or systemic adverse reactions to the vaccine by all vaccination route(s). Batch-to-batch safety tests are required unless safety of the product is demonstrated and APPROVED in the registration dossier and production is consistent with that described in chapter 1.1.8.

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The safety test is different to the innocuity test (see above).

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Live vaccines must either be demonstrated to be safe in pregnant cattle (i.e. no transmission to the fetus), or should be licensed with a warning not to use them in pregnant animals. Live vaccines containing cytopathic strains should have an appropriate warning of the risk of inducing mucosal disease in PI cattle.

913 iv) Batch potency
914 BVD vaccines must be demonstrated to produce adequate immune responses, when used in their
915 final formulation according to the manufacturer's published instructions. The minimum quantity of
916 infectious virus and/or antigen required to produce an acceptable immune response should be
917 determined. *In-vitro* assays should be used to monitor individual batches during production.

918 **2.3. Requirements for authorisation/registration/licensing**

919 **2.3.1. Manufacturing process**

920 For registration of a vaccine, all relevant details concerning manufacture of the vaccine and quality
921 control testing should be submitted to the relevant authorities. Unless otherwise specified by the
922 authorities, information should be provided from three consecutive vaccine batches with a volume
923 not less than 1/3 of the typical industrial batch volume.

924 There is no standard method for the manufacture of a BVD vaccine, but conventional laboratory
925 techniques with stationary, rolled or suspension (micro-carriers) cell cultures may be used.
926 Inactivated vaccines can be prepared by conventional methods, such as binary ethylenimine or beta-
927 propiolactone inactivation (Park & Bolin, 1987). A variety of adjuvants may be used.

928 **2.3.2. Safety requirements**

929 *In-vivo* tests should be undertaken using a single dose, overdose (for live vaccines only) and repeat
930 doses (taking into account the maximum number of doses for primary vaccination and, if appropriate,
931 the first revaccination/booster vaccination) and contain the maximum permitted antigen load and,
932 depending on the formulation of the vaccine, the maximum number of vaccine strains.

933 i) Target and non-target animal safety

934 The safety of the final product formulation of both live and inactivated vaccines should be assessed
935 in susceptible young calves that are free of maternally derived antibodies and in pregnant cattle. They
936 should be checked for any local reactions following administration, and, in pregnant cattle, for any
937 effects on the unborn calf. Live attenuated vaccines may contribute to immunosuppression that might
938 increase mortality. It may also contribute to the development of mucosal disease in PI animals that
939 is an animal welfare concern. Therefore vaccination of PI animals with live attenuated vaccines
940 containing cytopathic BVDV should be avoided. Live attenuated vaccines must not be capable of
941 being transmitted to other unvaccinated animals that are in close contact.

942 ii) Reversion-to-virulence for attenuated/live vaccines and environmental considerations

943 Virus seeds that have been passaged at least up to and preferably beyond the passage limit specified
944 for the seed should be inoculated into young calves to confirm that there is no evidence of disease.
945 If a live attenuated vaccine has been registered for use in pregnant animals, reversion to virulence
946 tests should also include pregnant animals. Live attenuated vaccines should not be transmissible to
947 unvaccinated 'in-contact' animals.

948 iii) Precautions (hazards)

949 BVDV is not considered to be a human health hazard. Standard good microbiological practice should
950 be adequate for handling the virus in the laboratory. A live virus vaccine should be identified as
951 harmless for people administering the product. However adjuvants included in either live or
952 inactivated vaccines may cause injury to people. Manufacturers should provide adequate warnings
953 that medical advice should be sought in the case of self-injection (including for adjuvants, oil-emulsion
954 vaccine, preservatives, etc.) with warnings included on the product label/leaflet so that the vaccinator
955 is aware of any danger.

956 **2.3.3. Efficacy requirements**

957 The potency of the vaccine should be determined by inoculation into seronegative and virus negative
958 calves, followed by monitoring of the antibody response. Antigen content can be assayed by ELISA
959 and adjusted as required to a standard level for the particular vaccine. Standardised assay protocols
960 applicable to all vaccines do not exist. Live vaccine batches may be assayed by infectivity titration.
961 Each production batch of vaccine should undergo potency and safety testing as batch release criteria.
962 BVD vaccines must be demonstrated to produce adequate immune responses, as outlined above,
963 when used in their final formulation according to the manufacturer's published instructions.

964 **2.3.4. Vaccines permitting a DIVA strategy (detection of infection in vaccinated animals)**
965 To date, there are no commercially available vaccines for BVDV that support use of a true DIVA
966 strategy. Experimental subunit vaccines based on baculovirus-expressed BVD viral glycoprotein E2
967 have been described but are not available commercially. They offer a future prospect of 'marker
968 vaccines' when used in connection with a complementary serological test. Experimental BVDV E2
969 DNA vaccines and BVDV E2 subunit vaccines expressed using transgenic plants and alphavirus
970 replicon or chimeric pestivirus vaccines have also been described.

971 **2.3.5. Duration of immunity**
972 There are few published data on the duration of antibody following vaccination with a commercial
973 product. Protocols for their use usually recommend a primary course of two inoculations and boosters
974 at yearly intervals. Only limited data are available on the antibody levels that correlate with protection
975 against respiratory infections (Bolin & Ridpath, 1995; Howard *et al.*, 1989) or *in-utero* infection
976 (Brownlie *et al.*, 1995). However, there are many different commercial formulations and these involve
977 a range of adjuvants that may support different periods of efficacy. Consequently, duration of
978 immunity data must be generated separately for each commercially available product by undertaking
979 challenge tests at the end of the period for which immunity has been claimed.

980 **2.3.6. Stability**
981 There are no accepted guidelines for the stability of BVD vaccines, but it can be assumed that
982 attenuated virus vaccine (freeze-dried) should remain potent for at least 1 year if kept at 4°C.
983 Inactivated virus vaccine could have a longer shelf life at 4°C. Lower temperatures could prolong
984 shelf life for either type, but adjuvants in killed vaccine may preclude this. Bulk antigens that have not
985 been formulated into finished vaccine can be reliably stored frozen at low temperatures but the
986 antigen quality should be monitored with *in-vitro* assays prior to incorporation into a batch of vaccine.

987 REFERENCES

- 988 BAKER J.C. (1995). The clinical manifestations of bovine viral diarrhoea infection. *Vet. Clin. North. Am. – Food Animal*
989 *Practice*, **11**, 425–445.
- 990 BAUERMANN F.V., FLORES E.F. & RIDPATH J.F. (2012). Antigenic relationships between bovine viral diarrhoea virus 1 and 2
991 and HoBi virus: possible impacts on diagnosis and control. *J. Vet. Diagn. Invest.* (official publication of the American
992 Association of Veterinary Laboratory Diagnosticians), **24**, 253–261.
- 993 BAUERMANN F.V., HARMON A., FLORES E.F., FALKENBERG S.M., REECY J.M. & RIDPATH J.F. (2013). *In vitro* neutralization of
994 HoBi-like viruses by antibodies in serum of cattle immunized with inactivated or modified live vaccines of bovine viral
995 diarrhoea viruses 1 and 2. *Vet. Microbiol.*, **166**, 242–245.
- 996 BOLIN S.R. & RIDPATH J.F. (1992). Differences in virulence between two noncytopathic bovine viral diarrhoea viruses in
997 calves. *Am. J. Vet. Res.*, **53**, 2157–2163.
- 998 BOLIN S.R. & RIDPATH J.F. (1995). Assessment of protection from systemic infection or disease afforded by low to
999 intermediate titers of passively acquired neutralizing antibody against bovine viral diarrhoea virus in calves. *Am. J. Vet. Res.*,
1000 **56**, 755–759.
- 1001 BROWNLIE J. (1985). Clinical aspects of the bovine virus diarrhoea/mucosal disease complex in cattle. *In Practice*, **7**, 195–
1002 202.
- 1003 BROWNLIE J. (1990). The pathogenesis of bovine virus diarrhoea virus infections. *Rev. sci. tech. Off. int. Epiz.*, **9**, 43–59.
- 1004 BROWNLIE J., CLARKE M.C., HOOPER L.B. & BELL G.D. (1995). Protection of the bovine fetus from bovine viral diarrhoea virus
1005 by means of a new inactivated vaccine. *Vet. Rec.*, **137**, 58–62.
- 1006 CHEN M., LIU M., LIU S. & SHANG Y. (2021). HoBi-like pestivirus infection leads to bovine death and severe respiratory
1007 disease in China. *Transbound. Emerg. Dis.*, **68**, 1069–1074.

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- 1008 CORNISH T.E., VAN OLPHEN A.L., CAVENDER J.L., EDWARDS J.M., JAEGER P.T., VIEYRA L.L., WOODARD L.F., MILLER D.R. &
1009 O'TOOLE D. (2005). Comparison of ear notch immunohistochemistry, ear notch antigen-capture ELISA, and buffy coat virus
1010 isolation for detection of calves persistently infected with bovine viral diarrhoea virus. *J. Vet. Diagn. Invest.*, **17**, 110–117.
- 1011 DUFFELL S.J. & HARKNESS J.W. (1985). Bovine virus diarrhoea-mucosal disease infection in cattle. *Vet. Rec.*, **117**, 240–245.
- 1012 EDWARDS S. (1990). The diagnosis of bovine virus diarrhoea-mucosal disease in cattle. *Rev. sci. tech. Off. int. Epiz.*, **9**,
1013 115–130.
- 1014 FRAY M.D., MANN G.E., BLEACH E.C.L., KNIGHT P.G., CLARKE M.C. & CHARLESTON B. (2002). Modulation of sex hormone
1015 secretion in cows by acute infection with bovine viral diarrhoea virus. *Reproduction*, **123**, 281–289.
- 1016 FULTON R.W., SALIKI J.T., BURGE L.J., DOFFAY J.M., BOLIN S.R., MAES R.K., BAKER J.C. & FREY M.L. (1997). Neutralizing
1017 antibodies to type-1 and type-2 bovine viral diarrhoea viruses – detection by inhibition of viral cytopathology and infectivity
1018 by immunoperoxidase assay. *Clin. Diagn. Lab. Immunol.*, **4**, 380–383.
- 1019 FUX R. & WOLF G. (2012). Transient elimination of circulating bovine viral diarrhoea virus by colostral antibodies in
1020 persistently infected calves: a pitfall for BVDV-eradication programs? *Vet. Microbiol.*, **161**, 1.
- 1021 GIVENS M.D., RIDDELL K.P., WALZ P.H., RHOADES J., HARLAND R., ZHANG Y., GALIK P.K., BRODERSEN B.W., COCHRAN A.M.,
1022 BROCK K.V., CARSON R.L. & STRINGFELLOW D.A. (2007). Noncytopathic bovine viral diarrhoea virus can persist in testicular
1023 tissue after vaccination of peri-pubertal bulls but prevents subsequent infection. *Vaccine*, **25**, 867–876.
- 1024 HOFFMANN B., DEPNER K., SCHIRRMIEIER H. & BEER M. (2006). A universal heterologous internal control system for duplex
1025 real-time RT-PCR assays used in a detection system for pestiviruses *J. Virol. Methods*, **136**, 200–209.
- 1026 HOUE H., BAKER J.C., MAES R.K., RUEGG P.L. & LLOYD J.W. (1995). Application of antibody titers against bovine viral diarrhoea
1027 virus (BVDV) as a measure to detect herds with cattle persistently infected with BVDV. *J. Vet. Diagn. Invest.*, **7**, 327–332.
- 1028 HOWARD C.J., CLARKE M.C. & BROWNLIE J. (1989). Protection against respiratory infection with bovine virus diarrhoea virus
1029 by passively acquired antibody. *Vet. Microbiol.*, **19**, 195–203.
- 1030 LETELLIER C. & KERKHOFS P. (2003). Real-time PCR for simultaneous detection and genotyping of bovine viral diarrhoea
1031 virus. *J. Virol. Methods*, **114**, 21–27.
- 1032 MCGOLDRICK A., BENSANDE E., IBATA G., SHARP G. & PATON D. J. (1999). Closed one-tube reverse transcription nested
1033 polymerase chain reaction for the detection of pestiviral RNA with fluorescent probes. *J. Virol. Methods*, **79**, 85–95.
- 1034 MCGOWAN M.R. & KIRKLAND P.D. (1995). Early reproductive loss due to bovine pestivirus infection. *Br. Vet. J.*, **151**, 263–
1035 270.
- 1036 MEYLING A. (1984). Detection of BVD virus in viraemic cattle by an indirect immunoperoxidase technique. *In: Recent*
1037 *Advances in Virus Diagnosis (CEC Seminar)*, McNulty M.S. & McFerran J.B., eds. Martinus Nijhoff, Belfast, UK, 37–46.
- 1038 MOENNIG V. & LIESS B. (1995). Pathogenesis of intrauterine infections with bovine viral diarrhoea virus. *Vet. Clin. North. Am.*,
1039 **11**, 477–487.
- 1040 MOENNIG V., HOUE H. & LINDBERG A. (2005). BVD control in Europe: current status and perspectives. *Anim. Health Res.*
1041 *Rev.*, **6**, 63–74.
- 1042 NISKANEN R. (1993). Relationship between the levels of antibodies to bovine viral diarrhoea virus in bulk tank milk and the
1043 prevalence of cows exposed to the virus. *Vet. Rec.*, **133**, 341–344.
- 1044 PARK B.K. & BOLIN S.R. (1987). Molecular changes of bovine viral diarrhoea virus polypeptides treated with binary
1045 ethylenimine, beta-propiolactone and formalin. *Res. Rep. Rural Dev. Admin. (L&V) Korea*, **29**, 99–103.
- 1046 PATON D.J., SANDS J.J. LOWINGS J.P., SMITH J.E., IBATA G., EDWARDS S. (1995). A proposed division of the pestivirus genus
1047 using monoclonal antibodies, supported by cross-neutralisation assays and genetic sequencing. *Vet. Res.*, **26**, 92–109.
-

1048 SCHWEIZER M., STALDER H., HASLEBACHER A., GRISIGER M., SCHWERMER H. & DI LABIO E. (2021). Eradication of bovine viral
1049 diarrhoea (BVD) in cattle in Switzerland: Lessons taught by the complex biology of the virus. *Front. Vet. Sci.*, **8**, 702730.

1050 VILCEK S., PATON D.J., DURKOVIC B., STROJNY L., IBATA G., MOUSSA A., LOITSCH A., ROSSMANITH W., VEGA S., SCICLUNA M.T.
1051 & PALFI V. (2001). Bovine viral diarrhoea virus genotype 1 can be separated into at least eleven genetic groups. *Arch. Virol.*,
1052 **146**, 99–115.

1053 VOGES H., HORNER G.W., ROWE S. & WELLENBERG G.J. (1998). Persistent bovine pestivirus infection localized in the testes
1054 of an immuno-competent, non-viremic bull. *Vet. Microbiol.*, **61**, 165–175.

1055 ZIMMER G., SCHOUSTRA W. & GRAAT E. A.M. (2002). Predictive values of serum and bulk milk sampling for the presence of
1056 persistently infected BVDV carriers in dairy herds. *Res. Vet. Sci.*, **72**, 75–82.

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1059 **NB:** There are WOAHA Reference Laboratories for bovine viral diarrhoea (please consult the WOAHA Web site:

1060 <https://www.woah.org/en/what-we-offer/expertise-network/reference-laboratories/#ui-id-3>)

1061 Please contact the WOAHA Reference Laboratories for any further information on
1062 diagnostic tests, reagents and vaccines for bovine viral diarrhoea

1063 **NB:** FIRST ADOPTED IN 1990. MOST RECENT UPDATES ADOPTED IN 2015.

40 Western blotting using the reaction between the P32 antigen of LSDV with test sera is both sensitive and
41 specific, but is difficult and expensive to carry out.

42 **Requirements for vaccines:** All strains of capripoxvirus examined so far, whether derived from cattle,
43 sheep or goats, are antigenically similar. Attenuated cattle strains, and strains derived from sheep and goats
44 have been used as live vaccines against LSDV.

45 A. INTRODUCTION

46 Lumpy skin disease (LSD) was first seen in Zambia in 1929, spreading into Botswana by 1943 (Haig, 1957), and then into
47 South Africa the same year, where it affected over eight million cattle causing major economic loss. In 1957 it entered
48 Kenya, ~~at the same time as associated with~~ an outbreak of sheep pox (Weiss, 1968). In 1970 LSD spread north into the
49 Sudan, by 1974 it had spread west as far as Nigeria, and in 1977 was reported from Mauritania, Mali, Ghana and Liberia.
50 Another epizootic of LSD between 1981 and 1986 affected Tanzania, Kenya, Zimbabwe, Somalia and the Cameroon, with
51 reported mortality rates in affected cattle of 20%. The occurrence of LSD north of the Sahara desert and outside the African
52 continent was confirmed for the first time in Egypt and Israel between 1988 and 1989, and was reported again in 2006
53 (Brenner *et al.*, 2006). In the past decade, LSD occurrences have been reported in the Middle Eastern, European and
54 Asian regions (for up-to-date information, consult WOAAH WAHIS interface⁴⁰). Lumpy skin disease outbreaks tend to be
55 sporadic, depending upon animal movements, immune status, and wind and rainfall patterns affecting vector populations.
56 The principal method of transmission is thought to be mechanical by various arthropod vectors (Tuppurainen *et al.*, 2015).

57 Lumpy skin disease virus (LSDV) belongs to the family *Poxviridae*, subfamily ~~*Chordopoxvirinae*~~ *Chordopoxviridae*, and
58 genus *Capripoxvirus*. In common with other poxviruses LSDV replicates in the cytoplasm of an infected cell, forming distinct
59 perinuclear viral factories. The LSD virion is large and brick-shaped measuring 293–299nm (length) and 262–273nm
60 (width). The LSDV genome structure is also similar to other poxviruses, consisting of double-stranded linear DNA that is
61 25% GC-rich, approximately 150,000 bp in length, and encodes around 156 open reading frames (ORFs). An inverted
62 terminal repeat sequence of 2200–2300 bp is found at each end of the linear genome. The linear ends of the genome are
63 joined with a hairpin loop. The central region of the LSDV genome contains ORFs predicted to encode proteins required
64 for virus replication and morphogenesis and exhibit a high degree of similarity with genomes of other mammalian
65 poxviruses. The ORFs in the outer regions of the LSDV genome have lower similarity and likely encode proteins involved
66 in viral virulence and host range determinants.

67 Phylogenetic analysis shows the majority of LSDV strains group into two monophyletic clusters (cluster 1.1 and 1.2)
68 (Biswas *et al.*, 2020; Van Schalkwyk *et al.*, 2021). Cluster 1.1 consists of LSDV Neethling vaccine strains that are based
69 on the LSDV/Neethling/LW-1959 vaccine strain (Kara *et al.*, 2003; Van Rooyen *et al.*, 1959; van Schalkwyk *et al.*, 2020)
70 and historic wild-type strains from South Africa. Cluster 1.2 consists of wild-type strains from southern Africa, Kenya, the
71 northern hemisphere, and the Kenyan KSGP O-240 commercial vaccine. In addition to these two clusters, there have
72 recently been recombinant LSDV strains isolated from clinical cases of LSD in the field in Russia and central Asia (Flannery
73 *et al.*, 2021; Sprygin *et al.*, 2018; 2020; Wang *et al.*, 2021). These recombinant viruses show unique patterns of accessory
74 gene alleles, consisting of sections of both wild-type and “vaccine” LSDV strains.

75 The severity of the clinical signs of LSD is highly variable and depends on a number of factors, including the strain of
76 capripoxvirus the age of the host, immunological status and breed. *Bos taurus* is generally more susceptible to clinical disease
77 than *Bos indicus*; the Asian buffalo (*Bubalus spp.*) has also been reported to be susceptible. Within *Bos taurus*, the fine-
78 skinned Channel Island breeds develop more severe disease, with lactating cows appearing to be the most at risk. However,
79 even among groups of cattle of the same breed kept together under the same conditions, there is a large variation in the
80 clinical signs presented, ranging from subclinical infection to death (Carn & Kitching, 1995). There may be failure of the virus
81 to infect the whole group, probably depending on the virulence of the virus isolate, immunological status of the host, host
82 genotype, and vector prevalence. Seroprevalence studies, experimental infections and case reports have provided indications
83 that several wildlife species (e.g. springbok, impala, giraffe, camel, banteng) are susceptible to LSDV infection (Dao *et al.*,
84 2022; Hedger & Hamblin, 1983; Kumar *et al.*, 2023; Porco *et al.*, 2023). The scarcity of documented outbreaks in wildlife and
85 the fact that available studies remain limited in number and mostly involve only a few animals, make it difficult to determine
86 the role of wildlife in LSDV epidemiology. This topic deserves further study, especially given the current spread of LSDV in
87 new geographical areas where large numbers of naïve, potentially susceptible wild bovines and other ruminants are present.

88 The incubation period under field conditions has not been reported, but following experimental inoculation is 6–9 days until
89 the onset of fever. In the acutely infected animal, there is an initial pyrexia, which may exceed 41°C and persist for 1 week.
90 All the superficial lymph nodes become enlarged. In lactating cattle there is a marked reduction in milk yield. Lesions
91 develop over the body, particularly on the head, neck, udder, scrotum, vulva and perineum between 7 and 19 days after
92 virus inoculation (Coetzer, 2004). The characteristic integumentary lesions are multiple, well circumscribed to coalescing,
93 0.5–5 cm in diameter, firm, flat-topped papules and nodules. The nodules involve the dermis and epidermis, and may

40 <https://www.woah.org/en/what-we-do/animal-health-and-welfare/disease-data-collection/>

94 extend to the underlying subcutis and occasionally to the adjacent striated muscle. These nodules have a creamy grey to
 95 white colour on cut section, which may initially exude serum, but over the ensuing 2 weeks a cone-shaped central core or
 96 sequestrum of necrotic material/necrotic plug ("sit-fast") may appear within the nodule. The acute histological lesions
 97 consist of epidermal vacuolar changes with intracytoplasmic inclusion bodies and dermal vasculitis. The inclusion bodies
 98 are numerous, intracytoplasmic, eosinophilic, homogenous to occasionally granular and they may occur in endothelial
 99 cells, fibroblasts, macrophages, pericytes, and keratinocytes. The dermal lesions include vasculitis with fibrinoid necrosis,
 100 oedema, thrombosis, lymphangitis, dermal-epidermal separation, and mixed inflammatory infiltrate. The chronic lesions
 101 are characterised by an infarcted tissue with a sequestered necrotic core, often rimmed by granulation tissue gradually
 102 replaced by mature fibrosis. At the appearance of the nodules, the discharge from the eyes and nose becomes
 103 mucopurulent, and keratitis may develop. Nodules may also develop in the mucous membranes of the mouth and
 104 alimentary tract, particularly the abomasum and in the trachea and the lungs, resulting in primary and secondary
 105 pneumonia. The nodules on the mucous membranes of the eyes, nose, mouth, rectum, udder and genitalia quickly
 106 ulcerate, and by then all secretions, ocular and nasal discharge and saliva contain LSD virus (LSDV). The limbs may be
 107 oedematous and the animal is reluctant to move. Pregnant cattle may abort, and there is a report of intrauterine
 108 transmission (Rouby & Aboulsoudb, 2016). Bulls may become permanently or temporarily infertile and the virus can be
 109 excreted in the semen for prolonged periods (Irons *et al.*, 2005). Recovery from severe infection is slow; the animal is
 110 emaciated, may have pneumonia and mastitis, and the necrotic plugs of skin, which may have been subject to fly strike,
 111 are shed leaving deep holes in the hide (Prozesky & Barnard, 1982).

112 The main differential diagnosis is pseudo-LSD caused by bovine herpesvirus 2 (BoHV-2). This is usually a milder clinical
 113 condition, characterised by superficial nodules, resembling only the early stage of LSD. Intra-nuclear inclusion bodies and
 114 viral syncytia are histopathological characteristics of BoHV-2 infection not seen in LSD. Other differential diagnoses (for
 115 integumentary lesions) include: dermatophilosis, dermatophytosis, bovine farcy, photosensitisation, actinomycosis,
 116 actinobacillosis, urticaria, insect bites, besnoitiosis, nocardiosis, demodicosis, onchocerciasis, pseudo-cowpox, and
 117 cowpox. Differential diagnoses for mucosal lesions include: foot and mouth disease, bluetongue, mucosal disease,
 118 malignant catarrhal fever, infectious bovine rhinotracheitis, and bovine papular stomatitis.

119 LSDV is not transmissible to humans. However, all laboratory manipulations must be performed at an appropriate
 120 containment level determined using biorisk analysis (see Chapter 1.1.4 *Biosafety and biosecurity: Standard for managing*
 121 *biological risk in the veterinary laboratory and animal facilities*).

122 B. DIAGNOSTIC TECHNIQUES

123 **Table 1.** Test methods available for the diagnosis of LSD and their purpose

Method	Purpose					
	Population freedom from infection	Individual animal freedom from infection prior to movement	Contribute to eradication policies	Confirmation of clinical cases	Prevalence of infection – surveillance	Immune status in individual animals or populations post-vaccination
Detection of the agent						
Virus isolation	+	++	+	+++	+	–
PCR	++	+++	++	+++	+	–
TEM	–	–	–	+	–	–
Detection of immune response						
VNT	++	++	++	++	++	++
IFAT	+	+	+	+	+	+
ELISA	++	++	++	++	++	++

124 Key: +++ = recommended for this purpose; ++ recommended but has limitations;
 125 + = suitable in very limited circumstances; – = not appropriate for this purpose.

126 PCR = polymerase chain reaction; TEM = Transmission electron microscopy; VNT = virus neutralisation test;
 127 IFAT = indirect fluorescent antibody test; ELISA = enzyme-linked immunosorbent assay.

128 **1. Detection of the agent**

129 **1.1. Specimen collection, submission and preparation**

130 Material for virus isolation and antigen detection should be collected as biopsies or from skin nodules at post-mortem
131 examination. Samples for virus isolation should preferably be collected within the first week of the occurrence of
132 clinical signs, before the development of neutralising antibodies (Davies, 1991; Davies *et al.*, 1971), however virus
133 can be isolated from skin nodules for at least 3–4 weeks thereafter. Samples for genome detection using conventional
134 or real-time polymerase chain reaction (PCR) may be collected when neutralising antibody is present. Following the
135 first appearance of the skin lesions, the virus can be isolated for up to 35 days and viral nucleic acid can be
136 demonstrated via PCR for up to 3 months (Tuppurainen *et al.*, 2005; Weiss, 1968). Buffy coat from blood collected
137 into heparin or EDTA (ethylene diamine tetra-acetic acid) during the viraemic stage of LSD (before generalisation of
138 lesions or within 4 days of generalisation), can also be used for virus isolation. Samples for histology should include
139 the lesion and tissue from the surrounding (non-lesion) area, be a maximum size of 2 cm³, and be placed immediately
140 following collection into ten times the sample volume of 10% neutral buffered formal saline.

141 Tissues in formalin have no special transportation requirements in regard to biorisks. Blood samples with
142 anticoagulant for virus isolation from the buffy coat should be placed immediately on ice after gentle mixing and
143 processed as soon as possible. In practice, the samples may be kept at 4°C for up to 2 days prior to processing, but
144 should not be frozen or kept at ambient temperatures. Tissues for virus isolation and antigen detection should be kept
145 at 4°C, on ice or at –20°C. If it is necessary to transport samples over long distances without refrigeration, the medium
146 should contain 10% glycerol; the samples should be of sufficient size (e.g. 1 g in 10 ml) that the transport medium
147 does not penetrate the central part of the biopsy, which should be used for virus isolation.

148 ~~Samples for histology should include the lesion and tissue from the surrounding (non-lesion) area, be a maximum~~
149 ~~size of 2 cm³, and be placed immediately following collection into ten times the sample volume of 10% neutral buffered~~
150 ~~formaldehyde. Tissues in formalin have no special transportation requirements in regard to biorisks.~~ Material for
151 histology should be prepared using standard techniques and stained with haematoxylin and eosin (H&E) (Burdin,
152 1959). Lesion material for virus isolation and antigen detection is minced using a sterile scalpel blade and forceps
153 and then macerated in a sterile steel ball-bearing mixer mill, or ground with a pestle in a sterile mortar with sterile
154 sand and an equal volume of sterile phosphate buffered saline (PBS) or serum-free modified Eagle's medium
155 containing sodium penicillin (1000 international units [IU]/ml), streptomycin sulphate (1 mg/ml), mycostatin
156 (100 IU/ml) or fungizone (amphotericin, 2.5 µg/ml) and neomycin (200 IU/ml). The suspension is freeze–thawed three
157 times and then partially clarified using a bench centrifuge at 600 *g* for 10 minutes. In cases where bacterial
158 contamination of the sample is expected (such as when virus is isolated from skin samples), the supernatant can be
159 filtered through a 0.45 µm pore size filter after the centrifugation step. Buffy coats may be prepared from unclotted
160 blood using centrifugation at 600 *g* for 15 minutes, and the buffy coat carefully removed into 5 ml of cold double-
161 distilled water using a sterile Pasteur pipette. After 30 seconds, 5 ml of cold double-strength growth medium is added
162 and mixed. The mixture is centrifuged at 600 *g* for 15 minutes, the supernatant is discarded and the cell pellet is
163 suspended in 5 ml growth medium, such as Glasgow's modified Eagle's medium (GMEM). After centrifugation at
164 600 *g* for a further 15 minutes, the resulting pellet is suspended in 5 ml of fresh GMEM. Alternatively, the buffy coat
165 may be separated from a heparinised sample by using a Ficoll gradient.

166 **1.2. Virus isolation on cell culture**

167 LSDV will grow in tissue culture of bovine, ovine or caprine origin. MDBK (Madin–Darby bovine kidney) cells are often
168 used, as they support good growth of the virus and are well characterised (Fay *et al.*, 2020). Primary cells, such as
169 lamb testis (LT) cells also support viral growth, but care needs to be taken to ensure they are not contaminated with
170 viruses such as bovine viral diarrhoea virus. One ml of clarified supernatant or buffy coat is inoculated onto a confluent
171 monolayer in a 25 cm² culture flask at 37°C and allowed to adsorb for 1 hour. The culture is then washed with warm
172 PBS and covered with 10 ml of a suitable medium, such as GMEM, containing antibiotics and 2% fetal calf serum. If
173 available, tissue culture tubes containing appropriate cells and a flying cover-slip, or tissue culture microscope slides,
174 are also infected.

175 The flasks/tissue culture tubes are examined daily for 7–14 days for evidence of cytopathic effects (CPE). Infected
176 cells develop a characteristic CPE consisting of retraction of the cell membrane from surrounding cells, and eventually
177 rounding of cells and margination of the nuclear chromatin. At first only small areas of CPE can be seen, sometimes
178 as soon as 2 days after infection; over the following 4–6 days these expand to involve the whole cell monolayer sheet.
179 If no CPE is apparent by day 14, the culture should be freeze–thawed three times, and clarified supernatant inoculated
180 on to a fresh cell monolayer. At the first sign of CPE in the flasks, or earlier if a number of infected cover-slips are
181 being used, a cover-slip should be removed, fixed in acetone and stained using H&E. Eosinophilic intracytoplasmic
182 inclusion bodies, which are variable in size but up to half the size of the nucleus and surrounded by a clear halo, are
183 diagnostic for poxvirus infection. PCR may be used as an alternative to H&E for confirmation of the diagnosis. The

184 CPE can be prevented or delayed by adding specific anti-LSDV serum to the medium. In contrast, the herpesvirus
185 that causes pseudo-LSD produces a Cowdry type A intranuclear inclusion body. It also forms syncytia.

186 An ovine testis cell line (OA3.T₉) has been evaluated for the propagation of capripoxvirus isolates (Babiuk *et al.*,
187 2007), however this cell line has been found to be contaminated with pestivirus and should be used with caution.

188 1.3. Polymerase chain reaction (PCR)

189 The conventional gel-based PCR method described below is a simple, fast and sensitive method for the detection of
190 capripoxvirus genome in EDTA blood, semen or tissue culture samples (Tuppurainen *et al.*, 2005).

191 1.3.1. Test procedure

192 The extraction method described below can be replaced using commercially available DNA extraction
193 kits.

194 i) Freeze and thaw 200 µl of blood in EDTA, semen or tissue culture supernatant and suspend in
195 100 µl of lysis buffer containing 5 M guanidine thiocyanate, 50 mM potassium chloride, 10 mM
196 Tris/HCl (pH 8); and 0.5 ml Tween 20.

197 ii) Cut skin and other tissue samples into fine pieces using a sterile scalpel blade and forceps.
198 Grind with a pestle in a mortar. Suspend the tissue samples in 800 µl of the above mentioned
199 lysis buffer.

200 iii) Add 2 µl of proteinase K (20 mg/ml) to blood samples and 10 µl of proteinase K (20 mg/ml) to
201 tissue samples. Incubate at 56°C for 2 hours or overnight, followed by heating at 100°C for
202 10 minutes. Add phenol:chloroform:isoamylalcohol (25:24:1 [v/v]) to the samples in a 1:1 ratio.
203 Vortex and incubate at room temperature for 10 minutes. Centrifuge the samples at 16,060 **g**
204 for 15 minutes at 4°C. Carefully collect the upper, aqueous phase (up to 200 µl) and transfer
205 into a clean 2.0 ml tube. Add two volumes of ice cold ethanol (100%) and 1/10 volume of 3 M
206 sodium acetate (pH 5.3). Place the samples at -20°C for 1 hour. Centrifuge again at 16,060 **g**
207 for 15 minutes at 4°C and discard the supernatant. Wash the pellets with ice cold 70% ethanol
208 (100 µl) and centrifuge at 16,060 **g** for 1 minute at 4°C. Discard the supernatant and dry the
209 pellets thoroughly. Suspend the pellets in 30 µl of nuclease-free water and store immediately at
210 -20°C (Tuppurainen *et al.*, 2005). Alternatively a column-based extraction kit may be used.

211 iv) The primers for this PCR assay were developed from the gene encoding the viral attachment
212 protein. The size of the expected amplicon is 192 bp (Ireland & Binopal, 1998). The primers
213 have the following gene sequences:

214 Forward primer 5'-TCC-GAG-CTC-TTT-CCT-GAT-TTT-TCT-TAC-TAT-3'

215 Reverse primer 5'-TAT-GGT-ACC-TAA-ATT-ATA-TAC-GTA-AAT-AAC-3'.

216 v) DNA amplification is carried out in a final volume of 50 µl containing: 5 µl of 10 × PCR buffer,
217 1.5 µl of MgCl₂ (50 mM), 1 µl of dNTP (10 mM), 1 µl of forward primer, 1 µl of reverse primer,
218 1 µl of DNA template (~10 ng), 0.5 µl of *Taq* DNA polymerase and 39 µl of nuclease-free water.
219 The volume of DNA template required may vary and the volume of nuclease-free water must
220 be adjusted to the final volume of 50 µl.

221 vi) Run the samples in a thermal cycler as follows: 2 minutes at 95°C; then 45 seconds at 95°C,
222 50 seconds at 50°C and 1 minute at 72°C (34 cycles); 2 minutes at 72°C and hold at 4°C until
223 analysis.

224 vii) Mix 10 µl of each sample with loading dye and load onto a 1.5% agarose gel in TAE buffer
225 (Tris/acetate buffer containing EDTA). Load a parallel lane with a 100 bp DNA-marker ladder.
226 Electrophoretically separate the products using approximately 8–10 V/cm for 40–60 minutes
227 and visualise with a suitable DNA stain and transilluminator.

228 Quantitative real-time PCR methods have been described that are reported to be faster and have
229 higher sensitivity than conventional PCRs (Balinsky *et al.*, 2008; Bowden *et al.*, 2008). A real-time
230 PCR method that differentiates between LSDV, sheep pox virus and goat pox virus has been
231 published (Lamien *et al.*, 2011).

232 Quantitative real-time PCR assays have been designed to differentiate between Neethling-based
233 LSDV strains, which are often used for vaccination, and wild-type LSDV strains from cluster 1.2
234 (Agianniotaki *et al.*, 2017; Pestova *et al.*, 2018; Vidanovic *et al.*, 2016). These “DIVA” assays (DIVA:
235 differentiation of infected from vaccinated animals) enable, for example, differentiation of “Neethling

236 response” caused by vaccination with a LSDV Neethling vaccine strain from disease caused by
237 infection with a cluster 1.2 wild-type virus. However these DIVA PCR assays cannot distinguish
238 between a LSDV Neethling vaccine strain and the novel recombinant LSDV strains ~~recently~~-isolated
239 from disease outbreaks in Asia (Byadovskaya *et al.*, 2021; Flannery *et al.*, 2021). These DIVA assays
240 are also not capable of discriminating between LSDV Neethling vaccine strains and recently
241 characterised (historic) wild-type viruses from South Africa belonging within cluster 1.1 (Van
242 Schalkwyk *et al.*, 2020; 2021). Consequently, in regions where recombinant strains (currently Asia
243 and possibly elsewhere) or wild-type cluster 1.1 strains are circulating (currently South Africa and
244 possibly elsewhere), these DIVA assays are not suitable for distinguishing vaccine and wild-type
245 virus. Thus, in order to overcome these constraints, whole genome sequencing is recommended.

246 1.4. Transmission electron microscopy

247 The characteristic poxvirus virion can be visualised using a negative staining preparation technique followed by
248 examination with an electron microscope. There are many different negative staining protocols, an example of which
249 is given below.

250 1.4.1. Test procedure

251 Before centrifugation, material from the original biopsy suspension is prepared for examination under
252 the transmission electron microscope by floating a 400-mesh hexagonal electron microscope grid,
253 with pioloform-carbon substrate activated by glow discharge in pentylamine vapour, onto a drop of
254 the suspension placed on parafilm or a wax plate. After 1 minute, the grid is transferred to a drop of
255 Tris/EDTA buffer, pH 7.8, for 20 seconds and then to a drop of 1% phosphotungstic acid, pH 7.2, for
256 10 seconds. The grid is drained using filter paper, air-dried and placed in the electron microscope.
257 The capripox virion is brick shaped, covered in short tubular elements and measures approximately
258 290 × 270 nm. A host-cell-derived membrane may surround some of the virions, and as many as
259 possible should be examined to confirm their appearance (Kitching & Smale, 1986).

260 The ~~capripox~~-virions of capripoxvirus are indistinguishable from those of orthopoxvirus, but, apart
261 from vaccinia virus and cowpox virus, which are both uncommon in cattle and do not cause
262 generalised infection, no other orthopoxvirus is known to cause lesions in cattle. However, vaccinia
263 virus may cause generalised infection in young immunocompromised calves. In contrast,
264 orthopoxviruses are a common cause of skin disease in domestic buffalo (*Bubalus bubalis*) causing
265 buffalo pox, a disease that usually manifests as pock lesions on the teats, but may cause skin lesions
266 at other sites, such as the perineum, the medial aspects of the thighs and the head. Orthopoxviruses
267 that cause buffalo pox cannot be readily distinguished from capripoxvirus by electron microscopy.
268 The virions of parapoxvirus ~~virions~~ that cause bovine papular stomatitis and pseudocowpox are
269 smaller, oval in shape and each is covered in a single continuous tubular element that appears as
270 striations over the virion. Capripoxvirus virions are also distinct from the herpesvirus that causes
271 pseudo-LSD (also known as “Allerton” or bovine herpes mammillitis).

272 1.5. Fluorescent antibody tests

273 Capripoxvirus antigen can be identified on infected cover-slips or tissue culture slides using fluorescent antibody
274 tests. Cover-slips or slides should be washed and air-dried and fixed in cold acetone for 10 minutes. The indirect test
275 using immune cattle sera is subject to high background colour and nonspecific reactions. However, a direct conjugate
276 can be prepared from sera from convalescent cattle (or from sheep or goats convalescing from capripox) or from
277 rabbits hyperimmunised with purified capripoxvirus. Uninfected tissue culture should be included as a negative control
278 as cross-reactions can cause problems due to antibodies to cellular components (pre-absorption of these from the
279 immune serum helps solve this issue).

280 1.6. Immunohistochemistry

281 Immunohistochemistry using F80G5 monoclonal antibody specific for capripoxvirus ORF 057 has been described for
282 detection of LSDV antigen in the skin of experimentally infected cattle (Babiuk *et al.*, 2008).

283 1.7. Isothermal genome amplification

284 Molecular tests using loop-mediated isothermal amplification to detect capripoxvirus genomes are reported to provide
285 sensitivity and specificity similar to real-time PCR with a simpler method and lower cost (Das *et al.*, 2012; Murray *et al.*,
286 2013). Field validation of the Das *et al.* method was reported by Omoga *et al.* (2016).

287 2. Serological tests

288 All the viruses in the genus *Capripoxvirus* share a common major antigen for neutralising antibodies and it is thus not
289 possible to distinguish strains of capripoxvirus from cattle, sheep or goats using serological techniques.

290 2.1. Virus neutralisation

291 A test serum can either be titrated against a constant titre of capripoxvirus (100 TCID₅₀ [50% tissue culture infective
292 dose]) or a standard virus strain can be titrated against a constant dilution of test serum in order to calculate a
293 neutralisation index. Because of the variable sensitivity of tissue culture to capripoxvirus, and the consequent difficulty
294 of ensuring the accurate and repeatable seeding of 100 TCID₅₀/well, the neutralisation index is the preferred method
295 in most laboratories, although it does require a larger volume of test sera. The test is described using 96-well flat-
296 bottomed tissue-culture grade microtitre plates, but it can be performed equally well in tissue culture tubes with the
297 appropriate changes to the volumes used, although it is more difficult to read an end-point in tubes.

298 2.1.1. Test procedure

- 299 i) Test sera, including a negative and a positive control, are diluted 1/5 in Eagle's/HEPES (N-2-
300 hydroxyethylpiperazine, N-2-ethanesulphonic acid) buffer and inactivated at 56°C for
301 30 minutes.
- 302 ii) Next, 50 µl of the first inactivated serum is added to columns 1 and 2, rows A to H of the
303 microtitre plate. The second serum is placed in columns 3 and 4, the third in columns 5 and 6,
304 the positive control serum is placed in columns 7 and 8, the negative control serum is placed in
305 columns 9 and 10, and 50 µl of Eagle's/HEPES buffer (without serum) is placed in columns 11
306 and 12, and to all wells in row H.
- 307 iii) A reference strain of capripoxvirus, usually a vaccine strain known to grow well in tissue culture,
308 with a titre of over log₁₀ 6 TCID₅₀ per ml is diluted in Eagle's/HEPES in bijoux bottles to give a
309 log dilution series of log₁₀ 5.0, 4.0, 3.5, 3.0, 2.5, 2.0, 1.5 TCID₅₀ per ml (equivalent to log₁₀ 3.7,
310 2.7, 2.2, 1.7, 1.2, 0.7, 0.2 TCID₅₀ per 50 µl).
- 311 iv) Starting with row G and the most diluted virus preparation, 50 µl of virus is added to each well
312 in that row. This is repeated with each virus dilution, the highest titre virus dilution being placed
313 in row A.
- 314 v) The plates are covered and incubated for 1 hour at 37°C.
- 315 vi) An appropriate cell suspension (such as MDBK cells) is prepared from pregrown monolayers
316 as a suspension of 10⁵ cells/ml in Eagle's medium containing antibiotics and 2% fetal calf serum.
317 Following incubation of the microtitre plates, 100 µl of cell suspension is added to all the wells,
318 except wells H11 and H12, which serve as control wells for the medium. The remaining wells of
319 row H are cell and serum controls.
- 320 vii) The microtitre plates are covered and incubated at 37°C for 9 days.
- 321 viii) Using an inverted microscope, the monolayers are examined daily from day 4 for evidence of
322 CPE. There should be no CPE in the cells of row H. Using the 0240 KSGP vaccine strain of
323 capripoxvirus, by way of example, the final reading is taken on day 9, and the titre of virus in
324 each duplicate titration is calculated using the Kärber method. If left longer, there is invariably a
325 'breakthrough' of virus in which virus that was at first neutralised appears to disassociate from
326 the antibody.
- 327 ix) *Interpretation of the results:* The neutralisation index is the log titre difference between the titre
328 of the virus in the negative serum and in the test serum. An index of ≥1.5 is positive. The test
329 can be made more sensitive if serum from the same animal is examined before and after
330 infection. Because the immunity to capripoxviruses is predominantly cell mediated, a negative
331 result, particularly following vaccination, after which the antibody response may be low, does
332 not imply that the animal from which the serum was taken is not protected.
- 333 x) Antibodies to capripoxvirus can be detected from 1 to 2 days after the onset of clinical signs.
334 These remain detectable for about 7 months.

335 2.2. Enzyme-linked immunosorbent assay

336 Enzyme-linked immunosorbent assays (ELISAs) for the detection of capripoxviral antibodies are widely used and are
337 available in commercial kit form (Milovanovic *et al.*, 2019; Samojlovic *et al.*, 2019).

338

2.3. Indirect fluorescent antibody test

339 Capripoxvirus-infected tissue culture grown on cover-slips or tissue culture microscope slides can be used for the
340 indirect fluorescent antibody test. Uninfected tissue culture control, and positive and negative control sera, should be
341 included in the test. The infected and control cultures are fixed in acetone at -20°C for 10 minutes and stored at 4°C .
342 Dilutions of test sera are made in PBS, starting at 1/20 or 1/40, and positive samples are identified using an anti-
343 bovine gamma-globulin conjugated with fluorescein isothiocyanate. Antibody titres may exceed 1/1000 after infection.
344 Sera may be screened at 1/50 and 1/500. Cross-reactions can occur with orf virus (contagious pustular dermatitis
345 virus of sheep), bovine papular stomatitis virus and perhaps other poxviruses.

346

2.4. Western blot analysis

347 Western blotting of test sera against capripoxvirus-infected cell lysate provides a sensitive and specific system for
348 the detection of antibody to capripoxvirus structural proteins, although the test is expensive and difficult to carry out.

349 Capripoxvirus-infected LT cells should be harvested when 90% CPE is observed, freeze-thawed three times, and
350 the cellular debris pelleted using centrifugation. The supernatant should be decanted, and the proteins should be
351 separated using SDS/PAGE (sodium dodecyl sulphate/polyacrylamide gel electrophoresis). A vertical discontinuous
352 gel system, using a stacking gel made up of acrylamide (5%) in Tris (125 mM), pH 6.8, and SDS (0.1%), and a
353 resolving gel made up of acrylamide (10–12.5%) in Tris (560 mM), pH 8.7, and SDS (0.1%), is recommended for use
354 with a glycine running buffer containing Tris (250 mM), glycine (2 M), and SDS (0.1%). Samples of supernatant should
355 be prepared by boiling for 5 minutes with an appropriate lysis buffer prior to loading. Alternatively, purified virus or
356 recombinant antigens may replace tissue-culture-derived antigen.

357 Molecular weight markers should be run concurrently with the protein samples. The separated proteins in the
358 SDS/PAGE gel should be transferred electrophoretically to a nitrocellulose membrane (NCM). After transfer, the NCM
359 is rinsed thoroughly in PBS and blocked in 3% bovine serum albumin (BSA) in PBS, or 5% skimmed milk powder in
360 PBS, on a rotating shaker at 4°C overnight. The NCM can then be separated into strips by employing a commercial
361 apparatus to allow the concurrent testing of multiple serum samples, or may be cut into strips and each strip incubated
362 separately thereafter. The NCM is washed thoroughly with five changes of PBS for 5 minutes on a rotating shaker,
363 and then incubated at room temperature on the shaker for 1.5 hours, with the appropriate serum at a dilution of 1/50
364 in blocking buffer (3% BSA and 0.05% Tween 20 in PBS; or 5% milk powder and 0.05% Tween 20 in PBS). The
365 membrane is again thoroughly washed and incubated (in blocking buffer) with anti-species immunoglobulin
366 horseradish-peroxidase-conjugated immunoglobulins at a dilution determined using titration. After further incubation
367 at room temperature for 1.5 hours, the membrane is washed and a solution of diaminobenzidine tetrahydrochloride
368 (10 mg in 50 ml of 50 mM Tris/HCl, pH 7.5, and 20 μl of 30% [v/v] hydrogen peroxide) is added. Incubation is
369 then undertaken for approximately 3–7 minutes at room temperature on a shaker with constant observation, and the
370 reaction is stopped by washing the NCM in PBS before excessive background colour is seen. A positive and negative
371 control serum should be used on each occasion.

372 Positive test samples and the positive control will produce a pattern consistent with reaction to proteins of molecular
373 weights 67, 32, 26, 19 and 17 kDa – the major structural proteins of capripoxvirus – whereas negative serum samples
374 will not react with all these proteins. Hyperimmune serum prepared against parapoxvirus (bovine papular stomatitis
375 or pseudocowpox virus) will react with some of the capripoxvirus proteins, but not the 32 kDa protein that is specific
376 for capripoxvirus.

377

C. REQUIREMENTS FOR VACCINES

378

1. Background: rationale and intended use of the product

379 Live attenuated strains of capripoxvirus have been used as vaccines specifically for the control of LSD (Brenner *et al.*,
380 2006; Capstick & Coakley, 1961; Carn, 1993). Capripoxviruses are cross reactive within the genus. Consequently, it is
381 possible to protect cattle against LSD using strains of capripoxvirus derived from sheep or goats (Coakley & Capstick,
382 1961). However, it is recommended to carry out controlled trials, using the most susceptible breeds, prior to introducing a
383 vaccine strain not usually used in cattle. The duration of protection provided by LSD vaccination is unknown.

384 Capripoxvirus vaccine strains can produce a large local reaction at the site of inoculation in *Bos taurus* breeds (Davies,
385 1991), which some stock owners find unacceptable. This has discouraged the use of vaccine, even though the
386 consequences of an outbreak of LSD are invariably more severe. Risk-benefit of vaccination should be assessed following
387 stakeholder discussion.

388 Vaccines are a key tool to control LSD. Different types of LSD vaccines have been developed and several are commercially
389 available (Tuppurainen *et al.*, 2021).

390 Live attenuated vaccines (LAV) based on the Neethling LSDV strain (homologous LAV vaccines) have been shown to offer
391 high levels of protection against LSD under experimental conditions (Haegeman *et al.*, 2021) and have been used
392 successfully to control the disease in the field, through systematic vaccination of the entire country's cattle population for
393 a number of consecutive years (Klement *et al.*, 2020). Homologous vaccines may induce fever, produce a local reaction
394 at the site of inoculation, cause a temporary reduction in milk production and on rare occasions induce a 'Neethling'
395 response (Ben-Gera *et al.*, 2015; Davies, 1991; Haegeman *et al.*, 2021). Such adverse effects, however, usually resolve
396 within a few days and are largely outweighed by the overall benefits of vaccination with homologous vaccines. The duration
397 of immunity induced by good quality live attenuated LSDV vaccines was shown to be at least 18 months (Haegeman *et*
398 *al.*, 2023).

399 As capripox viruses provide cross-reactive protection within the genus, heterologous LAVs comprising sheep pox virus or
400 goat pox virus strains have also been tested and used to protect cattle against LSD. Sheep pox virus-based heterologous
401 vaccines usually contain higher doses of virus than when administered to sheep. Although safe, their effectiveness in
402 protecting cattle against LSD is inferior compared to homologous vaccines (Ben-Gera *et al.*, 2015; Zhugunisso *et al.*,
403 2020). Heterologous vaccines containing goat pox virus strains for use in cattle against LSD have been developed more
404 recently. One such vaccine based on the Gorgan strain provided protection under experimental conditions comparable to
405 homologous vaccines (Gari *et al.*, 2015). On the other hand, a goat pox vaccine based on an attenuated Uttarkashi goat
406 pox virus strain performed suboptimally under field conditions in India (Naveem *et al.*, 2023), indicating that further research
407 is warranted before asserting that all goat pox virus-based vaccines induce protection equal to homologous vaccines in
408 cattle against LSD.

409 In addition, homologous inactivated vaccines against LSD have been developed and tested (Haegeman *et al.*, 2023; Hamdi
410 *et al.*, 2020; Wolff *et al.*, 2022). These vaccines are reported to be safe and efficacious. They however require a booster
411 vaccination one month after primo-vaccination and then every 6 months thereafter, based on the fact that the duration of
412 immunity is shorter than 1 year (Haegeman *et al.*, 2023).

413 None of the commercial vaccines currently available has practical DIVA capacity. This problem may be resolved in the
414 future by introducing new types of vaccines (e.g. vector-vaccines, subunit vaccines, mRNA vaccines) that are at various
415 stages of development and evaluation.

416 **2. Outline of production of LSD vaccines and minimum requirements for conventional** 417 **vaccines**

418 General requirements set for the facilities used for the production of vaccines and for the documentation and record keeping
419 throughout the whole manufacturing process are described in Chapter 1.1.8 *Principles of veterinary vaccine production*.
420 The documentation should include standard operating procedures (SOP) for the method of manufacture and each step for
421 the testing of cells and reagents used in the process, each batch and the final product.

422 The production of vaccines, including LSD vaccines, starts within research and development (R&D) facilities where vaccine
423 candidates are produced and tested in preclinical studies to demonstrate the quality, safety and efficacy of the product.

424 Minimum requirements for different production stages of veterinary vaccines are available in different chapters of the
425 *Terrestrial Manual*. These are intended to be used in combination with country-specific regulatory requirements for vaccine
426 production and release. Here we outline the most important requirements for the production of live and inactivated LSD
427 vaccines. Full requirements are available in Chapter 1.1.8 *Principles of veterinary vaccine production*, Chapter 2.3.3
428 *Minimum requirements for the organisation and management of a vaccine manufacturing facility* and Chapter 2.3.4
429 *Minimum requirements for the production and quality control of vaccine*, and other regulatory documentation.

430 **2.1. Quality assurance**

431 Facilities for manufacturing LSD vaccines should operate in line with the concepts of good laboratory practice (GLP)
432 and good manufacturing practice (GMP) to produce high quality products. Quality risk management and quality
433 control with adequate documentation management, as an integral part of the production process, have to be in place.
434 In case some activities of the production process are outsourced, those should also be appropriately defined,
435 recorded and controlled.

436 The vaccine production process (Outline of Production) should be documented in a series of standard operating
437 procedures (SOPs), or other documents describing the manufacturing of each batch and the final product (including
438 starting materials to be used, manufacturing steps, in-process controls and controls on the final product). Detailed
439 requirements for documentation management in the process of vaccine production are available in Chapter 2.3.3.

440 A completed Outline of Production is to be enclosed in a vaccine candidate dossier and used for the evaluation of
441 the production process and product by regulatory bodies.

442 **2.2. Process validation**

443 The dossier with the enclosed Outline of Production for the vaccine candidate has to be submitted for regulatory
444 approval, so it can be assessed and authorised by the competent authority to ensure compliance with local regulatory
445 requirements. Among others, data on quality, safety, and efficacy will be assessed. The procedures necessary to
446 obtain these data are described in the subsequent sections.

447 National regulatory authorities might also require official control authority re-testing (check testing) of final products
448 and batches in government laboratories or an independent batch quality control by a third party.

449 **3. Requirements for LSD vaccine candidates and batch production**

450 **3.1. Requirements for starting materials**

451 Live attenuated vaccines (LAV) and inactivated vaccines (IV) for LSD are produced using the system of limited and
452 controlled passages of master seed and working seed virus and cell banks with a specified maximum. This approach
453 aims to prevent possible and unwanted drift of properties of seed virus and cells that might arise from repeated
454 passaging.

455 **3.1.1. Characteristics of the seed virus**

456 Each seed strain of capripoxvirus used for vaccine production must be accompanied by records
457 clearly and accurately describing its origin, isolation and tissue culture or animal passage history.
458 Preferably, the species and strain of capripoxvirus are characterised using PCR or DNA sequencing
459 techniques.

460 A quantity of master seed vaccine virus should be prepared, frozen or desiccated and stored at low
461 temperatures such as -80°C and used to produce a consistent working seed for regular vaccine
462 production.

463 Each master seed strain must be non-transmissible, remain attenuated after further tissue culture
464 passage, and provide complete protection against challenge with virulent field strains for a minimum
465 of 1 year. It must produce a minimal clinical reaction in cattle when given via the recommended route.

466 The necessary safety and potency tests are described in Section C.2.2.4 *Final product batch tests*.

467 **2.1.2. Quality criteria (sterility, purity, freedom from extraneous agents)**

468 Each master seed must be tested to ensure its identity and shown to be free from adventitious
469 viruses, in particular pestiviruses, such as border disease and bovine viral diarrhoea virus, and free
470 from contamination with bacteria, fungi or mycoplasmas.

471 The general procedures for sterility or purity tests are described in Chapter 1.1.9 *Tests for sterility*
472 and *freedom from contamination of biological materials intended for veterinary use*.

473 Master seed virus is a quantity of virus of uniform composition derived from an original isolate,
474 passaged for a documented number of times and distributed into containers at one time and stored
475 adequately to ensure stability (via freezing or lyophilisation). Selection of master seed viruses (MSVs)
476 should ideally be based on their ease of growth in cell culture, virus yield, and in accordance with the
477 regional epidemiological importance. Also, measures to minimise transmissible spongiform
478 encephalopathies (TSE) contamination should be taken into account (see Section C.3.5.1 *Purity*
479 *tests*).

480 For each seed strain selected for LSD vaccine production, the following information should be
481 provided:

- 482 - Historical record: geographical origin, animal species from which the virus was recovered,
483 isolation procedure, tissue culture or animal passage history
- 484 - Identity: species and strain identification using DNA sequencing

-
- 485 - Purity: the absence of bacteria, fungi, mycoplasma, and other viruses (see Chapter 1.1.9 Tests
486 for sterility and freedom from contamination of biological materials intended for veterinary use)
- 487 - Safety (overdose, one/repeated dose tests, and reversion to virulence tests) (see Section C.3.3
488 Vaccine safety)
- 489 - Efficacy data, linked to a specified (protective) dose (see Section C.3.4 Vaccine efficacy)
- 490 - Stability

491 Each master seed strain selected for production of live attenuated LSD vaccines must remain
492 attenuated after further passage in animals (see Section C.3.3. Vaccine safety), produce minimal
493 clinical reaction when given via the recommended route, provide complete protection against
494 challenge with virulent field strains, and is ideally not transmissible.

495 A quantity of master seed virus should be prepared and stored to be further used for the preparation
496 of working seeds and production seeds. Working seed viruses may be expanded in one or more (but,
497 limited) cell culture passages from the master seed stock and used to produce vaccine batches. This
498 approach and limitation of seed virus passaging will assist in maintaining uniformity and consistency
499 in production.

500 **3.1.2. Master cell stocks**

501 The production process of LSD vaccines ideally employs an established master cell stock (MCS)
502 system with defined lowest and highest cell passage to be used to grow the vaccine virus. Primary
503 cells derived from normal tissues can be used in the production process, but the use of primary cells
504 has an inherently higher risk of introducing extraneous agents compared with the use of established
505 (well characterised) cell lines and should be avoided where alternative methods of producing effective
506 vaccines exist. For each MCS, manufacturers should demonstrate:

- 507 - MCS identity
- 508 - genetic stability by subculturing from the lowest to the highest passage used for production
- 509 - stable MCS karyotype with a low level of polyploidy
- 510 - freedom from oncogenicity or tumorigenicity by using *in-vivo* studies using the highest cell
511 passage that may be used for production
- 512 - purity of MCSs from extraneous bacteria, fungi, mycoplasma, and viruses
- 513 - implemented measures to lower TSE contamination risk (see Section C.3.5.1 Purity tests).

514 **3.2. Method of vaccine manufacturing**

515 The method of manufacture should be documented as the Outline of Production.

516 **2.2.1. Procedure**

517 **3.2.1. LSD vaccine batch production**

518 ~~Vaccine batches are produced on an appropriate cell line such as MDBK. As already mentioned in~~
519 ~~the first paragraphs of Section C, all steps undertaken in the production of vaccine batches should~~
520 ~~be described and documented in the Outline of Production. The production of LAV and IV against~~
521 ~~LSD starts with the inoculation of the required number of working vials of seed virus is reconstituted~~
522 ~~with GMEM or other in appropriate medium and inoculated onto a suitable primary or continuous cell~~
523 ~~line grown in suspension or monolayer. Cells should be harvested after 4–8 days when they exhibit~~
524 ~~50–70% CPE for maximum in the exponential growth phase. At the time highest viral infectivity, or~~
525 ~~earlier if CPE is extensive and cells appear ready to detach. Techniques such as loads are present,~~
526 ~~sonication or repeated freeze–thawing are is used to release the intracellular virus from the~~
527 ~~cytoplasm. The lysate may then be clarified using centrifugation to remove cellular debris (for~~
528 ~~example by use of centrifugation at 600 g for 20 minutes, with retention of the supernatant). A second~~
529 ~~passage of the virus may be required to produce sufficient virus for a production batch.~~

530 An aliquot of the virus suspension is titrated to check the virus titre. For LAV, the virus-containing
531 suspension is diluted to attain the dose at which the vaccine candidate will be evaluated or to at least
532 the determined protective dose for approved vaccines and is then mixed with a suitable protectant
533 such as an equal volume of sterile, chilled 5% lactalbumin hydrolysate and 10% sucrose (dissolved

534 in double distilled water or appropriate balanced salt solution), and transferred to individually
535 numbered ~~labelled~~ bottles or bags for storage at low temperatures such as -80°C, or for freeze-
536 drying. A written record of all the procedures followed must be kept for all vaccine batches.

537 **2.2.2. Requirements for substrates and media**

538 ~~The specification and source of all ingredients used in the manufacturing procedure should be~~
539 ~~documented and the freedom of extraneous agents (bacteria, fungi, mycoplasma and viruses) should~~
540 ~~be tested. The detailed testing procedure is described in Chapter 1.1.9. The use of antibiotics must~~
541 ~~meet the requirements of the licensing authority.~~

542 **2.2.3. In-process control**

543 i) ~~Cells~~

544 ii) ~~Records of the source of the master cell stocks should be maintained. The highest and lowest~~
545 ~~passage numbers of the cells that can be used for vaccine production must be indicated in the~~
546 ~~Outline of the Production. The use of a continuous cell line (such as MDBK, etc.) is strongly~~
547 ~~recommended, unless the virus strain only grows on primary cells. The key advantage of~~
548 ~~continuous over primary cell lines is that there is less risk of introduction of extraneous agents.~~

549 iii) ~~Serum~~

550 iv) ~~Serum used in the growth or maintenance medium must be free from antibodies to capripoxvirus~~
551 ~~and free from contamination with pestivirus or other viruses, extraneous bacteria, mycoplasma~~
552 ~~or fungi.~~

553 v) ~~Medium~~

554 vi) ~~Media must be sterile before use.~~

555 vii) ~~Virus~~

556 viii) ~~Seed virus and final vaccine must be titrated and pass the minimum release titre set by the~~
557 ~~manufacturer. For example, the minimum recommended field dose of the South African~~
558 ~~Neethling strain vaccines (Mathijs *et al.*, 2016) is \log_{10} 3.5 TCID₅₀, although the minimum~~
559 ~~protective dose is \log_{10} 2.0 TCID₅₀. Capripoxvirus is highly susceptible to inactivation by sunlight~~
560 ~~and allowance should be made for loss of activity in the field.~~

561 ix) ~~The recommended field dose of the Romanian sheep pox vaccine for cattle is \log_{10} 2.5 sheep~~
562 ~~infective doses (SID₅₀), and the recommended dose for cattle of the RM65 adapted strain of~~
563 ~~Romanian sheep pox vaccine is \log_{10} 3 TCID₅₀ (Coakley & Capstick, 1961).~~

564 **3.2.2. Inactivation process for inactivated LSD vaccines**

565 Unlike LAV, inactivated LSD vaccines contain inactivated antigens in combination with adjuvants to
566 strengthen the induced immune response after administration. The vaccine evaluation process
567 described below needs to show the amount of antigen necessary to elicit a protective immune
568 response. Currently, literature data indicate that an inactivated vaccine originating from an LSDV
569 virus stock with titre 10^4 cell culture infectious dose₅₀ (CCID₅₀)/ml before inactivation can be sufficient
570 to induce an efficient immune response to prevent clinical disease, viremia and virus shedding after
571 challenge of young cattle (Wolf *et al.*, 2022)

572 To monitor the inactivation process and the level of antigen inactivation, samples are taken at regular
573 intervals during inactivation and titrated. Inactivation conditions and the length of initial and repeated
574 exposure should be documented in detail since one or more factors during the process could
575 influence the outcomes. The inactivation kinetics should reach a predefined target e.g. one remaining
576 infectious unit per million doses (1×10^{-6} infectious units/dose) as suggested by APHIS (2013). The
577 confirmatory testing of inactivation is performed on each vaccine lot and represents an important part
578 of the inactivation process monitoring. In addition to all the procedures mentioned above, the
579 inactivation procedure and tests demonstrating that antigen inactivation is complete and consistent
580 must additionally be documented in the Outline of Production.

581

3.3. Vaccine safety

582 During the vaccine development process, vaccine safety must be evaluated in the target animal (target animal batch
583 safety test –TABST) to demonstrate the safety of the dose intended for registration. The animals used in the safety
584 testing should be representative (species, age and category [calves, heifers, bulls, cows,]) for all the animals for which
585 the vaccine is intended. Vaccinated and control groups are appropriately acclimatised, housed and managed in line
586 with animal welfare standards. Animal suffering has to be eliminated or reduced and euthanasia is recommended in
587 moribund animals.

588 Essential parameters to be evaluated in safety studies are local and systemic reactions to vaccination, including local
589 reactions at the site of administration, fever, effect on milk production, and induction of a 'Neethling' response. The
590 effect of the vaccine on reproduction needs to be evaluated where applicable.

591 A part of the safety evaluation of LAV and IV can be performed during the efficacy trials (see Section C.3.4 Vaccine
592 efficacy) by measuring local and systemic responses following vaccination and before challenge.

593 Guidelines for safety evaluation are provided by the European Medicine Agency (EMA) in VICH GL44: TABST for
594 LAV and IV (EMA, 2009). Safety aspects of LAV and IV against LSD to be evaluated are:

3.3.1. Overdose test for LAV

595 Local and systemic responses should be measured following an overdose test whereby 10× the
596 maximum vaccine titre is administered. If the maximum vaccine titre is not specified, 10× the minimum
597 vaccine titre can be applied in multiple injection sites. Ideally, the 10× dose is dissolved in the 1×
598 dose volume of the adjuvants or diluent. Generally, eight animals per group should be used (EMA,
599 2009).
600

3.3.2. One dose and repeat dose test

601 This aims to test the safety of the vaccine dose applied in the vaccination regime intended for
602 registration. LAV LSD vaccines require one dose per year, while inactivated LSD vaccines require a
603 booster dose in addition to the primary dose. The minimal recommended interval between
604 administrations is 14 days.
605

606 Generally, eight animals per group should be used unless otherwise justified (EMA, 2009). For each
607 target species, the most sensitive breed, age and sex proposed on the label should be used.
608 Seronegative animals should be used. In cases where seronegative animals are not reasonably
609 available, alternatives should be justified.

3.3.3. Reversion to virulence tests

610 Live attenuated vaccines inherently carry the risk of vaccine virus reverting to virulence when
611 repeated passages in a host species could occur due to shedding and transmission from vaccinated
612 animals to contact animals. LAV LSD vaccines should therefore be tested for non-reversion to
613 virulence by means of passage studies. Vaccine virus (MSV, not the finished vaccine) is inoculated
614 in a group of target animals of susceptible age via the natural route of infection or the route that is
615 most likely to result in infection. The vaccine virus is subsequently recovered from tissues or
616 excretions and is used directly to inoculate a further group of animals. After not less than four
617 passages (see chapter 1.1.8), i.e. use of a total of five groups of animals, the re-isolate must be fully
618 characterised, using the same procedures used to characterise the master seed virus.
619

3.3.4. Environmental consideration

620 This includes the evaluation of the ability of LAV LSD vaccines to be shed, to spread and to infect
621 contact target and non-target animals, and to persist in the environment.
622

2.2.4. Final product batch tests

623 i) — Sterility/purity

624 ii) — Vaccine samples must be tested for sterility/purity. Tests for sterility and freedom from
625 contamination of biological materials intended for veterinary use may be found in Chapter 1.1.9.
626

627 iii) — Safety and efficacy

- 628 iv) — The efficacy and safety studies should be demonstrated using statistically valid vaccination–
629 challenge studies using seronegative young LSDV susceptible dairy cattle breeds. The group
630 numbers recommended here can be varied if statistically justified. Fifteen cattle are placed in a
631 high containment level large animal unit and serum samples are collected. Five randomly
632 chosen vials of the freeze dried vaccine are reconstituted in sterile PBS and pooled. Two cattle
633 are inoculated with 10 times the recommended field dose of the vaccine, and eight cattle are
634 inoculated with the recommended field dose. The remaining five cattle are unvaccinated control
635 animals. The animals are clinically examined daily and rectal temperatures are recorded. On
636 day 21 after vaccination, the animals are again serum sampled and challenged with a known
637 virulent capripoxvirus strain. The challenge virus solution should also be tested free from
638 extraneous viruses. The clinical response is recorded during the following 14 days. Animals in
639 the unvaccinated control group should develop the typical clinical signs of LSD, whereas there
640 should be no local or systemic reaction in the vaccinates other than a raised area in the skin at
641 the site of vaccination, which should disappear after 4 days. Serum samples are again collected
642 on day 30 after vaccination. The day 21 serum samples are examined for seroconversion to
643 selected viral diseases that could have contaminated the vaccine, and the days 0 and
644 30 samples are compared to confirm the absence of antibody to pestivirus. Because of the
645 variable response in cattle to LSD challenge, generalised disease may not be seen in all of the
646 unvaccinated control animals, although there should be a large local reaction.
- 647 v) — Once the efficacy of the particular strain being used for vaccine production has been determined
648 in terms of minimum dose required to provide immunity, it is not necessary to repeat this on the
649 final product of each batch, provided the titre of virus present has been ascertained.
- 650 vi) — Batch potency
- 651 vii) — Potency tests in cattle must be undertaken for vaccine strains of capripoxvirus if the minimum
652 immunising dose is not known. This is usually carried out by comparing the titre of a virulent
653 challenge virus on the flanks of vaccinated and control animals. Following vaccination, the
654 flanks of at least three animals and three controls are shaved of hair. Log₁₀ dilutions of the
655 challenge virus are prepared in sterile PBS and six dilutions are inoculated intradermally (0.1 ml
656 per inoculum) along the length of the flank; four replicates of each dilution are inoculated down
657 the flank. An oedematous swelling will develop at possibly all 24 inoculation sites on the control
658 animals, although preferably there will be little or no reaction at the four sites of the most dilute
659 inocula. The vaccinated animals may develop an initial hypersensitivity reaction at sites of
660 inoculation within 24 hours, which should quickly subside. Small areas of necrosis may develop
661 at the inoculation site of the most concentrated challenge virus. The titre of the challenge virus
662 is calculated for the vaccinated and control animals; a difference in titre >log₁₀ 2.5 is taken as
663 evidence of protection.

664 **3.4. Vaccine efficacy**

665 Data enclosed in the vaccine candidate dossier should support the efficacy of the vaccine in each animal species for
666 each vaccination regimen that is described in the product label recommendation. This includes studies regarding the
667 onset of protection when claims for onset are made and for the duration of immunity. Efficacy studies should be
668 conducted with the vaccine candidate that has been produced at the highest passage level permitted for vaccine
669 production as specified in the Outline of Production.

670 Efficacy (and safety) should be demonstrated in vaccination–challenge studies using representative (by species, age
671 and category) seronegative healthy animals for which the vaccine is intended and which are tested negative for
672 standard viral pathogens.

673 An example of a vaccination–challenge test set-up is outlined here. The group numbers mentioned can be varied if
674 statistically justified. Thirteen animals are placed in a high containment large animal unit and are divided into two
675 groups:

- 676 - single/repeated dose test group (n=8) – animals inoculated with the vaccine dose and route intended for
677 registration (in case of an IV against LSD, a booster dose should follow primary vaccination after minimum 14
678 days).
- 679 - control group (n=5) – non-vaccinated animals

680 Throughout the *in-vivo* study, all animals are clinically examined and rectal temperatures recorded. Blood, serum and
681 swab samples are regularly collected and subjected to laboratory testing. On day 21 after the vaccination with a LAV
682 or after the booster vaccination for an IV, the animals in both groups are challenged with a known virulent LSDV

683 strain. The challenge virus solution should be of known titre and tested free from extraneous viruses. Experience
684 obtained from previous animal experiments indicates that a dose of challenge virus between $10^{4.0}$ and $10^{6.5}$ TCID₅₀
685 produces clinical disease in about half of the susceptible experimental cattle (.Tuppurainen *et al.*, 2021).

686 The clinical response following challenge is recorded over a period of 14 days. No clinical signs should occur in the
687 vaccinates, other than a local reaction at the site of inoculation. At least 1 animal in the unvaccinated control group
688 should develop the typical clinical signs of LSD. Although a generalised disease with skin nodules may not be seen
689 in all the unvaccinated control animals based on the knowledge that the outcome of a LSDV infection can range from
690 inapparent to severe, at the very least a large local reaction is to be expected.

691 Clinical and laboratory results will enable assessment of the safety and efficacy of the LSD vaccine candidate and
692 the induced immune responses. Serum samples collected at different time points during the trial can be examined to
693 study seroconversion against selected viral diseases that could have contaminated the vaccine.

694 **2.3. Requirements for regulatory approval**

695 **2.3.1. Safety requirements**

- 696 i) ~~Target and non-target animal safety~~
- 697 ii) ~~The vaccine must be safe to use in all breeds of cattle for which it is intended, including young~~
698 ~~and pregnant animals. It must also be non-transmissible and remain attenuated after further~~
699 ~~tissue culture passage.~~
- 700 iii) ~~Safety tests should be carried out on the final product of each batch as described in Section~~
701 ~~C.2.2.4.~~
- 702 iv) ~~Reversion to virulence for attenuated/live vaccines~~
- 703 v) ~~The selected final vaccine should not revert to virulence during further passages in target~~
704 ~~animals.~~
- 705 vi) ~~Environmental consideration~~
- 706 vii) ~~Attenuated vaccine should not be able to perpetuate autonomously in a cattle population.~~
707 ~~Strains of LSDV are not a hazard to human health.~~

708 **2.3.2. Efficacy requirements**

- 709 i) ~~For animal production~~
- 710 ~~The efficacy of the vaccine must be demonstrated in statistically valid vaccination challenge~~
711 ~~experiments under laboratory conditions. The group numbers recommended here can be varied if~~
712 ~~statistically justified. Fifteen cattle are placed in a high containment level large animal unit and serum~~
713 ~~samples are collected. Five randomly chosen vials of the freeze-dried vaccine are reconstituted in~~
714 ~~sterile PBS and pooled. Two cattle are inoculated with 10 times the field dose of the vaccine, eight~~
715 ~~cattle are inoculated with the recommended field dose. The remaining five cattle are unvaccinated~~
716 ~~control animals. The animals are clinically examined daily and rectal temperatures are recorded. On~~
717 ~~day 21 after vaccination, the animals are again serum sampled and challenged with a known virulent~~
718 ~~capripoxvirus strain using intravenous and intradermal inoculation (the challenge virus solution~~
719 ~~should also be tested and shown to be free from extraneous viruses). The clinical response is~~
720 ~~recorded during the following 14 days. Animals in the unvaccinated control group should develop the~~
721 ~~typical clinical signs of LSD, whereas there should be no local or systemic reaction in the vaccinates~~
722 ~~other than a raised area in the skin at the site of vaccination which should disappear after 4 days.~~
723 ~~Serum samples are again collected on day 30 after vaccination. The day 21 serum samples are~~
724 ~~examined for seroconversion to selected viral diseases that could have contaminated the vaccine,~~
725 ~~and the days 0 and 30 samples are compared to confirm the absence of antibody to pestivirus.~~
726 ~~Because of the variable response in cattle to challenge with LSDV, generalised disease may not be~~
727 ~~seen in all of the unvaccinated control animals, although there should be a large local reaction.~~

728 ~~Once the potency of the particular strain being used for vaccine production has been determined in~~
729 ~~terms of minimum dose required to provide immunity, it is not necessary to repeat this on the final~~
730 ~~product of each batch, provided the titre of virus present has been ascertained.~~

731 ii) — For control and eradication

732 Vaccination is the only effective way to control LSD outbreaks in endemic countries and recent
733 experiences of the disease in Eastern Europe and the Balkans suggests this is also true for outbreaks
734 in non-endemic countries. Unfortunately, currently no marker vaccines allowing a DIVA strategy are
735 available, although to a limited extent PCR can be used for certain vaccines.

736 The duration of immunity produced by LSDV vaccine strains is currently unknown.

737 **2.3.3. Stability**

738 All vaccines are initially given a shelf life of 24 months before expiry. Real-time stability studies are
739 then conducted to confirm the appropriateness of the expiry date. Multiple batches of the vaccine
740 should be re-titrated periodically throughout the shelf life period to determine the vaccine stability.

741 Properly freeze-dried preparations of LSDV vaccine, particularly those that include a protectant, such
742 as sucrose and lactalbumin hydrolysate, are stable for over 25 years when stored at
743 -20°C and for 2–4 years when stored at 4°C. There is evidence that they are stable at higher
744 temperatures, but no long-term controlled experiments have been reported. No preservatives other
745 than a protectant, such as sucrose and lactalbumin hydrolysate, are required for the freeze-dried
746 preparation.

747 **3.5. Batch/serial tests before release for distribution**

748 Quality tests on MSV and safety and efficacy tests on vaccine candidates are performed during the evaluation process
749 for new LSD vaccines. Once vaccines are approved to be used in the field, it remains important to verify the quality
750 of each vaccine batch produced. An independent batch quality control assessment may be warranted or requested
751 by national or international regulatory authorities.

752 **3.5.1. Purity test**

753 Purity is defined by the absence of different contaminants (bacteria, fungi, mycoplasma, and other
754 viruses; see full details in chapter 1.1.9) in the vaccine and its associated diluent/adjuvants. Virus
755 isolation and bacterial culture tests can be used to show freedom from live competent replicating
756 microorganisms, but molecular methods are more rapid and sensitive, but positives can be caused
757 by genome fragments and incompetent replicating microorganisms.

758 Besides the contaminants mentioned above, manufacturers should demonstrate implemented
759 measures to minimise the risk of TSE contamination in ingredients of animal origin such as:

- 760 - all ingredients of animal origin in production facilities are from countries recognised as having the lowest
761 possible risk of bovine spongiform encephalopathy
- 762 - tissues or other substances used are themselves recognised as being of low or nil risk of containing TSE
763 agents

764 **3.5.2. Identity tests**

765 In addition to identity tests performed on the MSV, the identity tests on final batches aim to
766 demonstrate the presence of only the selected capripoxvirus species and strain in the vaccine as
767 indicated in the Outline of Production and the absence of other strains or members of the genus and
768 any other viral contaminant that might arise during the production process. Identity testing could be
769 assured by using appropriate tests (e.g. PCRs, sanger sequencing, NGS).

770 **3.5.3. Potency tests**

771 Standard requirements for potency tests can be found in CFR Title 9 part 113, in the European
772 Pharmacopoeia, and in this Terrestrial Manual.

773 **3.5.3.1. Live vaccines**

774 The potency of LAV against LSD can be measured by means of virus titration. The virus titre
775 must, as a rule, be sufficiently greater than that shown to be protective in the efficacy test
776 for the vaccine candidate. This will ensure that at any time prior to the expiry date, the titre
777 will be at least equal to the evaluated protective titre. The titres of currently available

778 commercial homologous LSD vaccines range between 10³ and 10⁴ infectious units/dose
779 (Tuppurainen *et al.*, 2021).

780 **3.5.3.2. Inactivated LSD vaccines**

781 For inactivated LSD vaccines, potency tests are performed using vaccination–challenge
782 efficacy studies in animal hosts (see Section C.3.4. *Vaccine efficacy*).

783 **3.5.4. Safety/efficacy**

784 Safety and efficacy testing is undertaken during the evaluation process of the vaccine candidate, and
785 also needs to be performed on a number of vaccine batches until robust data are generated in line
786 with international and national regulations. Afterwards, when using a seed lot system in combination
787 with strict implementation of GMP standards and depending on local regulations, TABST could be
788 waived as described in VICH50 and VICH55, providing the titer has been ascertained using potency
789 testing. Batches or serials are considered satisfactory if local and systemic reactions to vaccination
790 are in line with those described in the dossier of the vaccine candidate and product literature.

791 **3.5.4.1. Field safety/efficacy tests**

792 Field testing of two or more batches should be performed on all animal categories for which
793 the product is indicated before release of the product for general use (see chapter 1.1.8).
794 The aim of these studies is to demonstrate the safety and efficacy of the product under
795 normal field conditions of animal care and use in different geographical locations where
796 different factors may influence product performance. A protocol for safety/efficacy testing in
797 the field has to be developed with defined observation and recording procedures. However,
798 it is generally more difficult to obtain statistically significant data to demonstrate efficacy
799 under field conditions. Even when properly designed, field efficacy studies may be
800 inconclusive due to uncontrollable outside influences.

801 **3.5.4.2. Duration of Immunity**

802 The duration of immunity (DOI) following vaccination should be demonstrated via challenge
803 or the use of a validated serology test. Efficacy testing at the end of the claimed period of
804 protection should be conducted in each species for which the vaccine is indicated or the
805 manufacturer should indicate that the DOI for that species is not known. Likewise, the
806 manufacturer should demonstrate the effectiveness of the recommended booster regime in
807 line with these guidelines, usually by measuring the magnitude and kinetics of the
808 serological response observed.

809 **3. Vaccines based on biotechnology**

810 A new generation of capripox vaccines is being developed that uses the LSDV as a vector for the expression and delivery
811 of immuno-protective proteins of other ruminant pathogens with the potential for providing dual protection (Boshra *et al.*,
812 2013; Wallace & Viljoen, 2005), as well as targeting putative immunomodulatory genes for inducing improved immune
813 responses (Kara *et al.*, 2018).

814 **4. Post-market studies**

815 **4.1. Stability**

816 Stability testing shall be carried out as specified in Annex II of Regulation (EU) 2019/6 and in the Ph. Eur. 0062:
817 Vaccines for veterinary use, on not fewer than three representative batches providing this mimics the full-scale
818 production described in the application. At the end of shelf-life, sterility has to be re-evaluated using sterility testing
819 or by showing container closure integrity. Multiple batches of the vaccine should be re-titrated periodically throughout
820 the shelf-life period to determine the vaccine stability.

821 **4.2. Post-marketing surveillance**

822 After release of a vaccine, its performance under field conditions should continue to be monitored by competent
823 authorities and by the manufacturer itself. Not all listed adverse effects may show up in the clinical trials performed
824 to assess safety and efficacy of the vaccine candidate due to the limited number of animals used. Post-marketing
825 surveillance studies can also provide information on vaccine efficacy when used in normal practice and husbandry
826 conditions, on duration of induced immunity, on ecotoxicity, etc.

827 First, a reliable reporting system should be in place to collect consumer complaints and notifications of adverse
828 reactions. Secondly, post-marketing surveillance should be established to investigate whether the reported
829 observations are related to the use of the product and to identify, at the earliest stage, any serious problem that may
830 be encountered from its use and that may affect its future uptake. Vaccinovigilance should be an on-going and integral
831 part of all regulatory programmes for LSD vaccines, especially for live vaccines.

832 REFERENCES

- 833 AGIANNIOTAKI E.I., CHAINTOUTIS S.C., HAEGEMAN A., TASIYOUDI K.E., DE LEEUW I., KATSOULOS P.D., SACHPATZIDIS A., DE CLERCQ
834 K., ALEXANDROPOULOS T., POLIZOPOULOU Z.S., CHONDROKOUKI E.D. & DOVAS C.I. (2017). Development and validation of a
835 TaqMan probe-based real-time PCR method for the differentiation of wild type lumpy skin disease virus from vaccine virus
836 strains. *J. Virol. Methods*, **249**, 48–57.
- 837 BABIUK S., BOWDEN T.R., PARKYN G., DALMAN B., MANNING L., NEUFELD J., EMBURY-HYATT C., COPPS J. & BOYLE D.B. (2008).
838 Quantification of lumpy skin disease virus following experimental infection in cattle. *Transbound. Emerg. Dis.*, **55**, 299–
839 307.
- 840 BABIUK S., PARKYN G., COPPS J., LARENCE J.E., SABARA M.I., BOWDEN T.R., BOYLE D.B. & KITCHING R.P. (2007). Evaluation
841 of an ovine testis cell line (OA3.Ts) for propagation of capripoxvirus isolates and development of an immunostaining
842 technique for viral plaque visualization. *J. Vet. Diagn. Invest.*, **19**, 486–491.
- 843 BALINSKY C.A., DELHON G., SMOLIGA G., PRARAT M., FRENCH R.A., GEARY S.J., ROCK D.L. & RODRIGUEZ L.L. (2008). Rapid
844 preclinical detection of sheep pox virus by a real-time PCR assay. *J. Clin. Microbiol.*, **46**, 438–442.
- 845 BEN-GERA J., KLEMENT E., KHINICH E., STRAM Y. & SHPIGEL N. (2015). Comparison of the efficacy of Neethling lumpy skin
846 disease virus and x10RM65 sheep-pox live attenuated vaccines for the prevention of lumpy skin disease – The results of
847 a randomized controlled field study. *Vaccine*, **33**, 4837–4842.
- 848 BISWAS S., NOYCE R.S., BABIUK L.A., LUNG O., BULACH D. M., BOWDEN T.R., BOYLE D. B., BABIUK S. & EVANS D.H. (2020).
849 Extended sequencing of vaccine and wild-type capripoxvirus isolates provides insights into genes modulating virulence
850 and host range. *Transbound. Emerg. Dis.*, **67**, 80–97.
- 851 BOSHRA H., TRUONG T., NFOR C., GERDTS V., TIKOO S., BABIUK L.A., KARA P., MATHER A., WALLACE D. & BABIUK S. (2013).
852 Capripoxvirus vectored vaccines against livestock diseases in Africa. *Antiviral Res.*, **98**, 217–227.
- 853 BOWDEN, T.R, BABIUK S.L, PARKYN G.R., COPPS J.S. & BOYLE D.B. (2008). Capripoxvirus tissue tropism and shedding: A
854 quantitative study in experimentally infected sheep and goats. *Virology*, **371**, 380–393.
- 855 BRENNER J., HAIMOVITZ M., ORON E., STRAM Y., FRIDGUT O., BUMBAROV V., KUZNETZOVA L., OVED Z., WASERMAN A., GARAZZI
856 S., PERL S., LAHAV D., EDERY N. & YADIN H. (2006). Lumpy skin sease (LSD) in a large dairy herd in Israel. *Isr. J. Vet. Med.*,
857 **61**, 73–77.
- 858 BURDIN M.L. (1959). The use of histopathological examination of skin material for the diagnosis of lumpy skin disease in
859 Kenya. *Bull. Epizoot. Dis. Afr.*, **7**, 27–36.
- 860 BYADOVSKAYA O., PESTOVA Y., KONONOV A., SHUMILOVA I., KONONOVA S., NESTEROV A., BABIUK S. & SPRYGIN A. (2021).
861 Performance of the currently available DIVA real-time PCR assays in classical and recombinant lumpy skin disease
862 viruses. *Transbound. Emerg. Dis.*, **68**, 3020–3024. doi: 10.1111/tbed.13942. Epub 2021 May 13. PMID: 33253485
- 863 CAPSTICK P.B. & COAKLEY W. (1961). Protection of cattle against lumpy skin disease. Trials with a vaccine against Neethling
864 type infection. *Res. Vet. Sci.*, **2**, 362–368
- 865 CARN V.M. (1993). Control of capripoxvirus infections. *Vaccine*, **11**, 1275–1279.
- 866 CARN V.M. & KITCHING, R.P. (1995). The clinical response of cattle following infection with lumpy skin disease (Neethling)
867 virus. *Arch. Virol.*, **140**, 503–513.
- 868 COAKLEY W. & CAPSTICK P.B. (1961). Protection of cattle against lumpy skin disease. Factors affecting small scale
869 production of tissue culture propagated virus vaccine. *Res. Vet. Sci.*, **2**, 369–371.

- 870 COETZER J.A.W. (2004). Lumpy skin disease. *In: Infectious Diseases of Livestock, Second Edition* Coetzer J.A.W. & Justin
871 R.C., eds. Oxford University Press, Cape Town, South Africa, 1268–1276.
- 872 DAO T.D., TRAN L.H., NGUYEN H.D., HOANG T.T., NGUYEN G.H., TRAN K.V.D., NGUYEN H.X., VAN DONG H., BUI A.N. & BUI V.N.
873 (2022). Characterization of Lumpy skin disease virus isolated from a giraffe in Vietnam. *Transbound. Emerg. Dis.*,
874 69(5):e3268-e3272. doi: 10.1111/tbed.14583. Epub 2022 May 10. PMID: 35502589
- 875 DAS A., BABIUK S. & MCINTOSH M.T. (2012). Development of a loop-mediated isothermal amplification assay for rapid
876 detection of capripoxviruses. *J. Clin. Microbiol.*, **50**, 1613–1620.
- 877 DAVIES F.G. (1991). Lumpy Skin Disease, a Capripox Virus Infection of Cattle in Africa. FAO, Rome, Italy.
- 878 DAVIES F.G., KRAUSS H., LUND L.J. & TAYLOR M. (1971). The laboratory diagnosis of lumpy skin disease. *Res. Vet. Sci.*, **12**,
879 123–127.
- 880 FAY P.C., COOK C.G., WIJESIRIWARDANA N., TORE G., COMTET L., CARPENTIER A., SHIH B., FREIMANIS G., HAGA I.R. & BEARD
881 P.M. (2020). Madin-Darby bovine kidney (MDBK) cells are a suitable cell line for the propagation and study of the bovine
882 poxvirus lumpy skin disease virus. *J. Virol. Methods*, **285**, 113943. doi: 10.1016/j.jviromet.2020.113943.
- 883 FLANNERY J., SHIH B., HAGA I.R., ASHBY M., CORLA A., KING S., FREIMANIS G., POLO N., TSE A.C., BRACKMAN C.J., CHAN J., PUN
884 P., FERGUSON A.D., LAW A., LYCETT S., BATTEN C. & BEARD P.M. (2021). A novel strain of lumpy skin disease virus causes
885 clinical disease in cattle in Hong Kong. *Transbound. Emerg. Dis.*, doi: 10.1111/tbed.14304
- 886 GARI G., ABIE G., GIZAW D., WUBETE A., KIDANE M., ASGEDOM H., BAYISSA B., AYELET G., OURA C.A.L., ROGER F. &
887 TUPPURAINEN E.S.M. (2015). Evaluation of the safety, immunogenicity and efficacy of three capripoxvirus vaccine strains
888 against lumpy skin disease virus. *Vaccine*, 33, 3256–3261. doi: 10.1016/j.vaccine.2015.01.035.
- 889 HAIG D. (1957). Lumpy skin disease. *Bull. Epizoot. Dis. Afr.*, **5**, 421–430.
- 890 HEDGER R.S. & HAMBLIN C. (1983). Neutralising antibodies to lumpy skin disease virus in African wildlife. *Comp. Immunol.*
891 *Microbiol. Infect. Dis.*, 6, 209–213. doi: 10.1016/0147-9571(83)90012-7. PMID: 6627909 DOI: 10.1016/0147-
892 9571(83)90012-7
- 893 HAEGEMAN A., DE LEEUW I., MOSTIN L., VAN CAMPE W., AERTS L., VENTER E., TUPPURAINEN E., SAEGERMAN C. & K. DE CLERCQ
894 (2021). Comparative Evaluation of Lumpy Skin Disease Virus-Based Live Attenuated Vaccines. *Vaccines*, 9, 473.
895 <https://doi.org/10.3390/vaccines9050473>
- 896 HAEGEMAN A., DE LEEUW I., MOSTIN L., VAN CAMPE W., PHILIPS W., ELHARRAK M., DE REGGE N. & DE CLERCQ K. (2023).
897 Duration of immunity induced after vaccination of cattle with a live attenuated or inactivated Lumpy skin disease virus
898 vaccine. *Microorganisms*, 11, 210. <https://doi.org/10.3390/microorganisms11010210>
- 899 HAMDI J., BOUMART Z., DAOUAM S., EL ARKAM A., BAMOUH Z., JAZOULI M., OMARI TADLAOUI K., FASSI FIHRI O., GAVRILOV B. & EL
900 HARRAK M. (2020). Development and Evaluation of an Inactivated Lumpy Skin Disease Vaccine for Cattle. *Vet. Microbiol.*,
901 245, 108689. doi: 10.1016/j.vetmic.2020.108689.
- 902 IRELAND D.C. & BINEPAL Y.S. (1998). Improved detection of capripoxvirus in biopsy samples by PCR. *J. Virol. Methods*, **74**,
903 1–7.
- 904 IRONS P.C., TUPPURAINEN E.S.M. & VENTER E.H. (2005). Excretion of lumpy skin disease virus in bull semen.
905 *Theriogenology*, **63**, 1290–1297.
- 906 KARA P.D., AFONSO C.L., WALLACE D.B., KUTISH G.F., ABOLNIK C., LU Z., VREEDE F.T., TALJAARD L.C., ZSAK A., VILJOEN G.J. &
907 ROCK D.L. (2003). Comparative sequence analysis of the South African vaccine strain and two virulent field isolates of
908 Lumpy skin disease virus. *Arch. Virol.*, **148**, 1335–1356.
- 909 KARA P.D., MATHER A.S., PRETORIUS A., CHETTY T., BABIUK S. & WALLACE D.B. (2018). Characterisation of putative
910 immunomodulatory gene knockouts of lumpy skin disease virus in cattle towards an improved vaccine. *Vaccine*, 36, 4708-
911 4715. doi: 10.1016/j.vaccine.2018.06.017.
- 912 KITCHING R.P. & SMALE C. (1986). Comparison of the external dimensions of capripoxvirus isolates. *Res. Vet. Sci.*, **41**, 425–
913 427.

- 914 KLEMENT E., BROGLIA A., ANTONIOU S.-E., TSIAMADIS V., E. PLEVRAKI, PETROVIĆ T., POLAČEK V., DEBELJAK Z., MITEVA A.,
915 ALEXANDROV T., MAROJEVIC D., PITE L., KONDRATENKO V., ATANASOV Z., GUBBINS S., STEGEMAN A. & CORTIÑAS ABRAHANTES J.
916 (2020). Neethling vaccine proved highly effective in controlling lumpy skin disease epidemics in the Balkans. *Prev. Vet.*
917 *Med.*, **181**, 104595 <https://doi.org/10.1016/j.prevetmed.2018.12.001>
- 918 KUMAR R., GODARA B., CHANDER Y., KACHHAWA J.P., DEDAR R.K., VERMA A., RIYESH T., PAL Y., BARUA S., TRIPATHI B.N. &
919 KUMAR N. (2023). Evidence of lumpy skin disease virus infection in camels. *Acta Trop.*, **242**, 106922. doi:
920 10.1016/j.actatropica.2023.106922. Epub 2023 Apr 7. PMID: 37031926
- 921 LAMIEN C.E., LELENTA M., GOGER W., SILBER R., TUPPURAINEN E., MATIJEVIC M., LUCKINS A.G. & DIALLO A. (2011). Real time
922 PCR method for simultaneous detection, quantitation and differentiation of capripoxviruses *J. Virol. Methods*, **171**, 134–140.
- 923 ~~MATHIJS E., VANDENBUSSCHE F., HAEGEMAN A., KING A., NTHANGENI B., POTGIETER C., MAARTENS L., VAN BORM S. & DE CLERCQ~~
924 ~~K. (2016). Complete Genome Sequences of the Neethling-Like Lumpy Skin Disease Virus Strains Obtained Directly from~~
925 ~~Three Commercial Live Attenuated Vaccines. *Genome Announc.*, **4** (6). pii: e01255-16. doi: 10.1128/genomeA.01255-16.~~
- 926 MILOVANOVIC M., DIETZE K., MILICEVIC V., RADOJICIC S., VALCIC M., MORITZ T. & HOFFMANN B. (2019). Humoral immune
927 response to repeated lumpy skin disease virus vaccination and performance of serological tests. *BMC Vet. Res.*, **15**, 80.
928 doi: 10.1186/s12917-019-1831-y.
- 929 MURRAY L., EDWARDS L., TUPPURAINEN E.S., BACHANEK-BANKOWSKA K., OURA C.A., MIOULET V. & KING D.P. (2013). Detection
930 of capripoxvirus DNA using a novel loop-mediated isothermal amplification assay. *BMC Vet. Res.*, **9**, 90.
- 931 OMOGA D.C.A., MACHARIA M., MAGIRI E., KINYUA J., KASIITI J. & HOLTON T. (2016). Molecular based detection, validation of a
932 LAMP assay and phylogenetic analysis of capripoxvirus in Kenya. *J. Adv. Biol. Biotech.*, **7**, 1–12.
- 933 PESTOVA Y., BYADOVSKAYA O., KONONOV A. & SPRYGIN A. (2018). A real time high-resolution melting PCR assay for detection
934 and differentiation among sheep pox virus, goat pox virus, field and vaccine strains of lumpy skin disease virus. *Mol. Cell.*
935 *Probes*, **41**, 57–60.
- 936 PORCO A., CHEA S., SOURS S., NOU V., GROENENBERG M., AGGER C., TUM S., CHHUON V., SORN S., HONG C., DAVIS B., DAVIS
937 S., KEN S., OLSON S.H. & FINE A.E. (2023). Case report: Lumpy skin disease in an endangered wild banteng (*Bos javanicus*)
938 and initiation of a vaccination campaign in domestic livestock in Cambodia. *Front. Vet. Sci.*, **10**:1228505. doi:
939 10.3389/fvets.2023.1228505
- 940 PROZESKY L. & BARNARD B.J.H. (1982). A study of the pathology of lumpy skin disease in cattle. *Onderstepoort J. Vet. Res.*,
941 **49**, 167–175.
- 942 ROUBY S. & ABOULSOUD E. (2016). Evidence of intrauterine transmission of lumpy skin disease virus. *Vet. J.*, **209**, 193–
943 195.
- 944 SAMOJLOVIC M., POLACEK V., GURJANOV V., LUPULOVIC D., LAZIC G., PETROVIĆ T., LAZIC S. (2019). Detection of antibodies
945 against lumpy skin disease virus by virus neutralization test and ELISA methods. *Acta Vet.*, **69**, 47–60.
- 946 SPRYGIN A., BABIN Y., PESTOVA Y., KONONOVA S., WALLACE D.B., VAN SCHALKWYK A., BYADOVSKAYA O., DIEV V., LOZOVY D. &
947 KONONOV A. (2018). Analysis and insights into recombination signals in lumpy skin disease virus recovered in the field.
948 *PLoS One*, **13**, e0207480.
- 949 SPRYGIN A., VAN SCHALKWYK A., SHUMILOVA I., NESTEROV A., KONONOVA S., PRUTNIKOV P., BYADOVSKAYA O. & KONONOV A.
950 (2020). Full-length genome characterization of a novel recombinant vaccine-like lumpy skin disease virus strain detected
951 during the climatic winter in Russia, 2019. *Arch. Virol.*, **165**, 2675–2677.
- 952 TUPPURAINEN E., DIETZE K., WOLFF J., BERGMANN H., BELTRAN-ALCRUDO D., FAHRION A., LAMIEN EULOGE C., BUSCH F., SAUTER-
953 LOUIS C., CONRATHS F.J., DE CLERCQ K., HOFFMANN B. & SASCHA K. (2021). Review: Vaccines and Vaccination against
954 Lumpy Skin Disease. *Vaccines* (Basel). **9**, 1136. doi: 10.3390/vaccines9101136
- 955 TUPPURAINEN E.S.M., VENTER E.H. & COETZER J.A.W. (2005). The detection of lumpy skin disease virus in samples of
956 experimentally infected cattle using different diagnostic techniques. *Onderstepoort J. Vet. Res.*, **72**, 153–164.
- 957 TUPPURAINEN E.S., VENTER E.H., COETZER J.A. & BELL-SAKYI L. (2015). Lumpy skin disease: attempted propagation in tick
958 cell lines and presence of viral DNA in field ticks collected from naturally-infected cattle. *Ticks Tick Borne Dis.*, **6**, 134–140.

-
- 959 VAN ROOYEN P.J., KOMM N.A.L., WEISS K.E. & ALEXANDER R.A. (1959). A preliminary note on the adaptation of a strain of
960 lumpy skin disease virus to propagation in embryonated eggs. *Bull. Epizoot. Dis. Afr.*, **7**, 79–85.
- 961 VAN SCHALKWYK A., BYADOVSKAYA O., SHUMILOVA I., WALLACE D.B. & SPRYGIN A. (2021). Estimating evolutionary changes
962 between highly passaged and original parental lumpy skin disease virus strains. *Transbound. Emerg. Dis.*, doi:
963 10.1111/tbed.14326.
- 964 VAN SCHALKWYK A., KARA P., EBERSOHN K., MATHER A., ANNANDALE C.H., VENTER E.H. & WALLACE D.B. (2020). Potential link
965 of single nucleotide polymorphisms to virulence of vaccine-associated field strains of lumpy skin disease virus in South
966 Africa. *Transbound. Emerg. Dis.*, **67**, 2946–2960.
- 967 VIDANOVIC D., SEKLER M., PETROVIC T., DEBELJAK Z., VASKOVIC N., MATOVIC K. & HOFFMAN B. (2016). Real time PCR assay
968 for the specific detection of field Balkan strain of lumpy skin disease virus. *Acta Vet. Brno*, **66**, 444–454.
- 969 WANG Y., ZHAO L., YANG J., SHI M., NIE F., LIU S., WANG Z., HUANG D., WU H., LI D., LIN H. & LI Y. (2021). Analysis of vaccine-
970 like lumpy skin disease virus from flies near the western border of China. *Transbound. Emerg. Dis.*, doi:
971 10.1111/tbed.14159
- 972 ~~WALLACE D.B. & VILJOEN G.J. (2005). Immune responses to recombinants of the South African vaccine strain of lumpy skin
973 disease virus generated by using thymidine kinase gene insertion. *Vaccine*, **23**, 3061–3067.~~
- 974 WEISS K.E. (1968). Lumpy skin disease. *Viol. Monogr.*, **3**, 111–131.
- 975 WOLFF J., BEER M. & HOFFMANN B. (2022). High Efficiency of Low Dose Preparations of an Inactivated Lumpy Skin Disease
976 Virus Vaccine Candidate. *Vaccines* (Basel), **10**, 1029. doi: 10.3390/vaccines10071029.
- 977 ZHUGUNISSOV K., BULATOV Y., ORYNBAYEV M., KUTUMBETOV L., ABDURAIMOV Y., SHAYAKHMETOV Y., TARANOV D., AMANOVA Z.,
978 MAMBETALIYEV M., ABSATOVA Z., AZANBEKOVA M., KHAIRULLIN B., ZAKARYA K. & TUPPURAINEN E. (2020). Goatpox virus (G20-
979 LKV) vaccine strain elicits a protective response in cattle against lumpy skin disease at challenge with lumpy skin disease
980 virulent field strain in a comparative study. *Vet Microbiol.*, **245**, 108695. doi: 10.1016/j.vetmic.2020.108695.

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983 **NB:** There are WOA Reference Laboratories for lumpy skin disease (please consult the WOA Web site:
984 <https://www.woah.org/en/what-we-offer/expertise-network/reference-laboratories/#ui-id-3>).
985 Please contact WOA Reference Laboratories for any further information on
986 diagnostic tests, reagents and vaccines for lumpy skin disease

987 **NB:** FIRST ADOPTED IN 1989. MOST RECENT UPDATES ADOPTED IN 2021.

2 MEETING OF THE BIOLOGICAL STANDARDS COMMISSION

3 Paris, 4–8 September 2023

4
5
6 CHAPTER 3.6.9.

7 EQUINE RHINOPNEUMONITIS (INFECTION WITH
8 EQUID HERPESVIRUS-1 AND 4)

9 SUMMARY

10 *Equine rhinopneumonitis (ER) is a collective term for any one of several contagious, clinical disease entities*
11 *of equids that may occur as a result of infection by either of two closely related herpesviruses, equid*
12 *alphaherpesvirus-1 and -4 (EHV-1 and EHV-4). Infection with EHV-1 is listed by WOAHP and is therefore the*
13 *focus of this chapter. EHV-1 is and EHV-4 are endemic in most domestic equine populations worldwide.*

14 *Primary infection by ~~either EHV-1 or EHV-4~~ is characterised by upper respiratory tract disease of varying*
15 *severity that is related to the age and immunological status of the infected animal. Following viraemia EHV-*
16 *1 also causes the more serious complications of abortion, perinatal foal death, or paralytic neurological*
17 *disease (equine herpesvirus myeloencephalopathy). ~~EHV-4 has been associated with sporadic cases of~~*
18 *~~abortion, but rarely multiple abortions and not the large outbreaks associated with EHV-1.~~ Like other*
19 *herpesviruses, EHV-1 and 4 induces long-lasting latent infections and can be reactivated following stress ~~or~~*
20 *~~pregnancy.~~ Furthermore, most horses are likely to be re-infected multiple times during their lifetime, often*
21 *~~mildly or subclinically. Detection of viral DNA or anti-EHV antibodies should therefore be interpreted with~~*
22 *~~care.~~*

23 **Identification of the agent:** *The standard method of identification of EHV-1 ~~and EHV-4~~ from appropriate*
24 *clinical or necropsy material is by polymerase chain reaction (PCR), ~~followed by laboratory isolation of the~~*
25 *~~virus in cell culture.~~*

26 *Positive identification of viral isolates as EHV-1 ~~or EHV-4~~ can be achieved by type-specific PCR or*
27 *sequencing. Viruses can be isolated in equine cell culture from nasal or nasopharyngeal swab extracts taken*
28 *from horses ~~during the febrile stage of~~ with acute respiratory tract infection, from the placenta, from ~~and~~ liver,*
29 *lung, spleen, adrenal glands or thymus of aborted fetuses and early foal deaths, and from the leukocyte*
30 *fraction of the blood of animals ~~with acute~~ during the febrile stage of EHV-1 infection. ~~Unlike EHV-4, EHV-1~~*
31 *~~will also grow in various non-equine cell types such as the RK-13 cell line and this property can be used to~~*
32 *~~distinguish between the two viruses.~~*

33 *A rapid presumptive diagnosis of abortion induced by EHV-1 ~~or (infrequently) EHV-4~~ can be achieved by*
34 *direct immunofluorescent detection of viral antigen in cryostat sections of placenta and tissues from aborted*
35 *fetuses, using a conjugated polyclonal antiserum.*

36 *Post-mortem demonstration of histopathological lesions of EHV-1 in placenta and tissues from aborted*
37 *fetuses, cases of perinatal foal death or in the central nervous system of neurologically affected animals*
38 *complements other diagnostic techniques ~~the laboratory diagnosis.~~*

39 **Serological tests:** *Most horses possess some level of antibody to EHV-1/4, the demonstration of specific*
40 *antibody in the serum collected from a single blood sample is therefore not confirmation of a positive*
41 *diagnosis of recent infection. Paired, acute and convalescent sera from animals suspected of being infected*

42 with EHV-1 or EHV-4 should be tested for a four-fold or greater rise in virus-specific antibody titre by either
43 virus neutralisation (VN) or complement fixation (CF) tests. Neither of these assays is type-specific but both
44 have proven useful for diagnostic purposes especially since the CF antibody response to recent infection is
45 relatively short-lived. Limited use has also been made of a type-specific enzyme-linked immunosorbent
46 assay (Crabb et al., 1995; Hartley et al., 2005).

47 **Requirements for vaccines:** Both live attenuated and inactivated viral vaccines are available for use in
48 assisting in the control of EHV-1/4. Vaccination is helpful in reducing the severity of respiratory infection in
49 young horses and the incidence of abortion in mares, however current vaccines are not licenced to protect
50 against neurological disease. Vaccination should not be considered a substitute for sound management
51 practices known to reduce the risk of infection. Revaccination at frequent intervals is recommended in the
52 case of each of the products, as the duration of vaccine-induced immunity is relatively short.

53 Standards for production and licensing of both attenuated and inactivated EHV-1/4 vaccines are established
54 by appropriate veterinary regulatory agencies in the countries of vaccine manufacture and use. A single set
55 of internationally recognised standards for EHV vaccines is not available. In each case, however, vaccine
56 production is based on the system of a detailed outline of production employing a well characterised cell line
57 and a master seed lot of vaccine virus that has been validated with respect to virus identity, safety, virological
58 purity, immunogenicity and the absence of extraneous microbial agents.

59

A. INTRODUCTION

60 Equine rhinopneumonitis (ER) is a historically-derived term that describes a constellation of several disease entities of
61 horses that may include respiratory disease, abortion, neonatal foal pneumonitis, or myeloencephalopathy (Allen & Bryans,
62 1986; Allen et al., 1999; Bryans & Allen, 1988; Crabb & Studdert, 1995). The disease has been is recognised for over 60
63 years as a threat to the international horse industry, and is caused by either of two members of the *Herpesviridae* family,
64 equid alphaherpesvirus-1 and -4 (EHV-1 and EHV-4). EHV-1 and EHV-4 are closely related alpha herpesviruses of horses
65 with nucleotide sequence identity within individual homologous genes ranging from 55% to 84%, and amino acid sequence
66 identity from 55% to 96% (Telford et al., 1992; 1998). The two herpesviruses ~~With the exception of EHV-1 in Iceland~~
67 (Thorsteinsdóttir et al., 2021), the two herpesviruses are considered endemic enzootic in all countries in which large
68 populations of horses are maintained as part of the cultural tradition or agricultural economy. There is no recorded evidence
69 that the two herpesviruses of ER pose any health risks to humans working with the agents. Infection with EHV-1 is listed
70 by WOAHP and is therefore the focus of this chapter.

71 Viral transmission to cohort animals occurs by inhalation of aerosols of virus-laden respiratory secretions. Morbidity tends
72 to be highest in young horses sharing the same air space. Aborted tissues and placental fluids from infected mares can
73 contain extremely high levels of live virus and represent a major source of infection. Extensive use of vaccines has not
74 eliminated EHV-1 infections, and the world-wide annual financial impact from this these equine pathogens is immense
75 considerable.

76 In horses under 3 years of age, clinical ER usually takes the form of an acute, febrile respiratory illness that spreads rapidly
77 through the group of animals. The viruses infects and multiplies multiply in epithelial cells of the respiratory mucosa. Signs
78 of infection become apparent 2–8 days after exposure to virus, and are characterised by fever, inappetence, depression,
79 and nasal discharge. The severity of respiratory disease varies with the age of the horse and the level of immunity resulting
80 from previous vaccination or natural exposure. Bi-phasic fever, viraemia and complications are more likely with EHV-1 than
81 EHV-4. Subclinical infections with EHV-1/4 are common, even in young animals. Although mortality from uncomplicated
82 ER is rare and complete recovery within 1–2 weeks is the normal outcome, respiratory infection is a frequent and significant
83 cause of interrupted schedules among horses assembled for training, racing, or other equestrian events. Fully protective
84 immunity resulting from infection is of short duration, and convalescent animals are susceptible to reinfection by EHV-1/4
85 after several months. Although reinfections ~~by the two herpesviruses~~ cause less severe or clinically inapparent respiratory
86 disease, the risks of subsequent abortion or neurological disease remain. Like other herpesviruses, EHV-1/4 causes long-
87 lasting latent infections and latently infected horses represent a potential infection risk for other horses. Virus can be
88 reactivated as a result of stress or pregnancy. The greatest clinical threats to individual breeding, racing, or pleasure horse
89 operations posed by ER are the potential abortigenic and neurological sequelae of EHV-1 respiratory infection. ER
90 abortions occur annually in horse populations worldwide and may be sporadic or multiple. Foals infected in utero may be
91 born alive and die within a few days of birth. EHV-1 neurological disease is less common than abortions but has been
92 recorded all over the world with associated fatalities. Outbreaks result in movement restrictions and, sometimes,
93 cancellation of equestrian events (Couroucé et al., 2023; FEI, 2021).

94 Neurological disease, also known as equine herpesvirus myeloencephalopathy, remains an infrequent but serious
95 complication of EHV-1 infection. A single mutation in the DNA polymerase gene (ORF30) has been associated with
96 increased risk of neurological disease, however strains without this change can also cause paralysis (Goodman et al.,
97 2007; Nugent et al., 2006). Strain typing techniques have been employed to identify viruses carrying the neuropathic

98 marker, and it can be helpful to be aware of an increased risk of neurological complications. However, for practical purposes
 99 strain typing is not relevant for agent identification, or international trade. Strain typing may be beneficial for implementation
 100 of biosecurity measures in the management of outbreaks of equine herpesvirus myeloencephalopathy.

101 Strain typing has been shown to be not reliable for predicting the clinical outcome of EHV-1 infection but can be useful in
 102 epidemiological investigations (Garvey *et al.*, 2019; Nugent *et al.*, 2006; Sutton *et al.*, 2019).

103 B. DIAGNOSTIC TECHNIQUES

104 Both EHV-1 and EHV-4 is transmitted by the respiratory route and has have the potential to be highly contagious viruses
 105 particularly where large numbers of horses are housed in the same air space. EHV1 and the former can cause explosive
 106 outbreaks of abortion or neurological disease. Rapid diagnostic methods are therefore essential useful for managing the
 107 disease. Real-time polymerase chain reaction (PCR) assays are widely routinely used by diagnostic laboratories worldwide
 108 and are both rapid and sensitive. Real-time PCR assays that allow simultaneous testing for EHV-1 and EHV-4 and
 109 quantification of viral load have been developed. Virus isolation has been replaced by real-time PCR as the frontline
 110 diagnostic test in the majority of laboratories but can also be useful, particularly for the detection of viraemia. This is also
 111 true of for EHV-1 associated abortions and neonatal foal deaths, when the high level of virus in the tissues usually produces
 112 a cytopathic effect in 1–3 days. Immunohistochemical or immunofluorescent approaches are employed in some
 113 laboratories can be extremely useful for rapid diagnosis of EHV-induced abortion from fresh or embedded tissue and are
 114 relatively straightforward. Several other techniques based on enzyme-linked immunosorbent assay (ELISA) or nucleic acid
 115 hybridisation probes have also been described, however their use is often restricted to specialised laboratories and they
 116 are not included here. Virus neutralisation (VN) and complement fixation (CF) are the most frequently used serological
 117 tests, and seroconversion in paired samples is considered indicative of exposure to virus by natural infection or by
 118 vaccination.

119 **Table 1. Test methods available for the diagnosis of equine rhinopneumonitis and their purpose**

Method	Purpose					
	<u>Population freedom from infection</u>	<u>Individual animal freedom from infection prior to movement</u>	Contribute to eradication policies ^(a)	<u>Confirmation of clinical cases</u>	<u>Prevalence of infection - surveillance</u>	<u>Immune status in individual animals or populations post-vaccination</u>
Identification of the agent^(b)						
Virus isolation	–	+++	–	+++	–	–
PCR	–	+++	–	+++	–	–
Direct immunofluorescence	=	=	=	++	=	=
Detection of immune response						
VN	++	++	=+	+++	+++	+++
ELISA	+	=+	=+	++	+++	+
CFT	–	–++	–	+++	–	–+++

120 Key: +++ = recommended for this purpose; ++ recommended but has limitations;

121 + = suitable in very limited circumstances; – = not appropriate for this purpose.

122 PCR = polymerase chain reaction; VN = virus neutralisation;

123 ELISA = enzyme-linked immunosorbent assay; CFT = complement fixation test.

124 ^(a)No eradication policies exist for equine rhinopneumonitis.

125 ^(b)A combination of agent identification methods applied on the same clinical sample is recommended.

126 1. Identification Detection of the agent

127 1.1. Collection and preparation of specimens

128 *Nasal/nasopharyngeal swabs:* swab extract can be used for DNA extraction and subsequent virus detection by PCR
129 using one of a variety of published techniques or commercially available kits (see below). Virus isolation can also be
130 attempted from the swab extracts. To increase the chances of isolating live virus, swabs are best obtained from
131 horses during the very early, febrile stages acute stage of the respiratory disease, and are collected via the nares by
132 sampling the area with a swab of an appropriate size and length for horses. After collection, the swab should be
133 removed and transported immediately to the virology laboratory in 3 ml of cold (not frozen) virus transport medium
134 (e.g. phosphate buffered saline [PBS] or serum-free MEM [minimal essential medium] with antibiotics). Virus
135 infectivity can be prolonged by the addition of bovine serum albumin, fetal calf serum or gelatine to 0.1% (w/v).

136 *Tissue samples:* total DNA can be extracted using a number of commercially available kits and used in PCR to detect
137 viral DNA (described below in Section B.1.2.1). Virus isolation from placenta and fetal tissues from suspect cases of
138 EHV-1 abortion is most successful when performed on aseptically collected samples of placenta, liver, lung, thymus,
139 adrenal glands and spleen. Virus may be isolated from post-mortem cases of EHV-1 neurological disease by culture
140 of samples of brain and spinal cord but such attempts to isolate virus are often unsuccessful; however, they may be
141 useful for PCR testing and pathological examination. Tissue samples should be transported to the laboratory and
142 held at 4°C until inoculated into tissue culture. Samples that cannot be processed within a few hours should be stored
143 at -70°C.

144 *Blood:* for virus detection by PCR or isolation from blood leukocytes, collect a 10–20 ml sample of blood, using an
145 aseptic technique in citrate, heparin or EDTA [ethylene diamine tetra-acetic acid] anticoagulant. EDTA is the preferred
146 anticoagulant for PCR testing in some laboratories as heparin may inhibit DNA polymerase. The samples should be
147 transported without delay to the laboratory on ice, but not frozen.

148 *Cerebrospinal fluid:* the detection of EHV-1 DNA in cerebrospinal fluid has been reported in cases of neurological
149 disease.

150 1.2. Virus detection by polymerase chain reaction

151 ~~PCR has become the primary diagnostic method for the detection of EHV-1 and EHV-4 in clinical specimens, paraffin-~~
152 ~~embedded archival tissue, or inoculated cell cultures (Borchers & Slater, 1993; Lawrence *et al.*, 1994; O’Keefe *et al.*,~~
153 ~~1994; Varrasso *et al.*, 2001). A variety of type-specific PCR primers have been designed to distinguish between the~~
154 ~~presence of EHV-1 and EHV-4. The correlation between PCR and virus isolation techniques for diagnosis of EHV-1~~
155 ~~or EHV-4 is high (Varrasso *et al.*, 2001). Diagnosis by PCR is rapid, sensitive, and does not depend on the presence~~
156 ~~of infectious virus in the clinical sample. For diagnosis of active infection by EHV, PCR methods are routinely used~~
157 ~~to detect EHV-1 DNA in nasopharyngeal swabs and tissue samples most reliable with tissue samples from aborted~~
158 ~~fetuses and placental tissue or from nasopharyngeal swabs of foals and yearlings. They are particularly useful in~~
159 ~~explosive outbreaks of abortion, respiratory or neurological disease in which a rapid identification and monitoring~~
160 ~~of the virus spread is critical for guiding management strategies, including movement restrictions. PCR examination of~~
161 ~~spinal cord and brain tissue, as well as peripheral blood mononuclear cells (PBMC), are important in seeking a~~
162 ~~diagnosis on a horse with neurological signs (Pronost *et al.*, 2012).~~

163 ~~Several PCR assays have been published. A nested PCR procedure can be used to distinguish between EHV-1 and~~
164 ~~EHV-4. A sensitive protocol suitable for clinical or pathological specimens (nasal secretions, blood leukocytes, brain~~
165 ~~and spinal cord, fetal tissues, etc.) has been described by Borchers & Slater (1993). However, nested PCR methods~~
166 ~~have a high risk of laboratory cross-contamination, and sensitive rapid one-step PCR tests to detect EHV-1 and EHV-~~
167 ~~4 (e.g. Lawrence *et al.*, 1994) are preferred. The WOA Reference Laboratories use quantitative real-time PCR~~
168 ~~assays such as those targeting heterologous sequences of major glycoprotein genes to distinguish between EHV-1~~
169 ~~and EHV-4. A multiplex real-time PCR targeting glycoprotein B gene of EHV-1 and EHV-4 was described by Diallo~~
170 ~~*et al.* (2007). PCR protocols have been developed that can differentiate between EHV-1 strains carrying the ORF30~~
171 ~~neuropathogenic marker, using both restriction enzyme digestion of PCR products (Fritsche & Borchers, 2011) or by~~
172 ~~quantitative real-time PCR (Allen *et al.*, 2007, Smith *et al.*, 2012). Methods have also been developed to type strains~~
173 ~~for epidemiological purposes, based on the ORF68 gene (Nugent *et al.*, 2006). The WOA Reference Laboratories~~
174 ~~employ in-house methods for strain typing, however these protocols have not yet been validated between different~~
175 ~~laboratories at an international level.~~

176 Real-time (or quantitative) PCR has become the method of choice for many the majority of diagnostic tests
177 laboratories and provides rapid and sensitive detection of viral DNA. Equine post-mortem tissues from newborn and
178 adult animals or equine fetal tissue from abortions (tissues containing lung, liver, spleen, thymus, adrenal gland and
179 placental tissues) can be used. For respiratory samples, equine nasopharyngeal swabs or deep nasal swabs

180 (submitted in a suitable viral transport medium), buffy coat, tracheal wash (TW) or broncho-alveolar lavage (BAL) are
181 all suitable. DNA should be extracted using an appropriate kit or robotic system.

182 There is no internationally standardised real-time PCR method for EHV-1 but Table 2 summarises the primer and
183 probe sequences for some of the most widely used assays. Type-specific PCR primers have been designed to
184 distinguish between the presence of EHV-1 and EHV-4. The optimised thermocycler times and temperatures are
185 documented in the publications cited.

186 **Table 2. Primer and probe sequences for EHV1/4 detection by real-time PCR**

<u>Primer</u>	<u>Primer sequence (5' to 3')</u>	<u>Target</u>	<u>Reference</u>
<u>Forward</u>	<u>CAT-GTC-AAC-GCA-CTC-CCA</u>		
<u>Reverse</u>	<u>GGG-TCG-GGC-GTT-TCT-GT</u>	<u>EHV-1 gB</u>	<u>Diallo et al., 2006</u>
<u>Probe</u>	<u>FAM-CCC-TAC-GCT-GCT-CC-MGB-NFQ</u>		
<u>Forward</u>	<u>CAT-ACG-TCC-CTG-TCC-GAC-AGA-T</u>		
<u>Reverse</u>	<u>GGTACTCGGCCTTTGACGAA</u>	<u>EHV-1 gB</u>	<u>Hussey et al., 2006</u>
<u>Probe</u>	<u>FAM-TGA-GAC-CGA-AGA-TCT-CCT-CCA-CCG-A-BHQ1</u>		
<u>Forward</u>	<u>TAT-ACT-CGC-TGA-GGA-TGG-AGA-CTT-T</u>		
<u>Reverse</u>	<u>TTG-GGG-CAA-GTT-CTA-GGT-GGT-T</u>	<u>EHV-1 gB</u>	<u>Pusterla et al., 2009</u>
<u>Probe</u>	<u>6FAM-ACA-CCT-GCC-CAC-CGC-CTA-CCG</u>		
<u>Forward</u>	<u>GCG-GGC-TCT-GAC-AAC-ACA-A</u>		
<u>Reverse</u>	<u>TTG-TGG-TTT-CAT-GGG-AGT-GTG-TA</u>	<u>EHV-1 gC</u>	ISO 17025 accredited for the detection of EHV-1 at WOAH Reference Laboratory
<u>Probe</u>	<u>FAM-TAA-CGC-AAA-CGG-TAC-AGA-A-BHQ1</u>		

187 *This multiplex real-time PCR test has been validated to ISO 17025 and is designed for use in a 96-well format. This
188 can be readily combined with automatic nucleic acid extraction methods. Discrimination between EHV-1 and EHV-4
189 is carried out by the incorporation of type-specific dual-labelled probes based on methods published by Hussey *et al.*
190 (2006) and Lawrence *et al.* (1994). To establish such a real-time PCR assay for diagnostic purposes, validation
191 against blinded samples is required. Sensitivity and specificity for the assay should be determined against each target.
192 Support for development of assays and appropriate sample panels can be obtained from the WOAH Reference
193 Laboratories. Reference material and sample panels for real-time PCR can be obtained from the WOAH Reference
194 Laboratories.

195 • **Point of care (POC) molecular tests**

196 Loop-mediated isothermal amplification (LAMP) assays for the detection of EHV-1 have been described
197 (Nemoto et al., 2011). An evaluation of a hydrolysis probe-based insulated isothermal PCR (iiPCR) assay
198 for the detection of EHV-1 showed it to have a high sensitivity and specificity compared with real-time PCR
199 (Balasuriya et al., 2017). However further validation of POC tests in the field is required.

200 • **Molecular characterisation**

201 Allelic discrimination real-time PCR assays identifying a single nucleotide polymorphism that was originally
202 suggested to distinguish between neuropathogenic and non-neuro-pathogenic EHV-1 strains have been
203 developed (Smith et al., 2012). However, investigations in many countries worldwide demonstrated that
204 the nucleotide substitution was not a reliable predictor of enhanced neuropathogenicity. Multilocus typing
205 and whole genome sequencing are useful for molecular epidemiological studies (Garvey et al., 2019;
206 Nugent et al., 2006; Sutton et al., 2019).

207 **1.3. Virus isolation**

208 Virus isolation is no longer a routine test used for EHV-1 detection in the majority of diagnostic laboratories but is
209 more often conducted for surveillance and research purposes. A number of cell types may be used for isolation of
210 EHV-1 (e.g. rabbit kidney [RK-13 (AATC-CCL37)], baby hamster kidney [BHK-21], Madin-Darby bovine kidney
211 [MDBK], pig kidney [PK-15], etc.). RK13 cells are commonly used for this purpose. For efficient primary isolation of

212 EHV-4 from horses with respiratory disease, equine-derived cell cultures must be used. Both EHV-1 and EHV-4 may
213 be isolated from nasopharyngeal samples using primary equine fetal kidney cells or equine fibroblasts derived from
214 dermal (E-Derm) or lung tissue. EHV-1 can be isolated on other cell types, as will be discussed later. The
215 nasopharyngeal swab and its accompanying transport medium are transferred into the barrel of a sterile 10-ml
216 syringe. Using the syringe plunger, the fluid is squeezed from the swab into a sterile tube. A portion of the expressed
217 fluid can be filtered through a sterile, 0.45-µm membrane syringe filter unit into a second sterile tube if heavy bacterial
218 contamination is expected, but this may also lower virus titre. Recently prepared cell monolayers in tissue culture
219 flasks are inoculated with the filtered, as well as the unfiltered, nasopharyngeal swab extract. Cell monolayers in
220 multiwell plates incubated in a 5% CO₂ environment may also be used. Virus is allowed to attach by incubating the
221 inoculated monolayers at 37°C. Monolayers of uninoculated control cells should be incubated in parallel.

222 At Recently prepared cell monolayers in tissue culture flasks or plates are inoculated with nasopharyngeal swab
223 extract or homogenised tissue: approximately 10% (w/v) pooled tissue homogenates of liver, lung, thymus, adrenal
224 and spleen (from aborted fetuses/neonatal foals) or of brain and spinal cord (from cases of neurological disease).
225 Virus is allowed to attach by incubating the end of the attachment period, inoculated monolayers at 37°C for 1 hour
226 after which the inocula are removed and the monolayers are rinsed twice with PBS to remove virus-neutralising
227 antibody that may or maintenance medium. Monolayers of uninoculated control cells should be present in the
228 nasopharyngeal secretions incubated in parallel. After addition of supplemented maintenance medium (MEM
229 containing 2% fetal calf serum [FCS] and twice the standard concentrations of antibiotics/antifungals [penicillin,
230 streptomycin, gentamicin, and amphotericin B]), the flasks are incubated at 37°C in a 5% CO₂ environment.

231 The use of a positive control virus samples of relatively low titre may be used to validate the isolation procedure
232 carries the risk that this may lead but should be processed separately to eventual avoid contamination of diagnostic
233 specimens. This risk can be minimised by using routine precautions and good laboratory technique, including the use
234 of biosafety cabinets, inoculating positive controls after the diagnostic specimens, decontaminating the surfaces in
235 the hood while the inoculum is adsorbing and using a positive control of relatively low titre. Inoculated flasks should
236 be inspected daily by microscopy for the appearance of characteristic herpesvirus cytopathic effect (CPE) (focal
237 rounding, increase in refractility, and detachment of cells). Cultures exhibiting no evidence of viral CPE after 1 week
238 of incubation should be blind-passaged into freshly prepared monolayers of cells, using small aliquots of both media
239 and cells as the inoculum. Further blind passage is usually not productive.

240 It can be useful to inoculate samples into both non-equine and equine cells in parallel to distinguish between EHV-1
241 and EHV-4, since EHV-4 can cause sporadic cases of abortion. Around 10% (w/v) pooled tissue homogenates of
242 liver, lung, thymus, and spleen (from aborted fetuses) or of central nervous system tissue (from cases of neurological
243 disease) are used for virus isolation. These are prepared by first mincing small samples of tissue into 1 mm cubes in
244 a sterile Petri dish with dissecting scissors, followed by macerating the tissue cubes further in serum free culture
245 medium with antibiotics using a homogeniser or mechanical tissue grinder. After centrifugation at 1200 g for
246 10 minutes, the supernatant is removed and 0.5 ml is inoculated into duplicate cell monolayers in tissue culture flasks.
247 Following incubation of the inoculated cells at 37°C for 1.5–2 hours, the inocula are removed and the monolayers are
248 rinsed twice with PBS or maintenance medium. After addition of 5 ml of supplemented maintenance medium, the
249 flasks are incubated at 37°C for up to 1 week or until viral CPE is observed. Cultures exhibiting no evidence of viral
250 CPE after 1 week of incubation should be passaged a second time into freshly prepared monolayers of cells, using
251 small aliquots of both media and cells as the inoculum.

252 Blood samples: EHV-1 and, infrequently, EHV-4 can be isolated from PBMC. Buffy coats may be prepared from
253 unclotted (heparinised) blood by centrifugation at 600–525 g for 45–5 minutes, and. The buffy coat is taken after the
254 plasma has been carefully removed. The buffy coat is then layered onto a PBMC separating solution (Ficoll; density
255 1077 g/ml, commercially available) and centrifuged at 400 g for 20 minutes. The PBMC interface (without most
256 granulocytes) is and washed twice in PBS (300 g for 10 minutes) and resuspended in 1 ml three times in 3 ml MEM
257 containing 2% FCS. As a quicker alternative method, PBMC may be collected by centrifugation directly from plasma.
258 (525 g for 5 minutes). Following the third wash, the buffy coat is harvested and resuspended in 2.5 ml MEM containing
259 2% FCS. An aliquot of the rinsed cell suspension is added to each of the duplicate monolayers of equine fibroblast,
260 equine fetal or RK-13 cell monolayers in 25 cm² flasks containing 8–10 ml freshly added maintenance medium. The
261 flasks can be used for DNA extraction. For virus isolation, the resuspended cells (1 ml) are co-cultivated with freshly
262 prepared primary equine lung or RK-13 cell suspensions (5 ml) in 25 cm² flasks. Confluent cell monolayers are not
263 used. The flasks are incubated at 37°C in a 5% CO₂ environment for 3 days or until the cells have reached 90%
264 confluence. The monolayers are then rinsed three times with 1 × PBS and supplemented with 5 ml MEM containing
265 2% FCS. They are incubated at 37°C for 7 days; either with or without removal of the inoculum. If PBMCs are not
266 removed prior to incubation, CPE may be difficult to detect in the presence of the massive inoculum of leukocytes:
267 each flask of cells is freeze-thawed after 7 for a further 4 days of incubation and the contents centrifuged at 300 g
268 for 10 minutes. Finally, 0.5 ml of the cell free, culture medium supernatant is transferred to freshly made cell
269 monolayers that are just subconfluent. These are incubated and observed daily for viral CPE for at least 5–6 days.
270 Again, samples, Samples exhibiting no evidence of viral CPE after 1 week of incubation should be passaged a second
271 time before discarding as negative.

272 Virus identity may be confirmed by PCR or by immunofluorescence with specific antisera. Virus isolates from
273 positive cultures should be submitted to a WOA Reference Laboratory for strain characterisation and to maintain
274 a geographically diverse archive. ~~Further strain characterisation for surveillance purposes or detection of the~~
275 ~~neurological marker can be provided at some laboratories.~~

276 **1.4. Virus detection by direct immunofluorescence**

277 Direct immunofluorescent detection of EHV-1 antigens in samples of post-mortem tissues collected from aborted
278 equine fetuses and the placenta provides a rapid preliminary diagnosis of herpesvirus abortion (Gunn, 1992). The
279 diagnostic reliability of this technique approaches that of virus isolation attempts from the same tissues.

280 In the United States of America (USA), potent polyclonal antiserum to EHV-1, prepared in swine and conjugated with
281 FITC, is available to veterinary diagnostic laboratories for this purpose from the National Veterinary Services
282 Laboratories of the United States Department of Agriculture (USDA). The antiserum cross-reacts with EHV-4 and
283 hence is not useful for serotyping, however virus typing can be conducted on any virus positive specimens by PCR.

284 Freshly dissected samples (5 × 5 mm pieces) of fetal tissue (lung, liver, thymus, and spleen) are frozen, sectioned
285 on a cryostat at -20°C, mounted on to microscope slides, and fixed with 100% acetone. After air-drying, the sections
286 are incubated at 37°C in a humid atmosphere for 30 minutes with an appropriate dilution of the conjugated swine
287 antibody to EHV-1. Unreacted antibody is removed by two washes in PBS, and the tissue sections are then covered
288 with aqueous mounting medium and a cover-slip, and examined for fluorescent cells indicating the presence of EHV
289 antigen. Each test should include a positive and negative control consisting of sections from known EHV-1 infected
290 and uninfected fetal tissue.

291 **1.5. Virus detection by immunoperoxidase staining**

292 Immunohistochemical (IH) staining methods, such as immunoperoxidase, have been developed for detecting EHV-1
293 antigen in fixed tissues of aborted equine fetuses, placental tissues or neurologically affected horses (Schultheiss *et*
294 *al.*, 1993; Whitwell *et al.*, 1992). Such techniques can be used as an alternative to immunofluorescence described
295 above and can also be readily applied to archival frozen or fixed tissue samples. Immunohistochemical staining for
296 EHV-1 is particularly useful for the simultaneous evaluation of morphological lesions and the identification of the virus.
297 Immunoperoxidase staining for EHV-1/4 may also be carried out on infected cell monolayers (~~van Maanen *et al.*,~~
298 2000). Adequate controls must be included with each immunoperoxidase test run for evaluation of both the method
299 specificity and antibody specificity. ~~In one WOA Reference Laboratory, this method is used routinely for frozen or~~
300 ~~fixed tissue, using if non-specific rabbit polyclonal sera is used raised against EHV-1. This staining method is not~~
301 ~~type-specific and therefore the staining method needs to be combined with virus isolation or PCR to discriminate~~
302 ~~between EHV-1 and EHV-4, however it provides a useful method for rapid diagnosis of EHV-induced abortion.~~

303 **1.6. Histopathology**

304 Histopathological examination of sections of fixed placenta and lung, liver, spleen, adrenal and thymus from aborted
305 fetuses and brain and spinal cord from neurologically affected horses should be carried out. In aborted fetuses,
306 eosinophilic intranuclear inclusion bodies present within bronchiolar epithelium or in cells at the periphery of areas of
307 hepatic necrosis are consistent with a diagnosis of herpesvirus infection. The characteristic microscopic lesion
308 associated with EHV-1 neuropathy is a degenerative thrombotic vasculitis of small blood vessels in the brain or spinal
309 cord (perivascular cuffing and infiltration by inflammatory cells, endothelial proliferation and necrosis, and thrombus
310 formation).

311 **2. Serological tests**

312 EHV-1 and EHV-4 are endemic in most parts of the world and seroprevalence is high, however serological testing of paired
313 sera can be useful for diagnosis of ER in horses. A positive diagnosis is based on the demonstration of significant increases
314 (four-fold or greater) in antibody titres in paired sera taken during the acute and convalescent stages of the disease. The
315 results of tests performed on sera from a single collection date are, in most cases, impossible to interpret with any degree
316 of confidence. The initial (acute phase) serum sample should be taken as soon as possible after the onset of clinical signs,
317 and the second (convalescent phase) serum sample should be taken 2–4 weeks later.

318 'Acute phase' sera from mares after abortion or from horses with EHV-1 neurological disease may already contain maximal
319 titres of EHV-1 antibody, with no increase in titres detectable in sera collected at later dates. In such cases, serological
320 testing of paired serum samples from clinically unaffected cohort members of the herd may prove useful for retrospective
321 diagnosis of ER within the herd.

322 Finally, the serological detection of antibodies to EHV-1 in heart or umbilical cord blood or other fluids of equine fetuses
323 can be of diagnostic value in cases of abortion especially when the fetus is virologically negative. The EHV-1/4 nucleic acid
324 may be identified from these tissues by PCR.

325 Serum antibody levels to EHV-1/4 may be determined by virus neutralisation (VN) (Thomson *et al.*, 1976), complement
326 fixation (CF) tests (Thomson *et al.*, 1976) or enzyme-linked immunosorbent assay (ELISA) (Crabb & Studdert, 1995). ~~There~~
327 ~~are no internationally recognised reagents or standardised techniques for performing any of the serological tests for~~
328 ~~detection of EHV-1/4 antibody; titre determinations on the same serum may differ from one laboratory to another.~~
329 Furthermore, The CF and VN tests detect antibodies that are cross-reactive between EHV-1 and EHV-4. Nonetheless, the
330 demonstration of a four-fold or greater rise in antibody titre to EHV-1 or EHV-4 during the course of a clinical illness provides
331 serological confirmation of recent infection with one of the viruses. Commercial ELISAs that distinguish EHV-1 and EHV-
332 4 antibodies are available but less widely used than the CF and VN tests. Unlike other alphaherpesviruses, DIVA⁴¹ ELISAs,
333 which have been very useful in eradication programmes for bovine rhinotracheitis and pseudorabies (Aujeszky's disease),
334 have not been developed for EHV-1/4.

335 The ~~microneutralisation test is a VN and the CF tests are~~ widely used and sensitive serological assays for detecting EHV-
336 1/4 antibody and will thus be described here.

337 2.1. Virus neutralisation test

338 This test is most commonly performed in flat-bottom 96-well microtitre plates (tissue culture grade) using a constant
339 dose of virus and doubling dilutions of equine test sera. At least ~~two-three~~ replicate wells for each serum dilution are
340 required. Heat-inactivated maintenance medium with a concentration of 2% FCS (HIMM) Serum-free MEM is used
341 throughout as a diluent. Virus stocks of known titre are diluted just before use to contain 100 TCID₅₀ (50% tissue
342 culture infective dose) in 25 µl. Monolayers of ~~E-Derm or RK-13 cells~~ are prepared monodispersed with EDTA/trypsin
343 and resuspended at a concentration of 5×10^5 /ml. ~~Note that RK-13 cells can be used with EHV-1 but do not show~~
344 ~~CPE with EHV-4.~~ Antibody positive and negative control equine sera and controls for cell viability, virus infectivity,
345 and test serum cytotoxicity, must be included in each assay. End-point VN titres of antibody are calculated by
346 determining the reciprocal of the highest serum dilution that protects ≥75% ~~100%~~ of the cell monolayer from virus
347 destruction in ~~both~~ of the replicate wells.

348 Serum toxicity may be encountered in samples from horses repeatedly vaccinated with a commercial vaccine
349 prepared from EHV-1 grown up in RK-13 cells. This can give rise to difficulties in interpretation of test reactions at
350 lower serum dilutions. The problem can be overcome using E-Derm or other non-rabbit kidney derived cell line.

351 2.1.1. Test procedure

352 A suitable test procedure is as follows:

- 353 i) Prepare semi-confluent monolayers in tissue culture microtitre plates.
- 354 ii) Inactivate test and control sera for 30 minutes in a water bath at 56°C.
- 355 iii) Add 40 25-µl of HIMM serum-free MEM to all wells of the microtitre assay plates.
- 356 iv) For test sample titration, pipette 25-40 µl of each test serum into duplicate triplicate wells of both
357 rows A and B of the plate. The first two rows serve as the dilution of the test serum and the third
358 row serves as the serum toxicity control and the second row as the first dilution of the test. Make
359 doubling dilutions of each serum starting with row B and proceeding to the bottom of the plate
360 by sequential mixing and transfer of 25-40 µl to each subsequent row of wells. Six sera can be
361 assayed in each plate. Add 40µl of HIMM to the serum control rows.
- 362 v) Add 40 25-µl of the appropriately diluted EHV-1 ~~or EHV-4~~ virus stock to ~~each-all~~ wells
363 (100 TCID₅₀/well) of the test plate except those of row A, which are the serum controls wells.
364 Note that the final serum dilutions, after addition of virus, run from a starting dilution of 1/4 to
365 1/256. A separate control plate should include titration of both a negative and positive (high and
366 low) horse serum-sera of known titre, cell control (no virus), and a back titration of virus control
367 (no serum), and a virus titration using six wells per log dilution (100 TCID₅₀ to 0.01 TCID₅₀/well)
368 calculate the actual amount of virus used in the test
- 369 vi) Incubate the plates for 1 hour at 37°C in 5% CO₂ atmosphere. Add 50 µl of the prepared ~~E-~~
370 ~~Derm or RK-13 cell suspension~~ (5×10^5 cells/ml) in MEM/10% FCS to each well.
- 371 vii) Transfer 50 µl from each well of the test and control plates to the tissue culture microtitre plates.

⁴¹ DIVA: detection of infection in vaccinated animals

- 372 viii) Incubate the plates for 2–4–5 days at 37°C in an atmosphere of 5% CO₂ in air.
- 373 ix) Examine the plates microscopically for CPE and record the results on a worksheet. Confirm the
374 validity of the test by establishing that the working dilution of stock virus is at 100 TCID₅₀/well,
375 that the (high and low) positive control sera are within one well of their pre-determined titre and
376 that the negative control serum is negative at a 1/4 dilution. This takes approximately 72 hours.
377 If at this stage the antigen is too weak the virus concentration may be increased by extending
378 the incubation period up to 5 days. If the antigen is too strong the test must be repeated.
- 379 Wells are scored as positive for neutralisation of virus if ≥ 75% of the cell monolayer remains
380 intact. The highest dilution of serum resulting in ≥ 75% neutralisation of virus (<25% CPE) in
381 replicate wells is the end-point titre for that serum. Examine the plates microscopically for CPE
382 and record the results on a worksheet.
- 383 x) Alternatively, the cell monolayers can be scored for CPE after fixing and staining as follows:
384 after removal of the culture fluid, immerse the plates for 15 minutes in a solution containing 2
385 mg/ml crystal violet, 10% formalin, 45% methanol, and 45% water. Then, rinse the plates
386 vigorously under a stream of running tap water. Wells containing intact cell monolayers stain
387 blue, while monolayers destroyed by virus do not stain. ~~Verify that the cell control, positive~~
388 ~~serum control, and serum cytotoxicity control wells stain blue, that the virus control and negative~~
389 ~~serum control wells are not stained, and that the actual amount of virus added to each well is~~
390 ~~between 10^{4.5} and 10^{2.5} TCID₅₀. Wells are scored as positive for neutralisation of virus if 100%~~
391 ~~of the cell monolayer remains intact. The highest dilution of serum resulting in complete~~
392 ~~neutralisation of virus (no CPE) in both duplicate wells is the end point titre for that serum.~~
- 393 xi) Calculate the neutralisation titre for each test serum, and compare acute and convalescent
394 phase serum titres from each animal for a four-fold or greater increase.

395 **2.2. Complement fixation test**

396 The CF test can be used for the detection and quantification of antibodies against EHV-1. The test determines whether
397 an antigen and an antibody are capable of forming a complex. The presence of an immune complex is revealed by
398 the detector system, which consists of guinea-pig complement and sensitised sheep red blood cells (SRBCs) coated
399 with rabbit haemolytic serum (haemolysin). In the absence of antibodies against equine herpesvirus, no
400 antibody/antigen complex is formed, the complement remains free in the solution and the sensitised SRBCs become
401 lysed. In the presence of antibodies against equine herpesvirus, an antibody/antigen complex is formed, the
402 complement becomes fixed and is therefore unable to lyse the SRBCs. They subsequently form a button at the bottom
403 of the test well.

404 Guinea-pig complement, rabbit haemolytic serum, complement fixation diluent (CFD) and bovine serum albumin
405 (BSA) can be obtained commercially. The dilution of guinea-pig complement that has activity at 3 HD (haemolytic
406 dose) in the presence of sensitised SRBCs should be optimised. The recommended dilution of rabbit haemolytic
407 serum (or the working dilution) is sometimes provided by the supplier. However, the optimal dilution of haemolysin
408 should be determined with the in use reagents (complement etc.) so that the test can be performed reproducibly. The
409 optimum concentration of antigen to be used in the test should be determined using an antigen versus antibody
410 chequerboard technique and by testing a panel of known positive sera.

411 The test is performed in U bottomed microtitre plates. Paired sera should be assayed on the same plate. An antibody
412 positive serum should be included as a control on each plate. All sera are tested on a second plate containing all
413 components except virus to check for anti-complementary activity. A back titration of the working dilution (3 HD) of
414 complement to 2 HD, 1 HD, 0.5 HD is set up in duplicate wells on the complement control plate (eight wells in total).
415 An SRBC control is set up in eight wells.

416 **2.2.1. Preparation of samples**

- 417 i) Samples and controls are prepared by adding 4 volumes (600 µl) of CFD to 1 volume (150 µl)
418 of test sera to give a 1/5 dilution.
- 419 ii) Diluted serum is inactivated for 30 minutes at 60°C to destroy the naturally occurring
420 complement.

421 **2.2.2. Test procedure**

- 422 i) Prepare the test plate and anti-complementary plate by adding 25 µl 0.05% BSA/CFD to all
423 wells except the first column (H).
- 424 ii) Add 50 µl of 0.05% BSA/CFD to the eight wells of the complement control (back titration).

-
- 425 iii) Add 75 µl of 0.05% BSA/CFD to eight wells of cell control.
- 426 iv) Add 50 µl of the diluted inactivated test serum and controls to the first well of each row on both
427 the test and anti-complementary plates. Serial doubling dilutions are then made by transferring
428 25 µl across the plate and discarding the final 25 ml.
- 429 v) Place the microtitre plates on ice for addition of antigen and complement.
- 430 vi) Add 25 µl of antigen (diluted to working strength in 0.05% BSA/CFD) to the test plates.
- 431 vii) Add 25 µl of 0.05% BSA/CFD to all wells of the anti-complementary plate to compensate for
432 lack of antigen.
- 433 viii) Add 25 µl of guinea-pig complement diluted in 0.05% BSA/CFD to 3 HD to all wells except the
434 complement control and SRBC control.
- 435 ix) Back titrate the working dilution of 3 HD complement to 2 HD, 1 HD and 0.5 HD in 200 µl
436 volumes. Add 25 µl of each dilution to the appropriate wells.
- 437 x) Incubate all plates at 4°C overnight.

2.2.3. Preparation and addition of sheep blood

- 439 i) SRBCs collected into Alsever's solution are washed twice in 0.05% BSA/PBS solution.
- 440 ii) Gently resuspend the SRBCs in 5–10 ml 0.05% BSA/CFD solution. Dilute to 2% SRBCS (v/v
441 packed cells) in BSA/CFD solution.
- 442 iii) Mix the 2% SRBCs with an equal volume of BSA/CFD solution containing haemolysin at its
443 optimal sensitising concentration to give a 1% SRBC solution. Prepare an appropriate volume
444 of this solution by allowing 3 ml per microtitre plate.
- 445 iv) Incubate at 37°C for 10 minutes. Store the 1% sensitised SRBCs overnight at 4°C.
- 446 v) The following day, incubate the 1% sensitised SRBCs at 37°C for 30 minutes. During the final
447 20 minutes of this incubation, transfer the test plates from 4°C to 37°C.
- 448 vi) At the end of the 30-minute incubation, add 25 ml of 1% sensitised SRBCs to all plates. Mix on
449 a plate shaker for 30 seconds.
- 450 vii) Incubate the plates at 37°C for 30 minutes. Shake the plates after 15 minutes and at the end of
451 this incubation (a total of three times).
- 452 viii) Incubate the plates at 4°C for 2 hours to allow the cells to settle.
- 453 ix) Read and record the test results after 2 hours.

2.2.4. Reading results

- 454 i) Confirm the validity of the test by establishing that the working dilution of complement is at 3 HD:
455 100% lysis at 3 HD and 2 HD, and 50% lysis at 1 HD. Distinct buttons should be visible in the
456 eight wells of the SRBC control.
- 457 ii) There must be 100% lysis observed at the 1/5 dilution for the negative control (<5). The antibody
458 titre of the positive control serum must read within one well of its predetermined titre.
- 459 iii) Confirm that there are no buttons visible on the anti-complementary plates. Buttoning indicates
460 either the presence of residual native complement in the sample or that there is a non-specific
461 complement fixing effect occurring. Sera that show anti-complementary activity should be
462 retested and treated as described below.
- 463 iv) In the test wells, buttoning indicates the presence of antibodies in the serum. The antibody titre
464 is the dilution at which there is 50% buttoning and 50% lysis observed.
- 465

2.2.5. Treatment of samples showing anti-complementary activity

- 466 i) Add 50 µl of guinea-pig complement to 150 µl of the serum showing anti-complementary
467 activity.
- 468 ii) Incubate the sample at 37°C for 30 minutes.
- 469 iii) Add 550 µl of CFD (1:5 dilution).
- 470 iv) Heat inactivate at 60°C for 30 minutes.
- 471

472 C. REQUIREMENTS FOR VACCINES

473 1. Background

474 Both live attenuated and inactivated vaccines are available for use in horses as licensed, commercially prepared products
475 for use in reducing the impact of disease in horses caused by EHV-1/4 infection. The products contain different
476 permutations of EHV-1 and EHV-4 and some also include equine influenza virus.

477 Clinical experience has demonstrated that vaccination can be useful for reducing clinical signs of respiratory disease and
478 incidence of abortion, however none of the vaccines protects against neurological disease. Multiple doses repeated
479 annually, of each of the currently marketed ER vaccines are recommended by their respective manufacturers. Vaccination
480 schedules vary with a particular vaccine.

481 The indications stated on the product label for use of several available vaccines for ER are either as a preventative of
482 herpesvirus-associated respiratory disease, or as an aid in the prevention of abortion, or both. A minority of ~~Only four~~
483 vaccine products have met the regulatory requirements for claiming efficacy in providing protection from herpesvirus
484 abortion as a result of successful vaccination and challenge experiments in pregnant mares. None of the vaccine products
485 have been demonstrated to prevent the occurrence of neurological disease sometimes associated with EHV-1 infection.

486 Guidelines for the production of veterinary vaccines are given in Chapter 1.1.8 *Principles of veterinary vaccine production*.
487 The guidelines given here and in chapter 1.1.8 are intended to be general in nature and may be supplemented by national
488 and regional requirements.

489 2. Outline of production and minimum requirements for vaccines

490 2.1. Characteristics of the seed

491 The master seed virus (MSV) for ER vaccines must be prepared from strains of EHV-1 and/or EHV-4 that have been
492 positively and unequivocally identified ~~by both serological and genetic tests~~. Seed virus must be propagated in a cell
493 line approved for equine vaccine production by the appropriate regulatory agency. A complete record of original
494 source (including isolate number, location, year of isolation), passage history, medium used for propagation, etc.,
495 shall be kept for the master seed preparations of both the virus(es) and cell stock(s) intended for use in vaccine
496 production.

497 2.1.1. Biological characteristics of the master seed

498 Permanently stored stocks of both MSV and master cell stock (MCS) used for vaccine production
499 must be demonstrated to be pure, safe and, in the case of MSV, also immunogenic.

500 Generally, the fifth passage from the MSV and the twentieth passage from the MCS are the highest
501 allowed for vaccine production. Results of all quality control tests on master seeds must be recorded
502 and made a part of the licensee's permanent records.

503 2.1.2. Quality criteria

504 Tests for master seed purity include prescribed procedures that demonstrate the virus and cell seed
505 stocks to be free from bacteria, fungi, mycoplasmas, and extraneous viruses. Special tests must be
506 performed to confirm the absence of equine arteritis virus, equine infectious anaemia virus, equine
507 influenza virus, equine herpesvirus-2, -3, and -5, equine rhinitis A and B viruses, the alphaviruses of
508 equine encephalomyelitis, bovine viral diarrhoea virus (BVDV – common contaminant of bovine
509 serum), and porcine parvovirus (PPV – potential contaminant of porcine trypsin). The purity check
510 should also include the exclusion of the presence of EHV-1 from EHV-4 MSV and *vice versa*.

511 2.1.3. Validation as a vaccine strain

512 Tests for immunogenicity of the EHV-1/4 MSV stocks should be performed in horses on an
513 experimental test vaccine prepared from the highest passage level of the MSV allowed for use in
514 vaccine production. The test for MSV immunogenicity consists of vaccination of horses with low
515 antibody titres to EHV-1/4, with doses of the test vaccine that will be recommended on the final
516 product label. Second serum samples should be obtained and tested for significant increases in
517 neutralising antibody titre against the virus, 21 days after the final dose.

518 Samples of each lot of MSV to be used for preparation of live attenuated ER vaccines must be tested
519 for safety in horses determined to be susceptible to the virulent wild-type virus, including pregnant

520 mares in the last 4 months of gestation. Vaccine safety must be demonstrated in a 'safety field trial'
521 in horses of various ages from three different geographical areas. The safety trial should be
522 conducted by independent veterinarians using a prelicensing batch of vaccine. EHV-1 vaccines
523 making a claim for efficacy in controlling abortion must be tested for safety in a significant number of
524 late gestation pregnant mares, using the vaccination schedule that will be recommended by the
525 manufacturer for the final vaccine product.

526 **2.2. Method of manufacture**

527 **2.2.1. Procedure**

528 A detailed protocol of the methods of manufacture to be followed in the preparation of vaccines for
529 ER must be compiled, approved, and filed as an Outline of Production with the appropriate licensing
530 agency. Specifics of the methods of manufacture for ER vaccines will differ with the type (live or
531 inactivated) and composition (EHV-1 only, EHV-1 and EHV-4, EHV-4 and equine influenza viruses,
532 etc.) of each individual product, and also with the manufacturer.

533 **2.2.2. Requirements for ingredients**

534 Cells, virus, culture medium, and medium supplements of animal origin that are used for the
535 preparation of production lots of vaccine must be derived from bulk stocks that have passed the
536 prescribed tests for bacterial, fungal, and mycoplasma sterility; nontumorigenicity; and absence of
537 extraneous viral agents.

538 **2.2.3. Final product batch tests**

539 i) Sterility

540 Samples taken from each batch of completed vaccine are tested for bacteria, fungi, and mycoplasma
541 contamination. Procedures to establish that the vaccine is free from extraneous viruses are also
542 required; such tests should include inoculation of cell cultures that allow detection of the common
543 equine viruses, as well as techniques for the detection of BVDV and PPV in ingredients of animal
544 origin used in the production of the batch of vaccine.

545 ii) Identity

546 Identity tests shall demonstrate that no other vaccine strain is present when several strains are
547 propagated in a laboratory used in the production of multivalent vaccines.

548 iii) Safety

549 Safety tests shall consist of detecting any abnormal local or systemic adverse reactions to the vaccine
550 in the host species by all vaccination route(s). Tests to assure safety of each production batch of ER
551 vaccine must demonstrate complete inactivation of virus (for inactivated vaccines) as well as a level
552 of residual virus-killing agent that does not exceed the maximal allowable limit (e.g. 0.2% for
553 formaldehyde).

554 iv) Batch potency

555 Batch potency is examined on the final formulated product. ~~Batch control of antigenic potency for~~
556 ~~EHV-1 vaccines only may be tested by measuring the ability of dilutions of the vaccine to protect~~
557 ~~hamsters from challenge with a lethal dose of hamster adapted EHV-1 virus. Although potency~~
558 ~~testing on production batches of ER vaccine may also be performed by vaccination of susceptible~~
559 ~~horses followed by assay for seroconversion, the recent availability of virus type specific MABs has~~
560 ~~permitted development of less costly and more rapid *in-vitro* immunoassays exist for antigenic~~
561 ~~potency. The basis for such *in-vitro* assays for ER vaccine potency is the determination, by use of~~
562 ~~the-specific MAb, of the presence of at least the minimal amount of viral antigen within each batch of~~
563 ~~vaccine that correlates with the required level of protection (or seroconversion rate) in a standard~~
564 ~~animal test for potency.~~

565 **2.3. Requirements for authorisation/registration/licencing**

566 **2.3.1. Manufacturing process**

567 For registration of vaccine, all relevant details concerning manufacture of the vaccine and quality
568 control testing (see Sections C.2.1 and C.2.2) should be submitted to the authorities. This information

569 shall be provided from three consecutive vaccine batches with a volume not less than 1/3 of the
570 typical industrial batch volume.

571 **2.3.2 Safety requirements**

572 Vaccine safety should be evaluated in vaccinated animals using different assays (see Section
573 2.2.3.iii).

574 **2.3.3 Efficacy requirements**

575 Vaccine efficacy (protection) is estimated in vaccinated animals directly by evaluating their resistance
576 to live pathogen challenge.

577 **2.3.4 Duration of immunity**

578 As part of the licensing or marketing authorisation procedure, the manufacturer may be required to
579 demonstrate the duration of immunity (DOI) of a given vaccine by either challenge or alternative test
580 at the end of the claimed period of protection.

581 Tests to establish the duration of immunity to EHV-1/4 or EHV1/4 achieved by immunisation with
582 each batch of vaccine are not required. The results of many reported observations indicate that
583 immunity induced by vaccination against EHV-1 or EHV induced immunity to EHV-1/4 is not more
584 than a few months in duration; these observations are reflected in the frequency of revaccination
585 recommended on ER vaccine product labels.

586 **2.3.5 Stability**

587 As part of the licensing or marketing authorisation procedure, the manufacturer will be required to
588 demonstrate the stability of all the vaccine's properties at the end of the claimed shelf-life period.
589 Storage temperature shall be indicated and warnings should be given if product is damaged by
590 freezing or ambient temperature.

591 At least three production batches of vaccine should be tested for shelf life before reaching a
592 conclusion on the vaccine's stability. When stored at 4°C, inactivated vaccine products generally
593 maintain their original antigenic potency for at least 1 year. Lyophilised preparations of the live virus
594 vaccine are also stable during storage for 1 year at 4°C. Following reconstitution, live virus vaccine
595 is unstable and cannot be stored without loss of potency.

596 **Note:** current vaccines are authorised for prevention of respiratory disease or as an aid in the prevention of abortion.
597 Unless the vaccine's ability to prevent neurological disease is under investigation, the virus used in the challenge
598 experiments should not be a strain with a history of inducing neurological disease.

599 **REFERENCES**

600 ~~ALLEN G.P. (2007). Development of a real time polymerase chain reaction assay for rapid diagnosis of neuropathogenic~~
601 ~~strains of equine herpesvirus 1. *J Vet. Diagn. Invest.*, **19**, 69–72.~~

602 ~~ALLEN G.P. & BRYANS J.T. (1986). Molecular epidemiology, pathogenesis and prophylaxis of equine herpesvirus-1~~
603 ~~infections. *In: Progress in Veterinary Microbiology and Immunology*, Vol. 2, Pandey R., ed. Karger, Basel, Switzerland &~~
604 ~~New York, USA, 78–144.~~

605 ALLEN G.P., KYDD J.H., SLATER J.D. & SMITH K.C. (1999). Recent advances in understanding the pathogenesis,
606 epidemiology, and immunological control of equid herpesvirus-1 (EHV-1) abortion. *Equine Infect. Dis.*, **8**, 129–146.

607 ALLKOEFER A., GARVEY M., RYAN E., LYONS R., RYAN M., LUKASEVICIUTE G., WALSH C., VENNER M. & CULLINANE A. (2021).
608 Primary vaccination in foals: a comparison of the serological response to equine influenza and equine herpesvirus vaccines
609 administered concurrently or 2 weeks apart. *Arch. Virol.*, **166**, 571–579.

610 ATASEVEN V.S., DAĞALP S.B., GÜZEL M., BAŞARAN Z., TAN M.T. & GERAGHTY B. (2009). Prevalence of equine herpesvirus-1
611 and equine herpesvirus-4 infections in equidae species in Turkey as determined by ELISA and multiplex nested PCR. *Res.*
612 *Vet. Sci.*, **86**, 339–344.

- 613 BALASURIYA U.B.R., LEE P.-Y.A., TSAI Y.-L., TSAI C.-F., SHEN Y.-H., CHANG H.-F. G., SKILLMAN A., WANG H.-T.T., PRONOST S.
614 & ZHANG Y. (2017). Translation of a laboratory-validated equine herpesvirus-1 specific real-time PCR assay into an
615 insulated isothermal polymerase chain reaction (iiPCR) assay for point-of-need diagnosis using POKKIT™ nucleic acid
616 analyzer. *J. Virol. Methods*, **241**, 58–63.
- 617 BANNAI H., MAE N., ODE H., NEMOTO M., TSUJIMURA K., YAMANAKA T., KONDO T. & MATSUMURA T. (2014). Successful control
618 of winter pyrexias caused by equine herpesvirus type 1 in Japanese training centers by achieving high vaccination
619 coverage. *Clin. Vaccine Immunol.*, **21**, 1070–1076.
- 620 BANNAI H., TSUJIMURA K., NEMOTO M., OHTA M., YAMANAKA T., KOKADO H. & MATSUMURA T. (2019). Epizootiological
621 investigation of equine herpesvirus type 1 infection among Japanese racehorses before and after the replacement of an
622 inactivated vaccine with a modified live vaccine. *BMC Vet. Res.*, **15**, 280.
- 623 BARBIC L., LOJKIC I., STEVANOVIC V., BEDEKOVIC T., STARESINA V., LEMO N., LOJKIC M. & MADIC J. (2012). Two outbreaks of
624 neuropathogenic equine herpesvirus type 1 with breed-dependent clinical signs. *Vet. Rec.*, **170**, 227.
- 625 BRESGEN C., LÄMMER M., WAGNER B., OSTERRIEDER N. & DAMIANI A.M. (2012). Serological responses and clinical outcome
626 after vaccination of mares and foals with equine herpesvirus type 1 and 4 (EHV-1 and EHV-4) vaccines. *Vet. Microbiol.*,
627 **160**, 9–16.
- 628 COUROUCÉ A., NORMAND C., TESSIER C., POMARES R., THÉVENOT J., MARCILLAUD-PITEL C., LEGRAND L., PITEL P.H., PRONOST
629 S. & LUPO C. (2023). Equine Herpesvirus-1 Outbreak During a Show-Jumping Competition: A Clinical and Epidemiological
630 Study. *J. Equine Vet. Sci.*, **128**, 104869.
- 631 BORCHERS K. & SLATER J. (1993). A nested PCR for the detection and differentiation of EHV-1 and EHV-4. *J. Virol. Methods*,
632 **45**, 331–336.
- 633 BRYANS J.T. & ALLEN G.P. (1988). Herpesviral diseases of the horse. In: Herpesvirus Diseases of Animals, Wittman G., ed.
634 Kluwer, Boston, USA, 176–229.
- 635 CRABB B.S., MACPHERSON C.M., REUBEL G.H., BROWNING G.F., STUDDERT M.J. & DRUMMER H.E. (1995). A type-specific
636 serological test to distinguish antibodies to equine herpesviruses 4 and 1. *Arch. Virol.*, **140**, 245–258.
- 637 CRABB B.S. & STUDDERT M.J. (1995). Equine herpesviruses 4 (equine rhinopneumonitis virus) and 1 (equine abortion virus).
638 *Adv. Virus Res.*, **45**, 153–190.
- 639 DIALLO I.S., HEWITSON G., WRIGHT L., RODWELL B.J. & CORNEY B.G. (2006). Detection of equine herpesvirus type 1 using a
640 real-time polymerase chain reaction. *J. Virol. Methods*, **131**, 92–98.
- 641 DIALLO I.S., HEWITSON G., WRIGHT L.L., KELLY M.A., RODWELL B.J. & CORNEY B.G. (2007). Multiplex real-time PCR for
642 detection and differentiation of equid herpesvirus 1 (EHV-1) and equid herpesvirus 4 (EHV-4). *Vet. Microbiol.*, **123**, 93–
643 103.
- 644 EL BRINI Z., FASSI FIGHRI O. & PAILLOT R. (2021). Seroprevalence of Equine Herpesvirus 1 (EHV-1) and Equine Herpesvirus
645 4 (EHV-4) in the Northern Moroccan Horse Populations. *Animals (Base)*, **11**, 2851.
- 646 FÉDÉRATION EQUESTRE INTERNATIONALE (FEI) (2021). Management of an EHV-1 outbreak at FEI events and its international
647 impact. *Vet. Rec.*, **189**, e905. <https://doi.org/10.1002/vetr.905>
- 648 FOOTE C.E., GILKERSON J.R., WHALLEY J.M. & LOVE D.N. (2003). Seroprevalence of equine herpesvirus 1 in mares and foals
649 on a large Hunter Valley stud farm in years pre- and postvaccination. *Aust. Vet. J.*, **81**, 283–288.
- 650 GARVEY M., LYONS R. & HECTOR R.D. (2019). Molecular Characterisation of Equine Herpesvirus 1 Isolates from Cases of
651 Abortion, Respiratory and Neurological Disease in Ireland between 1990 and 2017. *Pathogens*, **8**, 7.
- 652 GILDEA S., SANCHEZ HIGGINS M.J., JOHNSON G., WALSH C. & CULLINANE A. (2016). Concurrent vaccination against equine
653 influenza and equine herpesvirus – a practical approach. *Influenza Other Respir. Viruses*, **10**, 433–437.
- 654 GILKERSON J. R., WHALLEY J. M., DRUMMER H. E., STUDDERT M. J. & LOVE D. N. (1999). Epidemiology of EHV-1 and EHV-4 in
655 the mare and foal populations on a Hunter Valley stud farm: are mares the source of EHV-1 for unweaned foals. *Vet.*
656 *Microbiol.*, **68**, 27–34.

- 657 GRYSPEERDT A., VANDERKERCKHOVE A., VAN DOORSSELAERE J., VAN DE WALLE G., & NAUWYNCK H. (2011). Description of an
658 unusually large outbreak of nervous system disorders caused by equine herpesvirus 1 (EHV1) in 2009 in Belgium. *Vlaams*
659 *Diergeneeskundig Tijdschrift*, **80**, 147–153.
- 660 FRITSCHÉ A.K. & BORCHERS K. (2011). Detection of neuropathogenic strains of equid herpesvirus 1 (EHV-1) associated with
661 abortions in Germany. *Vet. Microbiol.*, **147**, 176–180.
- 662 GUNN H.M. (1992). A direct fluorescent antibody technique to diagnose abortion caused by equine herpesvirus. *Irish Vet.*
663 *J.*, **44**, 37–40.
- 664 HELDENS J.G., HANNANT D., CULLINANE A.A., PRENDERGAST M.J., MUMFORD J.A., NELLY M., KYDD J.H., WESTSTRATE M.W. &
665 VAN DEN HOVEN R. (2001). Clinical and virological evaluation of the efficacy of an inactivated EHV1 and EHV4 whole virus
666 vaccine (Duvaxyn EHV1.4). Vaccination/challenge experiments in foals and pregnant mares. *Vaccine*, **19**, 4307–4317.
- 667 HENNINGER R.W., REED S.M., SAVILLE W.J., ALLEN G.P., HASS G.F., KOHN C.W. & SOFALY C. (2007). Outbreak of neurologic
668 disease caused by equine herpesvirus-1 at a university equestrian center. *J. Vet. Intern. Med.*, **21**, 157–165.
- 669 GOODMAN L.B., LOREGIAN A., PERKINS G.A., NUGENT J., BUCKLES E.L., MERCORELLI B., KYDD J.H., PALÙ G., SMITH K.C.,
670 OSTERRIEDER N. & DAVIS-POYNTER N. (2007). A point mutation in a herpesvirus polymerase determines neuropathogenicity.
671 *PLoS Pathog.*, **3** (11), e160.
- 672 HARTLEY C.A., WILKS C.R., STUDDERT M.J. & GILKERSON J.R. (2005). Comparison of antibody detection assays for the
673 diagnosis of equine herpesvirus 1 and 4 infections in horses. *Am. J. Vet. Res.*, **66**, 921–928.
- 674 HUSSEY S.B., CLARK R., LUNN K.F., BREATHNACH C., SOBOLL G., WHALLEY J.M. & LUNN D.P. (2006). Detection and
675 quantification of equine herpesvirus-1 viremia and nasal shedding by real-time polymerase chain reaction. *J. Vet. Diagn.*
676 *Invest.*, **18**, 335–342.
- 677 KYDD J. H., WATTRANG E. & HANNANT D. (2003). Pre-infection frequencies of equine herpesvirus-1 specific, cytotoxic T
678 lymphocytes correlate with protection against abortion following experimental infection of pregnant mares. *Vet. Immunol.*
679 *Immunopathol.*, **96**, 207–217.
- 680 LAWRENCE G.L., GILKERSON J., LOVE D.N., SABINE M. & WHALLEY J.M. (1994). Rapid, single-step differentiation of equid
681 herpesvirus 1 and 4 from clinical material using the polymerase chain reaction and virus-specific primers. *J. Virol. Methods*,
682 **47**, 59–72.
- 683 MCCARTAN C.G., RUSSELL M.M., WOOD J.L. & MUMFORD J.A. (1995). Clinical, serological and virological characteristics of
684 an outbreak of paresis and neonatal foal disease due to equine herpesvirus-1 on a stud farm. *Vet. Rec.*, **136**, 7–12.
- 685 MOORE, S.E., Strang, C.L., Marr, C.M., Newton, R. and Cameron, I.J. (2019), Management of an outbreak of multiple
686 equine herpesvirus type 1 abortions among vaccinated mares on a large UK Thoroughbred stud farm. *Vet Rec Case Rep*,
687 **7**: e000799.
- 688 NEMOTO M., OHTA M., TSUJIMURA K., BANNAI H., YAMANAKA T., KONDO T. & MATSUMURA T. (2011). Direct detection of equine
689 herpesvirus type 1 DNA in nasal swabs by loop-mediated isothermal amplification (LAMP). *J. Vet. Med. Sci.*, **73**, 1225–
690 1227.
- 691 NUGENT J., BIRCH-MACHIN I., SMITH K.C., MUMFORD J.A., SWANN Z., NEWTON J.R., BOWDEN R.J., ALLEN G.P. & DAVIS-POYNTER
692 N. (2006). Analysis of equid herpesvirus 1 strain variation reveals a point mutation of the DNA polymerase strongly
693 associated with neuropathogenic versus nonneuropathogenic disease outbreaks. *J. Virol.*, **80**, 4047–4060.
- 694 PRONOST S., LEGRAND L., PITEL P.H., WEGGE B., LISSENS J., FREYMUTH F., RICHARD E. & FORTIER G. (2012). Outbreak of
695 equine herpesvirus myeloencephalopathy in France: a clinical and molecular investigation. *Transbound. Emerg. Dis.*, **59**,
696 256–263.
- 697 PUSTERLA N., KALSCHUR M., PETERS D., BIDWELL L., HOLTZ S., BARNUM S. & LAWTON K. (2023). Investigation of the Frequency
698 of Detection of Common Respiratory Pathogens in Nasal Secretions and Environment of Healthy Sport Horses Attending
699 a Multi-Week Show Event during the Summer Months. *Viruses*, **15**, 1225.
- 700 PUSTERLA N., SANDLER-BURTNESS E., BARNUM S., HILL L.A., MENDONSA E., KHAN R., PORTNER D., RIDLAND H. & SCHUMACHER
701 S. (2022). Frequency of Detection of Respiratory Pathogens in Nasal Secretions From Healthy Sport Horses Attending a
702 Spring Show in California. *J. Equine Vet. Sci.*, **117**, 104089.

- 703 PUSTERLA N., WILSON W.D., MAPES S., FINNO C., ISBELL D., ARTHUR R.M. & FERRARO G.L. (2009). Characterization of viral
704 loads, strain and state of equine herpesvirus-1 using real-time PCR in horses following natural exposure at a racetrack in
705 California. *Vet. J.*, **179**, 230–239.
- 706 O'KEEFE J.S., JULIAN A., MORIARTY K., MURRAY A. & WILKS C.R. (1994). A comparison of the polymerase chain reaction with
707 standard laboratory methods for the detection of EHV-1 and EHV-4 in archival tissue samples. *N.Z. Vet. J.*, **42**, 93–96.
- 708 SCHULTHEISS P.C., COLLINS J.K. & CARMAN J. (1993). Use of an immunoperoxidase technique to detect equine herpesvirus-
709 1 antigen in formalin-fixed paraffin-embedded equine fetal tissues. *J. Vet. Diagn. Invest.*, **5**, 12–15.
- 710 Singh B.K., Ahuja S. & Gulati B.R. (2004). Development of a neutralizing monoclonal antibody-based blocking ELISA for
711 detection of equine herpesvirus 1 antibodies. *Vet. Res. Commun.*, **28**, 437–446.
- 712 SMITH F.L., WATSON J.L., SPIER S.J., KILCOYNE I., MAPES S., SONDER C. & PUSTERLA N. (2018). Frequency of shedding of
713 respiratory pathogens in horses recently imported to the United States. *J. Vet. Intern. Med.*, **32**, 1436–1441.
- 714 SMITH K.L., LI Y., BREHENY P., COOK R.F., HENNEY P.J., SELLS S., PRONOST S., LU Z., CROSSLEY B.M., TIMONEY P.J. &
715 BALASURIYA U.B. (2012). Development and validation of a new and improved allelic discrimination real-time PCR assay for the
716 detection of equine herpesvirus-1 (EHV-1) and differentiation of A2254 from G2254 strains in clinical specimens. *J.*
717 *Clin. Microbiol.*, **50**, 1981–1988.
- 718 STRANG C. & NEWTON R. (2017). Control and disease clearance after neurological EHV-1 in the UK. *Vet. Rec.*, **181**, 678–
719 679.
- 720 SUTTON G., GARVEY M., CULLINANE A., JOURDAN M., FORTIER C., MOREAU P., FOURSIN M., GRYSPEERDT A., MAISONNIER V.,
721 MARCILLAUD-PITEL C., LEGRAND L., PAILLOT R. & PRONOST S. (2019). Molecular Surveillance of EHV-1 Strains Circulating in
722 France during and after the Major 2009 Outbreak in Normandy Involving Respiratory Infection, Neurological Disorder, and
723 Abortion. *Viruses*, **11**, 916.
- 724 TELFORD E.A.R., WATSON M.S., MCBRIDE K. & DAVISON A.J. (1992). The DNA sequence of equine herpesvirus 1. *Virology*,
725 **189**, 304–316.
- 726 TELFORD E.A.R., WATSON M.S., PERRY J., CULLINANE A.A. & DAVISON A.J. (1998). The DNA sequence of equine herpesvirus
727 4. *J. Gen. Virol.*, **79**, 1197–1203.
- 728 THOMSON G.R., MUMFORD J.A., CAMPBELL J., GRIFFITHS L. & CLAPHAM P. (1976). Serological detection of equid herpesvirus
729 1 infections of the respiratory tract. *Equine Vet. J.*, **8**, 58–65.
- 730 THORSTEINSDÓTTIR L., GUÐMUNDSSON G., JENSSON H., TORSTEINSDÓTTIR S. & SVANSSON V. (2021). Isolation of equid
731 alphaherpesvirus 3 from a horse in Iceland with equine coital exanthema. *Acta Vet. Scand.*, **63**, 6.
- 732 VAN MAANEN C., VREESWIJK J., MOONEN P., BRINKHOF J. DE BOER-LUIJTZE E. & TERPSTRA C. (2000). Differentiation and
733 genomic and antigenic variation among fetal, respiratory, and neurological isolates from EHV1 and EHV4 infections in The
734 Netherlands. *Vet. Q.*, **22**, 88–93.
- 735 VAN MAANEN C., WILLINK D.L., SMEENK L.A., BRINKHOF J. & TERPSTRA C. (2000). An equine herpesvirus 1 (EHV1) abortion
736 storm at a riding school. *Vet. Q.*, **22**, 83–87.
- 737 VARRASSO A., DYNON K., FICORILLI N., HARTLEY C.A., STUDDERT M.J. & DRUMMER H.E. (2001). Identification of equine
738 herpesviruses 1 and 4 by polymerase chain reaction. *Aust. Vet. J.*, **79**, 563–569.
- 739 WHITWELL K.E., GOWER S.M. & SMITH K.C. (1992). An immunoperoxidase method applied to the diagnosis of equine
740 herpesvirus abortion, using conventional and rapid microwave techniques. *Equine Vet. J.*, **24**, 10–12.
- 741 YASUNAGA S., MAEDA K., MATSUMURA T., KONDO T. & KAI K. (2000). Application of a type-specific enzyme-linked
742 immunosorbent assay for equine herpesvirus types 1 and 4 (EHV-1 and -4) to horse populations inoculated with inactivated
743 EHV-1 vaccine. *J. Vet. Med. Sci.*, **62**, 687–691.

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746 **NB:** There are WOA Reference Laboratories for equine rhinopneumonitis (please consult the WOA Web site:
747 <https://www.woah.org/en/what-we-offer/expertise-network/reference-laboratories/#ui-id-3>).

748 Please contact the WOA Reference Laboratories for any further information on

749 diagnostic tests, reagents and vaccines for equine rhinopneumonitis
750 and to submit strains for further characterisation.
751 **NB:** FIRST ADOPTED IN 1990. MOST RECENT UPDATES ADOPTED IN 2017.

2 MEETING OF THE BIOLOGICAL STANDARDS COMMISSION

3 Paris, 4–8 September 2023

4
5 SECTION 3.8.

6 ~~OVIDAE AND CAPRINAE~~

7 CHAPTER 3.8.1.

8 BORDER DISEASE

9 SUMMARY

10 *Border disease (BD) is a viral disease of sheep and goats first reported in sheep in 1959 from the border*
11 *region of England and Wales, and since recorded world-wide. Prevalence rates in sheep vary from 5% to*
12 *50% between countries and from region to region within countries. Clinical signs include barren ewes,*
13 *abortions, stillbirths and the birth of small weak lambs. Affected lambs can show ~~and a fine~~ tremor, abnormal*
14 *body conformation and hairy fleeces (so-called ‘hairy-shaker’ or ‘fuzzy’ lambs). Consequently, the disease*
15 *has sometimes been referred to as ‘hairy shaker disease’. Vertical transmission plays an important role in*
16 *the epidemiology of the disease. Infection of fetuses can result in the birth of persistently infected (PI) lambs.*
17 *These PI lambs are viraemic, antibody negative and constantly excrete virus. The virus spreads from sheep*
18 *to sheep, with PI animals being the most potent source of infection. Infection in goats is less common with*
19 *abortion being the main presenting sign.*

20 *BD is caused by the Pestivirus border disease virus (BDV), but in some parts of the world, especially where*
21 *there is close contact between sheep or goats and cattle, the same clinical signs may be caused by infection*
22 *with bovine viral diarrhoea virus (BVDV). Therefore the genetic and antigenic differences between BDV and*
23 *BVDV need to be taken into consideration when investigating disease outbreaks or certifying animals or*
24 *germplasm for international movement. It is important to identify the viraemic PI animals so that they will not*
25 *be used for breeding or trading purposes. Serological testing is insufficient. However, it is generally*
26 *considered that serologically positive, nonviraemic sheep are ‘safe’, do not present a risk as latent infections*
27 *are not known to occur in recovered animals. Pregnant seropositive, nonviraemic animals may, however,*
28 *present a risk by carrying a PI fetus that cannot be detected until after parturition.*

29 ***Identification of the agent:*** *BDV is a species of Pestivirus (Pestivirus ovis) in the family Flaviviridae and is*
30 *closely related to classical swine fever virus (Pestivirus suis) and BVDV viruses, which are classified in the*
31 *distinct species Pestivirus bovis (commonly known as BVDV type 1), Pestivirus tauri (formerly BVDV type 2)*
32 *and Pestivirus brazilense (BVDV type 3 or Hobi-like pestivirus). Nearly all isolates of BDV are*
33 *noncytopathogenic in cell culture. There are no defined serotypes but virus isolates exhibit considerable*
34 *antigenic diversity. A number of separate genotypes, have been identified.*

35 *Apparently healthy PI sheep resulting from congenital infection can be identified by direct detection of virus*
36 *or nucleic acid in blood or tissues or by virus isolation in cell culture followed by immunostaining to detect*
37 *the noncytopathogenic virus.*

38 **Diagnostic methods:** The demonstration of virus by culture and antigen detection may be less reliable in
39 lambs younger than 2 months that have received colostral antibody. Acute infection is usually subclinical
40 and viraemia is transient and difficult to detect. The isolation of virus from tissues of aborted or stillborn
41 lambs is often difficult but virus can be detected by sensitive reverse transcriptase polymerase chain reaction
42 methods that are able to detect residual nucleic acid. However, tissues and blood from PI sheep more than
43 a few months old contain high levels of virus, which can be easily identified by isolation and direct methods
44 to detect antigens or nucleic acids. As sheep may be infected with BVDV, it is preferable to use diagnostic
45 assays that are 'pan-pestivirus' reactive and will readily detect all strains of BDV and BVDV.

46 **Serological tests:** Acute infection with BDV is best confirmed by demonstrating seroconversion using paired
47 or sequential samples from several animals in the group. The enzyme-linked immunosorbent assay and
48 virus neutralisation test (VNT) are the most commonly used antibody detection methods. Due to the antigenic
49 differences between BDV and BVDV, assays for the detection of antibodies to BDV, especially by VNT,
50 should preferably be based on a strain of BDV.

51 **Requirements for vaccines:** There is no standard vaccine for BDV, but a commercial killed whole-virus
52 vaccine has been produced. Ideally, such a vaccine should be suitable for administration to females before
53 breeding for prevention of transplacental infection. The use of BVDV vaccines has been advocated, but the
54 antigenic diversity of BD viruses must be considered. In many instances, the antigenic diversity of BDV
55 strains is sufficiently different to BVDV that a BVDV vaccine is unlikely to provide protection.

56 BD viruses have contaminated several modified live veterinary vaccines produced in sheep cells or
57 containing sheep serum. This potential hazard should be recognised by manufacturers of biological
58 products.

59 A. INTRODUCTION

60 Border disease virus (BDV) is a *Pestivirus* of the family *Flaviviridae* and is closely related to classical swine fever virus
61 (CSFV) and bovine viral diarrhoea virus (BVDV). There are ~~four~~ four number of officially recognised species, namely – BDV
62 (*Pestivirus ovis*) CSFV (*Pestivirus suis*), BVDV types 1 and 2 (taxonomically known as *Pestivirus bovis* and *Pestivirus tauri*,
63 respectively) and ~~BDV (ICTV, 2016) BVDV 3 or Hobi-like pestivirus (*Pestivirus brazilense*)~~, but a number of other
64 pestiviruses that are considered to be distinct species have been reported. While CSF viruses are predominantly restricted
65 to pigs, examples of there are situations where the other ~~three~~ three species have all been recovered from sheep. While the
66 majority of isolates have been identified as BD viruses in areas where sheep or goats are raised in isolation from other
67 species (Vilcek *et al.*, 1997), in regions where there is close contact between small ruminants and cattle, BVDV may be
68 frequently identified (Carlsson, 1991). Nearly all virus isolates of BDV are noncytopathogenic, although occasional
69 cytopathic viruses have been isolated (Vantsis *et al.*, 1976). BDV spreads naturally among sheep by the oro-nasal route
70 and by vertical transmission. It is principally a cause of congenital disease in sheep and goats, but can also cause acute
71 and persistent infections. Infection is less common in goats, in which persistent infection is rare as abortion is the main
72 presenting sign. Pigs may also be infected by pestiviruses other than CSFV and antibodies to BDV in pigs may interfere
73 with tests for the diagnosis of CSF (Oguzoglu *et al.*, 2001). Several genotypes of BD viruses from sheep, goats and
74 Pyrenean chamois (*Rupicapra pyrenaica pyrenaica*) have been described. Phylogenetic analysis using computer-assisted
75 nucleotide sequence analysis suggests that genetic variability among BD viruses is greater than within each of the other
76 *Pestivirus* species. Four distinguishable genogroups of BDV have been described as well as putative novel *Pestivirus*
77 genotypes from Tunisian sheep and a goat (Becher *et al.*, 2003; Vilcek & Nettleton, 2006). The chamois BD virus is similar
78 to isolates from sheep in the Iberian Peninsula (Valdazo-Gonzalez *et al.*, 2007). This chapter describes BDV infection in
79 sheep. Chapter 3.4.7 *Bovine viral diarrhoea* should also be consulted for related diagnostic methods.

80 1. Acute infections

81 Healthy newborn and adult sheep exposed to BDV usually experience only mild or inapparent disease. Slight fever and a
82 mild leukopenia are associated with a short-lived viraemia detectable between days 4 and 11 post-infection, after which
83 virus neutralising antibody appears in the serum (Thabti *et al.*, 2002).

84 Acute infections are best diagnosed serologically using paired sera from a representative number of sheep. Occasional
85 BDV isolates have been shown to produce high fever, profound and prolonged leukopenia, anorexia, conjunctivitis, nasal
86 discharge, dyspnoea and diarrhoea, and 50% mortality in young lambs. One such isolate was recovered from a severe
87 epidemic of BD among dairy sheep in 1984 (Chappuis *et al.*, 1986). A second such isolate was a BDV contaminant of a
88 live CSFV vaccine (Wensvoort & Terpstra, 1988).

89 2. Fetal infection

90 The main clinical signs of BD are seen following the infection of pregnant ewes. While the initial maternal infection is
91 subclinical or mild, the consequences for the fetus are serious. Fetal death may occur at any stage of pregnancy, but is
92 more common in fetuses infected early in gestation. Small dead fetuses may be resorbed or their abortion may pass
93 unnoticed as the ewes continue to feed well and show no sign of discomfort. As lambing time approaches, the abortion of
94 larger fetuses, stillbirths and the premature births of small, weak lambs will be seen. Confirmation that an abortion or
95 stillbirth is due to BDV is often difficult to establish, but virus may be isolated from fetal tissues in some cases. The use of
96 an appropriate real-time reverse-transcription polymerase chain reaction (RT-PCR) assay may give a higher level of
97 success because of the advantages of high sensitivity and the ability to detect genome from non-infectious virus. In aborted
98 fetuses, it is also possible to detect virus by immunohistochemistry of brain, thyroid and other tissues (Thur *et al.*, 1997).
99 Samples of fetal fluids or serum should be tested for BDV antibody.

100 During lambing, an excessive number of barren ewes will become apparent, but it is the diseased live lambs that present
101 the main clinical features characteristic of BD. The clinical signs exhibited by BD lambs are very variable and depend on
102 the breed of sheep, the virulence of the virus and the time at which infection was introduced into the flock. Affected lambs
103 are usually small and weak, many being unable to stand. Nervous signs and fleece changes are often apparent. The
104 nervous signs of BD are its most characteristic feature. The tremor can vary from violent rhythmic contractions of the
105 muscles of the hindlegs and back, to barely detectable fine trembling of the head, ears, and tail. Fleece abnormalities are
106 most obvious in smooth-coated breeds, which develop hairy fleeces, especially on the neck and back. Abnormal brown or
107 black pigmentation of the fleece may also be seen in BD-affected lambs. Blood samples to be tested for the presence of
108 BDV or antibody should be collected into anticoagulant from suspect lambs before they have received colostrum. Once
109 lambs have ingested colostrum, it is difficult to isolate virus until they are 2 months old and maternal antibody levels have
110 waned. However, during this period, it may be possible to detect viral antigen in skin biopsies, by immunohistochemistry,
111 in washed leukocytes by enzyme-linked immunosorbent assay (ELISA) or by real-time RT-PCR. ELISAs directed at
112 detection of the Erns antigen appear to be less prone to interference by maternal antibodies and can often be used to
113 detect antigen in serum.

114 With careful nursing, a proportion of BD lambs can be reared, although deaths may occur at any age. The nervous signs
115 gradually decline and can disappear by 3–6 months of age. Weakness, and swaying of the hind-quarters, together with
116 fine trembling of the head, may reappear at times of stress. Affected lambs often grow slowly and under normal field
117 conditions many will die before or around weaning time. In cases where losses at lambing time have been low and no
118 lambs with obvious signs of BD have been born, this can be the first presenting sign of disease.

119 Some fetal infections occurring around mid-gestation can result in lambs with severe nervous signs, locomotor
120 disturbances and abnormal skeletons. Such lambs have lesions of cerebellar hypoplasia and dysplasia, hydranencephaly
121 and porencephaly resulting from necrotising inflammation. The severe destructive lesions appear to be immune mediated,
122 and lambs with such lesions frequently have high titres of serum antibody to BDV. Most lambs infected in late gestation
123 are normal and healthy and are born free from virus but with BDV antibody. Some such lambs can be weak and may die
124 in early life (Barlow & Patterson, 1982).

125 3. Persistent viraemia

126 When fetuses survive an infection that occurs before the onset of immune competence, they are born with a persistent
127 viraemia. The ovine fetus can first respond to an antigenic stimulus between approximately 60 and 85 days of its 150-day
128 gestation period. In fetuses infected before the onset of immune competence, viral replication is uncontrolled and 50%
129 fetal death is common. In lambs surviving infection in early gestation, virus is widespread in all organs. Such lambs appear
130 to be tolerant of the virus and have a persistent infection, usually for life. A precolostral blood sample will be virus positive
131 and antibody negative. Typically, there is no inflammatory reaction and the most characteristic pathological changes are
132 in the central nervous system (CNS) and skin. Throughout the CNS, there is a deficiency of myelin, and this causes the
133 nervous signs. In the skin, primary wool follicles increase in size and the number of secondary wool follicles decreases,
134 causing the hairy or coarse fleece.

135 Persistently viraemic sheep can be identified by the detection of viral antigens, nucleic acids or infectious virus in a blood
136 sample. Viraemia is readily detectable by testing of serum at any time except within the first 2 months of life, when virus
137 may be masked by colostral antibody and, possibly, in animals older than 4 years, some of which develop low levels of
138 anti-BDV antibody (Nettleton *et al.*, 1992). Methods other than virus isolation may be preferred to avoid interference from
139 antibodies. When the presence of colostral antibodies is suspected, the virus may be detected in washed leukocytes and
140 in skin by using sensitive ELISAs. Although virus detection in blood during an acute infection is difficult, persistent viraemia
141 should be confirmed by retesting animals after an interval of at least 3 weeks. The use of real-time RT-PCR should be
142 considered at all times and for any sample type due to its high analytical sensitivity and the lack of interference from
143 antibodies in a sample.

144 Some viraemic sheep survive to sexual maturity and are used for breeding. Lambs born to these infected dams are always
 145 persistently viraemic. Persistently viraemic sheep are a continual source of infectious virus to other animals and their
 146 identification is a major factor in any control programme. Sheep being traded should be screened for the absence of BDV
 147 viraemia.

148 Usually persistently infected (PI) rams have poor quality, highly infective semen and reduced fertility. All rams used for
 149 breeding should be screened for persistent BDV infection on a blood sample. Semen samples can also be screened for
 150 virus, but virus isolation is much less satisfactory than from blood because of the toxicity of semen for cell cultures. Real-
 151 time RT-PCR for detection of pestivirus nucleic acid would usually overcome toxicity problems, and thus this assay should
 152 be useful for testing semen from rams.

153 4. Late-onset disease in persistently viraemic sheep

154 Some PI sheep housed apart from other animals spontaneously develop intractable diarrhoea, wasting, excessive ocular
 155 and nasal discharges, sometimes with respiratory distress. At necropsy such sheep have gross thickening of the distal
 156 ileum, caecum and colon resulting from focal hyperplastic enteropathy. Cytopathic BDV can be recovered from the gut of
 157 these lambs. With no obvious outside source of cytopathic virus, it is most likely that such virus originates from the lamb's
 158 own virus pool, similar to what occurs with BVDV. Other PI sheep in the group ~~do not~~ develop the disease. This
 159 syndrome, which has been produced experimentally and recognised in occasional field outbreaks of BD, has several
 160 similarities with bovine mucosal disease (Nettleton *et al.*, 1992).

161 B. DIAGNOSTIC TECHNIQUES

162 **Table 1.** Test methods available for diagnosis of border disease and their purpose

Method	Purpose					
	Population freedom from infection	Individual animal freedom from infection prior to movement	Contribute to eradication policies	Confirmation of clinical cases	Prevalence of infection – surveillance	Immune status in individual animals or populations post-vaccination
Identification of the agent ^(a)						
Virus isolation	+	++	++	+++	–	–
Antigen detection by ELISA	+	++	+++	+++	–	–
NA detection by real-time RT-PCR	+++	+++	+++	+++	+++	–
NA detection by ISH	–	–	–	+	–	–
Detection of immune response						
ELISA	++	++	++	+	++	++
VN	+++	+++	++	+++	+++	+++

163 Key: +++ = recommended for this purpose; ++ recommended but has limitations;

164 + = suitable in very limited circumstances; – = not appropriate for this purpose.

165 ELISA = enzyme-linked immunosorbent assay; IHC = immunohistochemistry; NA = nucleic acid; RT-PCR = reverse-transcription
 166 polymerase chain reaction; ISH = *in-situ* hybridisation; VN = virus neutralisation.

167 ^(a)A combination of agent identification methods applied on the same clinical sample is recommended.

168 1. Identification of the agent

169 There is no designated WOAHA Reference Laboratory for BDV, but the reference laboratories for BVDV or CSFV will be
170 able to provide advice⁴². One of the most sensitive proven methods for identifying BDV remains virus isolation. However,
171 a broadly reactive real-time RT-PCR assay (preferably pan-pestivirus reactive) will usually provide higher analytical
172 sensitivity than virus isolation, can be used to test samples that are difficult to manage by virus isolation and can be
173 performed in a few hours. Antigen-detection ELISA and immunohistochemical techniques on tissue sections are also
174 valuable methods for identifying BDV-infected animals.

175 1.1. Virus isolation

176 It is essential that laboratories undertaking virus isolation have a guaranteed supply of pestivirus-free susceptible
177 cells and bovine serum, or equivalent, that contain no anti-pestivirus activity and no contaminating virus. It is important
178 that a laboratory quality assurance programme be in place. Chapter 3.4.7 provides detailed methods for virus isolation
179 in either culture tubes or microplates for the isolation of pestiviruses from sheep or goat samples, including serum,
180 whole blood, semen and tissues. The principles and precautions outlined in that chapter for the selection of cell
181 cultures, medium components and reagents are equally relevant to this chapter. Provided proven pan-pestivirus
182 reactive reagents (e.g. monoclonal antibodies [MAbs], primers and probes for real-time RT-PCR) are used for antigen
183 or nucleic acid detection, the principal difference is the selection of appropriate cell cultures.

184 BD virus can be isolated in a number of primary or secondary ovine cell cultures (e.g. kidney, testes, lung). Ovine cell
185 lines for BDV growth are rare. Semicontinuous cell lines derived from fetal lamb muscle (FLM), whole embryo (Thabti
186 *et al.*, 2002) or sheep choroid plexus can be useful, but different lines vary considerably in their susceptibility to the
187 virus. Ovine cells have been used successfully for the isolation and growth of BD viruses and BVDV types 1 and 2
188 from sheep. In regions where sheep may become infected with BVD viruses from cattle, a virus isolation system using
189 both ovine and bovine cells could be optimal. However, bovine cells have lower sensitivity for the primary isolation
190 and growth of some BD viruses, so reliance on bovine cells alone is inadvisable. Details of suitable bovine cell cultures
191 are provided chapter 3.4.7. The precautions outlined in that chapter for the establishment of cells and medium
192 components that are free from contamination with either pestiviruses or antibodies, and measures to ensure that the
193 cells are susceptible to a wide range of local field strains are equally relevant to systems for detection of BDV.

194 From live animals, serum is the most frequently used sample to be tested for the presence of infectious virus.
195 However, for difficult cases, the most sensitive way to confirm pestivirus viraemia is to wash leukocytes repeatedly
196 (at least three times) in culture medium before co-cultivating them with susceptible cells in either cell culture tubes or
197 microplates. After culture for 5–7 days, the cultures should be frozen and thawed once and an aliquot of diluted culture
198 fluid passaged onto further susceptible cells grown in microplates or on chamber slides to allow antigen detection by
199 immunocytochemistry. Staining for noncytotoxic pestiviruses will usually detect virus at the end of the primary
200 passage, but to detect slow-growing viruses in poorly permissive cells two passages are desirable. It is recommended
201 that the culture supernatant used as inoculum for the second passage is diluted approximately 1/100 in new culture
202 medium because some high titred field isolates will replicate poorly if passaged undiluted (i.e. at high multiplicity of
203 infection – moi).

204 Tissues should be collected from dead animals in virus transport medium. In the laboratory, the tissues are ground
205 to give a 10–20% (w/v) suspension, centrifuged to remove debris, and the supernatant passed through 0.45 µm
206 filters. Spleen, lung, thyroid, thymus, kidney, brain, lymph nodes and gut lesions are the best organs for virus isolation.

207 Semen can be examined for the presence of BDV, but raw semen is strongly cytotoxic and must be diluted, usually
208 at least 1/10 in culture medium. As the major threat of BDV-infected semen is from PI rams, blood is a more reliable
209 clinical sample than semen for identifying such animals. There are many variations in virus isolation procedures. All
210 should be optimised for maximum sensitivity using a standard reference virus preparation and, whenever possible,
211 recent BDV field isolates. Most of the limitations of virus isolation for the detection of BDV in serum or blood, tissues
212 or semen can be overcome by the use of a proven, sensitive pan-pestivirus reactive real-time RT-PCR. Some
213 laboratories screen samples by real-time RT-PCR and undertake virus isolation on positive samples to collect BDV
214 strains for future reference or research purposes.

215 For specific technical details of virus isolation procedures, including immunoperoxidase staining, refer to chapter
216 3.4.7.

42 Please consult the WOAHA Web site: <https://www.woaha.org/en/what-we-offer/expertise-network/reference-laboratories/#ui-id-3>

217

1.2. Nucleic acid detection methods

218 The complete genomic sequences of three BD viruses have been determined and compared with those of other
219 pestiviruses (Becher *et al.*, 1998; Ridpath & Bolin, 1997). Phylogenetic analysis shows BD viruses to be more closely
220 related to CSFV than to BVDV (Becher *et al.*, 2003; Van Rijn *et al.*, 1997; Vilcek & Nettleton, 2006; Vilcek *et al.*,
221 1997). Real-time RT-PCR for diagnosing pestivirus infection is now used widely and a number of formats have been
222 described. Real-time RT-PCR assays have the advantages of being able to detect both infectious virus and residual
223 nucleic acid, the latter being of value for investigating abortions and lamb deaths. Furthermore, the presence of virus-
224 specific antibodies in a sample will have no adverse effect on the sensitivity of the real-time RT-PCR assay. These
225 assays are also useful for screening semen and, when recommended nucleic acid extraction protocols are followed,
226 are less affected by components of the semen compared with virus isolation. Because of the potential for small
227 ruminants to be infected with genetically different strains of BDV or with strains of BVDV, a ~~proven~~ pan-pestivirus
228 reactive real-time RT-PCR with proven high sensitivity should be used. To ensure that the genetic spectrum of BDV
229 strains is sufficiently covered, it may be necessary to apply a broadly reactive BDV specific real time RT-PCR in
230 parallel to maximise diagnostic sensitivity. Suitable protocols for both nucleic acid extraction as well as the real-time
231 RT-PCR are described in chapter 3.4.7. All precautions to minimise laboratory contamination should be followed
232 closely.

233 After testing samples in a pan-pestivirus reactive assay, samples giving ~~positive results can any level of reactivity~~
234 should be investigated further by the application of a BDV-specific real-time RT-PCR (Willoughby *et al.*, 2006). It is
235 important to note however that different genotypes of BDV may be circulating in some populations, especially wild
236 ruminants such as chamois and deer, and may be transferred to sheep. An assay that is specific for the detection of
237 BDV should be used with some caution as variants or previously unrecognised genotypes may not be detected,
238 hence the value of initially screening samples with a pan-pestivirus reactive real-time RT-PCR. Nevertheless, there
239 are also situations where a pan-pestivirus reactive real-time RT-PCR may have lower analytical sensitivity.
240 Consequently, in any situation where BDV infection is suspected, the application of several diagnostic methods is
241 recommended. Maternal serology can also play an important role as negative results should exclude the potential
242 involvement of a pestivirus.

1.3. Enzyme-linked immunosorbent assay for antigen detection

244 ELISAs for the direct detection of pestivirus antigen in blood and tissues of infected animals have proven to be
245 extremely useful for the detection of PI animals and the diagnosis of disease. The first ELISA for pestivirus antigen
246 detection was described for detecting viraemic sheep and was later modified into a double MAb capture ELISA for
247 use in sheep and cattle (Entrican *et al.*, 1994). The test is most commonly employed to identify PI viraemic sheep
248 using washed, detergent-lysed blood leukocytes. The sensitivity is close to that of virus isolation and it is a practical
249 method for screening large numbers of blood samples. As with virus isolation, high levels of colostral antibody can
250 mask persistent viraemia. The ELISA is more effective than virus isolation in the presence of antibody, but may give
251 false-negative results in viraemic lambs younger than 2 months old. The ELISA is usually not sensitive enough to
252 detect acute BDV infections on blood samples. As well as for testing leukocytes, the antigen ELISA can also be used
253 on tissue suspensions, especially spleen, from suspected PI sheep and, as an alternative to immunofluorescence
254 and immunoperoxidase methods, on cell cultures. Several pestivirus ELISA methods have been published but there
255 are at present no commercially available kits that have been fully validated for detecting BDV. Prior to use for
256 regulatory purposes, these kits should be validated in the region where they are to be used to ensure that a wide
257 range of field strains of BDV can be detected and that they are suitable for the sample types to be tested.

1.4. Immunohistochemistry

259 Viral antigen demonstration is possible in most of the tissues of PI animals (Braun *et al.*, 2002; Thur *et al.*, 1997)
260 although this is not a method that is routinely used for diagnostic purposes. This should be done on acetone-fixed
261 frozen tissue sections (cryostat sections) or paraffin wax embedded samples using appropriate antibodies. Pan-
262 pestivirus reactive antibodies with NS2-3 specificity are suitable. Tissues with a high amount of viral antigen are brain,
263 thyroid gland, lung and oral mucosa. Skin biopsies have been shown to be useful for *in-vivo* diagnosis of persistent
264 BDV infection.

2. Serological tests

266 Antibody to BDV is usually detected in sheep sera using VN or an ELISA. The less sensitive agar gel immunodiffusion test
267 is not recommended. Control positive and negative reference sera must be included in every test. These should give results
268 within predetermined limits for the test to be considered valid. Single sera can be tested to determine the prevalence of
269 BDV in a flock, region or country. For diagnosis, however, acute and convalescent sera are the best samples for confirming
270 acute BDV infection. Repeat sera from one animal should always be tested alongside each other on the same plate to
271 provide a reliable comparison of titres.

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2.1. Virus neutralisation test

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Due to antigenic diversity among pestiviruses the choice of test virus is difficult (Dekker *et al.*, 1995; Nettleton *et al.*, 1998). No single strain of BDV is ideal. A local strain that gives the highest antibody titre with a range of positive sheep sera should be used.

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Because there are few cytopathogenic strains of BDV available, to achieve optimal analytical sensitivity, it is more usual to employ a representative local non-cytopathogenic strain and read the assay after immunoperoxidase staining of the cells. Proven highly sensitive, pestivirus-free sheep cells such as lamb testis or kidney cells are suitable and can be maintained as cryogenically frozen stocks for use over long periods of time. The precautions outlined for selection of pestivirus-free medium components are equally applicable to reagents to be used in VN tests. A recommended procedure follows.

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2.1.1. Test procedure

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i) The test sera are heat-inactivated for 30 minutes at 56°C.

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ii) From a starting dilution of 1/4, serial twofold dilutions of the test sera are made in a cell-culture grade flat-bottomed 96-well microtitre plate, using cell culture medium as diluent. For each sample, three or four wells are used at each dilution depending on the degree of precision required. Also, for each sample and at each serum dilution, one well is left without virus to monitor for evidence of sample toxicity that could mimic viral cytopathology or interfere with virus replication. Control positive and negative sera should also be included in each batch of tests.

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iii) An equal volume (e.g. 50 µl) of a stock of BDV containing 100 TCID₅₀ (50% tissue culture infective dose) is added to each well. A back titration of virus stock is also done in some spare wells to check the potency of the virus (acceptance limits ~~30–80~~–300 TCID₅₀).

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iv) The plate is incubated for 1 hour at 37°C.

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v) A flask of suitable cells (e.g. ovine testis or kidney cells) is trypsinised and the cell concentration is adjusted to 2 × 10⁵/ml. 100 µl of the cell suspension is added to each well of the microtitre plate.

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vi) The plate is incubated at 37°C for 4–5 days, either in a 5% CO₂ atmosphere or with the plate sealed.

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vii) The wells are examined microscopically to ensure that there is no evidence of toxicity or cytopathic effect (CPE), then fixed and stained by immunoperoxidase staining using an appropriate MAb. The VN titre for each serum is the dilution at which the virus is neutralised in 50% of the wells. This can be calculated by the Spearman–Kärber or Reed Muench methods. A seronegative animal will show no neutralisation at the lowest dilution of serum (i.e. 1/4), equivalent to a final dilution of 1/8. For accurate comparison of antibody titres, and particularly to demonstrate significant (more than fourfold) changes in titre, samples should be tested in parallel in the same test

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viii) Occasionally there may be a need to determine whether antibody in a flock is against a virus belonging to a particular *Pestivirus* serogroup. A differential VN test can be used in which sera are titrated out against representative viruses from each of the four *Pestivirus* groups, i.e. BDV, BVDV types 1 and 2, and CSFV. Maximum titre will identify the infecting serotype and the spectrum of cross-reactivity with the other serotypes will also be revealed.

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2.2. Enzyme-linked immunosorbent assay

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An MAb-capture ELISA for measuring BDV antibodies has been described. Two pan-pestivirus MAbs that detect different epitopes on the immunodominant nonstructural protein NS 2/3 are used to capture detergent-lysed cell-culture grown antigen. The results correlate qualitatively with the VN test (Fenton *et al.*, 1991).

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2.2.1. Antigen preparation

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Use eight 225 cm² flasks of newly confluent FLM cells; four flasks will be controls and four will be infected. Wash the flasks and infect four with a 0.01–0.1 m.o.i. of Moredun cytopathic BDV. Allow the virus to adsorb for 2 hours at 37°C. Add maintenance media containing 2% FBS (free from BDV antibody), and incubate cultures for 4–5 days until CPE is obvious. Pool four control flask supernatants and separately pool four infected flask supernatants. Centrifuge at 3000 *g* for 15 minutes to pellet cells. Discard the supernatants. Retain the cell pellets. Wash the flasks with

324 50 ml of PBS and repeat the centrifugation step as above. Pool all the control cell pellets in 8 ml PBS
325 containing 1% Nonidet P40 and return 2 ml to each control flask to lyse the remaining attached cells.
326 Repeat for infected cells. Keep the flasks at 4°C for at least 2 hours agitating the small volume of fluid
327 on the cells vigorously every 30 minutes to ensure total cell detachment. Centrifuge the control and
328 infected antigen at 12,000 **g** for 5 minutes to remove the cell debris. Supernatant antigens are stored
329 at –70°C in small aliquots.

330 2.2.2. Test procedure

- 331 i) The two MAbs are diluted to a predetermined dilution in 0.05 M bicarbonate buffer, pH 9.6. All
332 wells of a suitable ELISA-grade microtitre plate (e.g. Nunc maxisorb, Greiner 129b) are coated
333 overnight at 4°C.
- 334 ii) After washing three times in PBST, a blocking solution of PBST containing 10% horse serum
335 (PBSTH) is added to all wells, which are incubated at 37°C for 1 hour.
- 336 iii) The antigen is diluted to a predetermined dilution in PBSTH and alternate rows of wells are
337 coated with virus and control antigens for 1 hour at 37°C. The plates are then washed three
338 times in PBST before addition of test sera.
- 339 iv) Test sera are diluted 1/50 in PBSTH and added to duplicate virus and duplicate control wells
340 for 1 hour at 37°C. The plates are then washed three times in PBST.
- 341 v) Anti-ovine IgG peroxidase conjugate is diluted to a predetermined dilution in PBSTH and added
342 to all wells for 1 hour at 37°C. The plates are washed three times in PBST.
- 343 vi) A suitable activated enzyme substrate/chromogen, such as ortho-phenylene diamine (OPD) or
344 tetramethyl benzidine (TMB), is added). After colour development, the reaction is stopped with
345 sulphuric acid and the absorbance read on an ELISA plate reader. The mean value of the two
346 control wells is subtracted from the mean value of the two virus wells to give the corrected
347 absorbance for each serum. Results are expressed as corrected absorbance with reference to
348 the corrected absorbance of known positive and negative sera. Alternatively, ELISA titres can
349 be extrapolated from a standard curve of a dilution series of a known positive reference serum.
- 350 vii) If antigens of sufficient potency can be produced the MAb capture stage can be omitted. In this
351 case alternate rows of wells are coated with virus and control antigen diluted to a predetermined
352 dilution in 0.05 M bicarbonate buffer, pH 9.6, overnight at +4°C. The plates are washed and
353 blocked as in step ii above. After washing, diluted test sera are added and the test proceeds
354 from step iv as above.

355 C. REQUIREMENTS FOR VACCINES

356 1. Background

357 To be useful, a BDV vaccine should be effective when administered to female sheep before breeding to prevent
358 transplacental infection. Experimental and commercial inactivated whole virus BDV vaccines have been produced in
359 Europe (Brun *et al.*, 1993; Vantsis *et al.*, 1980). Unlike vaccines for BVDV, there is limited demand for vaccines against
360 BDV and those produced have only been inactivated products. No live attenuated or recombinant subunit vaccines for
361 BDV have been produced commercially.

362 Pestivirus contaminants of modified live virus vaccines have been found to be a cause of serious disease following their
363 use in pigs, cattle, sheep and goats. Contaminated vaccines have included those used for the control of Aujeszky's disease,
364 CSF, rotavirus, coronavirus, rinderpest, sheep pox and contagious pustular dermatitis. The insidious ability of pestiviruses
365 to cross the placenta, and thus establish PI animals, gives them the potential to contaminate vaccines through cells, serum
366 used as medium supplement, or seed stock virus. As nearly all isolates of pestiviruses are noncytopathic, they will remain
367 undetected unless specific tests are carried out. Although such contamination should be less likely to be a problem with
368 an inactivated vaccine, nevertheless steps should be taken to ensure that materials used in production are not
369 contaminated.

370 1.1. Characteristics of a target product profile

371 Traditionally, pestivirus vaccines fall into two classes: modified live or inactivated virus vaccines. The essential
372 requirement for both types is to afford a high level of fetal infection. Only inactivated vaccines have been produced
373 for BDV. Properly formulated inactivated vaccines are very safe to use but, to obtain satisfactory levels of immunity,
374 they usually require booster vaccinations, which may be inconvenient. Because of the propensity for antigenic
375 variability, the vaccine should contain strains of BDV that are closely matched to viruses found in the area in which

376 they are used. This may present particular challenges with BDV in regions where several antigenic types have been
377 found. Due to the need to customise vaccines for the most commonly encountered strains within a country or region,
378 it is not feasible to produce a vaccine antigen bank that can be drawn upon globally

379 Guidance for the production of veterinary vaccines is given in Chapter 1.1.8 *Principles of veterinary vaccine*
380 *production*. The guidelines given here and in chapter 1.1.8 are intended to be general in nature and may be
381 supplemented by national and regional requirements.

382 **2. Outline of production and minimum requirements for vaccines**

383 **2.1. Characteristics of the seed**

384 An ideal vaccine should contain a strain or strains of virus that give protection against all sheep pestiviruses. This
385 may be challenging however, because of the range of pestiviruses with which sheep can be infected. There is
386 considerable antigenic variation across these viruses – both between viruses that have been classified in the BDV
387 genogroup as well as between viruses in the BVDV1 and BVDV2 genotypes (Becher *et al.*, 2003; Vilcek & Nettleton,
388 2006; Wensvoort *et al.*, 1989). Infection of sheep with the putative BVDV-3 genotype has also been described (Decaro
389 *et al.*, 2012). It is likely that the antigenic composition of a vaccine will vary from region to region to provide an
390 adequate antigenic match with dominant virus strains. Cross-neutralisation studies are required to establish optimal
391 combinations. Nevertheless it would appear that any BDV vaccine should contain at least a representative of the BDV
392 and BVDV (type 1) groups. Characterisation of the biologically cloned vaccine viruses should include typing with
393 MAbs and genotyping (Paton *et al.*, 1995).

394 **2.1.1. Quality criteria (sterility, purity, freedom from extraneous agents)**

395 It is crucial to ensure that all materials used in the preparation of the bulk antigens have been
396 extensively screened to ensure freedom from extraneous agents. This should include master and
397 working seeds, the cell cultures and all medium supplements such as bovine serum. Some bovine
398 viruses and particularly BVDV can readily infect small ruminants such as sheep. Therefore, it is
399 particularly important to ensure that any serum used that is of bovine origin is free of both adventitious
400 BVDV and antibodies against BVDV strains because low levels of either virus or antibody can mask
401 the presence of the other. Materials and vaccine seeds should be tested for sterility and freedom
402 from contamination with other agents, especially viruses as described in the chapter 1.1.8 and
403 Chapter 1.1.9 *Tests for sterility and freedom from contamination of biological materials intended for*
404 *veterinary use*.

405 If a vaccine passes basic tests, the efficacy of vaccination should ultimately be measured by the
406 capacity to prevent transplacental transmission. Effective challenge of vaccinated pregnant ewes at
407 50–60 days gestation has been achieved by intranasal installation of virus or by mixing with PI sheep
408 (Brun *et al.*, 1993). Usually this reliably produces persistently viraemic offspring in non-immune ewes.
409 In regions where multiple genotypes of BDV viruses are commonly encountered, efficacy in protecting
410 against multiple strains should be measured.

411 **2.2. Method of manufacture**

412 **2.2.1. Procedure**

413 Inactivated vaccines have been prepared using conventional laboratory techniques with stationary or
414 rolled cell cultures. Inactivants have included formalin and beta-propiolactone. Adjuvants have
415 included aluminium hydroxide and oil (Brun *et al.*, 1993; Vantsis *et al.*, 1980). Optimal yields depend
416 on the cell type and isolate used. A commercial BDV vaccine containing two strains of virus has been
417 prepared on ovine cell lines (Brun *et al.*, 1993). Cells must be produced according to a seed-lot
418 system from a master cell seed (MCS) that has been shown to be free from all contaminating
419 microorganisms. Vaccine should only be produced in cells fewer than 20 passages from the MCS.
420 Control cells from every passage should be checked for pestivirus contamination. Standard
421 procedures may be used, with the expectation for harvesting noncytopathic virus on days 4–7 after
422 inoculation of cultures. The optimal yield of infectious virus will depend on several factors, including
423 the cell culture, isolate used and the initial seeding rate of virus. These factors should be taken into
424 consideration and virus replication kinetics investigated to establish the optimal conditions for large-
425 scale virus production. Whether a live or inactivated vaccine, the essential aim will be to produce a
426 high-titred virus stock. This bulk antigen preparation can subsequently be prepared according to the
427 type of vaccine being considered.

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2.2.2. Requirements for ingredients

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BDV vaccines have usually been grown in cell cultures of ovine origin that are frequently supplemented with medium components of animal origin. The material of greatest concern is bovine serum due to the potential for contamination with BVD viruses and antibodies to these viruses. These adventitious contaminants not only affect the efficiency of production but also may mask the presence of low levels of infectious BVDV that may have undesirable characteristics. In addition to the virus seeds, all materials should be tested for sterility and freedom from contamination with other agents, especially viruses as described in chapters 1.1.8 and 1.1.9. Furthermore, materials of bovine or ovine origin should originate from a country with negligible risk for transmissible spongiform encephalopathies (see chapter 1.1.9).

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2.2.3. In-process controls

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In-process controls are part of the manufacturing process. Cultures should be inspected regularly to ensure that they remain free from gross bacterial contamination, and to monitor the health of the cells and the development or absence of CPE, as appropriate. While the basic requirement for efficacy is the capacity to induce an acceptable neutralising antibody response, during production, target concentrations of antigen required to achieve an acceptable response may be monitored indirectly by assessment of the quantity of infectious virus or antigen mass that is produced. Rapid diagnostic assays such as the ELISA are useful for monitoring BVDV antigen production. Alternatively, the quality of a batch of antigen may be determined by titration of the quantity of infectious virus present, although this may underestimate the quantity of antigen. For inactivated vaccines, infectivity is evaluated before inactivation. For inactivated vaccines the inactivation kinetics should be established so that a suitable safety margin can be determined and incorporated into the routine production processes. At the end of production, *in-vitro* cell culture assays should be undertaken to confirm that inactivation has been complete. These innocuity tests should include a sufficient number of passages and volume of inoculum to ensure that very low levels of infectious virus would be detected if present.

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2.2.4. Final product batch tests

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i) Sterility

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Tests for sterility and freedom from contamination of biological materials intended for veterinary use may be found in chapter 1.1.9.

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ii) Identity

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Identity tests should demonstrate that no other strain of BDV is present when several strains are propagated in a facility producing multivalent vaccines.

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iii) Safety

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Samples from inactivated vaccines should be tested rigorously for viable virus. Samples of the product should be passaged for a minimum of three passages in sensitive cell cultures to ensure absence of live BDV. This *in-vitro* monitoring can be augmented by injecting two BDV-seronegative sheep with 20 doses of unformulated antigen as part of a standard safety test. Presence of live virus will result in the development of a more convincing serological response than will occur with inactivated virus alone. The sheep sera can also be examined for antibody to other prescribed agents.

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Safety tests shall also consist of detecting any abnormal local or systemic adverse reactions to the vaccine by all vaccination route(s). Batch-to-batch safety tests are required unless safety of the product is demonstrated and approved in the registration dossier and production is consistent with that described in chapter 1.1.8. Vaccines must either be demonstrated to be safe in pregnant sheep (i.e. no transmission to the fetus), or should be licensed with a warning not to use them in pregnant animals.

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iv) Batch potency

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Vaccine potency is best tested in seronegative sheep in which the development and level of antibody is measured. BVD vaccines must be demonstrated to produce adequate immune responses when used in their final formulation according to the manufacturer's published instructions. The minimum quantity of infectious virus or antigen required to produce an acceptable immune response should be determined. An indirect measure of potency is given by the level of virus infectivity prior to inactivation. *In-vitro* assays should be used to monitor individual batches during production. The antigen content following inactivation can be assayed by MAb-capture ELISA and related to the results of established

481 *in-vivo* potency results. It should be demonstrated that the lowest recommended dose of vaccine can
482 prevent transplacental transmission of BDV in pregnant sheep.

483 **2.3. Requirements for authorisation/registration/licensing**

484 **2.3.1. Manufacturing process**

485 For registration of a vaccine, all relevant details concerning manufacture of the vaccine and quality
486 control testing should be submitted to the relevant authorities. Unless otherwise specified by the
487 authorities, information should be provided from three consecutive vaccine batches with a volume
488 not less than 1/3 of the typical industrial batch volume.

489 There is no standard method for the manufacture of a BDV vaccine, but conventional laboratory
490 techniques with stationary, rolled or suspension (micro-carriers) cell cultures may be used.
491 Inactivated vaccines can be prepared by conventional methods, such as binary ethylenimine, formalin
492 or beta-propiolactone inactivation (Park & Bolin, 1987). A variety of adjuvants may be used.

493 **2.3.2. Safety requirements**

494 *In-vivo* tests should be undertaken using repeat doses (taking into account the maximum number of
495 doses for primary vaccination and, if appropriate, the first revaccination/booster vaccination) and
496 contain the maximum permitted antigen load and, depending on the formulation of the vaccine, the
497 maximum number of vaccine strains.

498 i) Target and non-target animal safety

499 The safety of the final product formulation of inactivated vaccines should be assessed in susceptible
500 young sheep that are free of maternally derived antibodies and in pregnant ewes. They should be
501 checked for any local reactions following administration, and, in pregnant ewes, for any effects on
502 the unborn lamb.

503 ii) Reversion-to-virulence for attenuated/live vaccines and environmental considerations

504 In the event that a live virus vaccine was developed for BDV, virus seeds that have been passaged
505 at least up to and preferably beyond the passage limit specified for the seed should be inoculated
506 into young lambs to confirm that there is no evidence of disease. If a live attenuated vaccine has
507 been registered for use in pregnant animals, reversion to virulence tests should also include pregnant
508 animals. Live attenuated vaccines should not be transmissible to unvaccinated 'in-contact' animals.

509 iii) Precautions (hazards)

510 BDV is not considered to be a human health hazard. Standard good microbiological practice should
511 be adequate for handling the virus in the laboratory. While the inactivated virus in a vaccine should
512 be identified as harmless for people administering the product, adjuvants included in the vaccine may
513 cause injury to people. Manufacturers should provide adequate warnings that medical advice should
514 be sought in the case of self-injection (including for adjuvants, oil-emulsion vaccine, preservatives,
515 etc.) with warnings included on the product label/leaflet so that the vaccinator is aware of any danger.

516 **2.3.3. Efficacy requirements**

517 The potency of the vaccine should be determined by inoculation into seronegative and virus negative
518 lambs, followed by monitoring of the antibody response. Antigen content can be assayed by infectivity
519 titration prior to inactivation and subsequently by ELISA and adjusted as required to a standard level
520 for the particular vaccine. Standardised assay protocols applicable to all vaccines do not exist. Live
521 vaccine batches may be assayed by infectivity titration. Each production batch of vaccine should
522 undergo potency and safety testing as batch release criteria. BVD vaccines must be demonstrated
523 to produce adequate immune responses, as outlined above, when used in their final formulation
524 according to the manufacturer's published instructions.

525 **2.3.4. Vaccines permitting a DIVA strategy (detection of infection in vaccinated animals)**

526 To date, there are no commercially available vaccines for BDV that support use of a true DIVA
527 strategy.

528 **2.3.5. Duration of immunity**
529 Inactivated vaccines are unlikely to provide sustained levels of immunity and it is likely that after an
530 initial course of two or three injections annual booster doses may be required. Insufficient information
531 is available to determine any correlation between vaccinal antibody titres in the dam and fetal
532 protection. As there are likely to be different commercial formulations and these involve a range of
533 adjuvants, there are likely to be different periods of efficacy. Consequently, duration of immunity data
534 must be generated separately for each commercially available product by undertaking challenge tests
535 at the end of the period for which immunity has been claimed.

536 **2.3.6. Stability**
537 There are no accepted guidelines for the stability of BDV vaccines, but it can be assumed that an
538 inactivated virus vaccine should remain potent for at least 1 year if kept at 4°C and probably longer.
539 Lower temperatures could prolong shelf life but adjuvants in a killed vaccine may preclude this. Bulk
540 antigens that have not been formulated into finished vaccine can be reliably stored frozen at low
541 temperatures, but the antigen quality should be monitored with *in-vitro* assays prior to incorporation
542 into a batch of vaccine.

543 **REFERENCES**

- 544 BARLOW R.M. & PATTERSON D.S.P. (1982). Border disease of sheep: a virus-induced teratogenic disorder. *Adv. Vet. Med.*
545 (*Suppl. J. Vet. Med.*), **36**, 1–87.
- 546 BECHER P., AVALOS-RAMIREZ R., ORLICH M., CEDILLO ROSALES S., KONIG, M., SCHWEIZER M., STALDER H., SCHIRMEIR H & THIEL
547 H.-J. (2003). Genetic and antigenic characterisation of novel pestivirus genotypes; Implications for classification. *Virology*,
548 **311**, 96–104.
- 549 BECHER P., ORLICH M. & THIEL H.-J. (1998). Complete genomic sequence of border disease virus a pestivirus from sheep.
550 *J. Virol.*, **72**, 5165–5173.
- 551 BRAUN U., HILBE M., EHRENSPERGER F., SALIS F., ALTHER P., STRASSER M., STALDER H.P. & PETERHANS E. (2002). Border
552 Disease in einem Schafbetrieb. *Schweiz. Arch. Tierheilk.*, **144**, 419–426.
- 553 BRUN A., LACOSTE F., REYNAUD G., KATO F. & SAINT-MARC B. (1993). Evaluation of the potency of an inactivated vaccine
554 against border disease pestivirus infection in sheep. *In: Proceedings of the Second Symposium on Pestiviruses*, Edwards
555 S., ed. Fondation Marcel Merieux, Annecy, France, 1–3 October 1992, 257–259
- 556 CARLSSON U. (1991). Border disease in sheep caused by transmission of virus from cattle persistently infected with bovine
557 virus diarrhoea virus. *Vet. Rec.*, **128**, 145–147.
- 558 CHAPPUIS G., BRUN A., KATO F., DAUVERGNE M., REYNAUD G. & DURET C. (1986). Etudes serologiques et immunologiques
559 realisees a la suite de l'isolement d'un pestivirus dans un foyer ovina chez des moutons de L'Aveyron. *In: Pestiviruses des*
560 Ovins et des Bovins, Espinasse J. & Savey M. eds. Ste Françoise de Buiatrie, Paris, France, **55**, 66.
- 561 DECARO N., MARI V., LUCENTE M., SCIARRETTA R., MORENO A., ARMENISE C., LOSURDO M., CAMERO M., LORUSSO E., CORDIOLI
562 P., & BUONAVOGLIA C. (2012). Experimental infection of cattle, sheep and pigs with 'Hobi'-like pestivirus. *Vet. Microbiol.*,
563 **155**, 165–171.
- 564 DEKKER A., WENSVOORT G. & TERPSTRA C. (1995). Six antigenic groups within the genus pestivirus as identified by cross-
565 neutralisation assays. *Vet. Microbiol.*, **47**, 317–329.
- 566 ENTRICAN G., DAND A. & NETTLETON P.F. (1994). A double monoclonal-antibody ELISA for detecting pestivirus antigen in
567 the blood of viraemic cattle and sheep. *Vet. Microbiol.*, **43**, 65–74.
- 568 FENTON A., SINCLAIR J.A., ENTRICAN G., HERRING J.A. & NETTLETON P.F. (1991). A monoclonal antibody capture ELISA to
569 detect antibody to border disease virus in sheep sera. *Vet. Microbiol.*, **28**, 327–333.
- 570 INTERNATIONAL COMMITTEE ON TAXONOMY OF VIRUSES (2016). *Virus Taxonomy 2015 release*.
571 <http://www.ictvonline.org/virusTaxonomy.asp>

- 572 NETTLETON P.F., GILMOUR J.S., HERRING J.A. & SINCLAIR J.A. (1992). The production and survival of lambs persistently
573 infected with border disease virus. *Comp. Immunol. Microbiol. Infect. Dis.*, **15**, 179–188.
- 574 NETTLETON P.F., GILRAY J.A., RUSSO P. & DLISSI E. (1998). Border disease of sheep and goats *Vet. Res.*, **29**, 327–340.
- 575 OGUZOGLU T.C., FLOEGEL-NIESMANN G., FREY H.R. & MOENNIG V. (2001). Differential diagnosis of classical swine fever and
576 border disease: seroepidemiological investigation of a pestivirus infection on a mixed sheep and swine farm. *Dtsch
577 Tierarztl. Wochenschr.*, **108**, 210–213.
- 578 PARK B.K. & BOLIN S.R. (1987). Molecular changes of bovine viral diarrhoea virus polypeptides treated with binary
579 ethylenimine, beta-propiolactone and formalin. *Res. Rep. Rural Dev. Admin. (L&V) Korea*, **29**, 99–103.
- 580 PATON D.J., SANDS J.J., LOWINGS J.P., SMITH J.E., IBATA G. & EDWARDS S. (1995). A proposed division of the pestivirus genus
581 into subgroups using monoclonal antibodies, supported by cross-neutralization assays and genetic sequencing. *Vet. Res.*,
582 **26**, 92–109.
- 583 RIDPATH J.F. & BOLIN S.R. (1997). Comparison of the complete genomic sequence of the border disease virus, BD31, to
584 other pestiviruses. *Virus Res.*, **50**, 237–243.
- 585 THABTI F., FRONZAROLI L., DLISSI E., GUIBERT J.M., HAMMAMI S., PEPIN M. & RUSSO P. (2002). Experimental model of border
586 disease virus infection in lambs: comparative pathogenicity of pestiviruses isolated in France and Tunisia. *Vet. Res.*, **33**,
587 35–45.
- 588 THUR B., HILBE M., STRASSER M. & EHRENSPERGER F. (1997). Immunohistochemical diagnosis of pestivirus infection
589 associated with bovine and ovine abortion and perinatal death. *Am. J. Vet. Res.*, **58**, 1371–1375.
- 590 VALDAZO-GONZALEZ B., ALVAREZ-MARTINEZ M. & SANDVIK T. (2007). Genetic and antigenic typing of border Disease virus
591 isolates in sheep from the Iberian peninsula. *Vet. J.*, **174**, 316–324.
- 592 VAN RIJN P.A., VAN GENNIP H.G.P., LEENCLERSE C.H., BRUSCHKE C.J.M., PATON D.J., MOORMANN R.J.M. & VAN OIRSCHOT J.T.
593 (1997). Subdivision of the pestivirus genus based on envelope glycoprotein E2 *Virology*, **237**, 337–348.
- 594 VANTSIS J.T., BARLOW R.M., FRASER J. & MOULD D.L. (1976). Experiments in border disease VIII. Propagation and properties
595 of a cytopathic virus. *J. Comp. Pathol.*, **86**, 111–120.
- 596 VANTSIS J.T., RENNIE J.C., GARDINER A.C., WELLS P.W., BARLOW R.M. & MARTIN W.B. (1980). Immunisation against Border
597 disease. *J. Comp. Path.*, **90**, 349–354.
- 598 VILCEK S. & NETTLETON P.F. (2006). Pestiviruses in wild animals *Vet. Microbiol.*, **116**, 1–12.
- 599 VILCEK S., NETTLETON P.F., PATON D.J. & BELAK S. (1997). Molecular characterization of ovine pestiviruses. *J. Gen. Virol.*,
600 **78**, 725–735.
- 601 WENSVOORT G. & TERPSTRA C. (1988). Bovine viral diarrhoea virus infection in piglets born to sows vaccinated against
602 swine fever with contaminated virus. *Res. Vet. Sci.*, **45**, 143–148.
- 603 WENSVOORT G., TERPSTRA C. & DE KLUYVER E.P. (1989). Characterisation of porcine and some ruminant pestiviruses by
604 cross-neutralisation. *Vet. Microbiol.*, **20**, 291–306.
- 605 WILLOUGHBY K., VALDAZO-GONZALEZ, B., MALEY M., GILRAY J. & NETTLETON P.F. (2006). Development of a real time RT-PCR
606 to detect and type ovine pestiviruses. *J. Virol. Methods*, **132**, 187–194.

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608

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* *

609 **NB:** At the time of publication (2017) there were no WOA Reference Laboratories
610 for border disease (please consult the WOA Web site:
611 <https://www.woah.org/en/what-we-offer/expertise-network/reference-laboratories/#ui-id-3>).

612 **NB:** FIRST ADOPTED IN 1996. MOST RECENT UPDATES ADOPTED IN 2017.

4
5 CHAPTER 3.8.12.

6 SHEEP POX AND GOAT POX

7 SUMMARY

8 Sheep pox and goat pox are contagious, viral diseases of sheep and goats characterised by fever,
9 generalised papules or nodules, vesicles (rarely), internal lesions (particularly in the lungs), and death. Both
10 diseases are caused by strains of capripoxvirus, all of which can infect sheep and goats. Although most of
11 the strains examined cause more severe clinical disease in either sheep or goats, some strains have been
12 isolated that are equally pathogenic in both species.

13 Sheeppox virus (SPPV) and goatpox virus (GTPV) are the causative agents of sheep pox and goat pox, and
14 with lumpy skin disease virus (LSDV) make up the genus Capripoxvirus in the family Poxviridae. Sheep pox
15 and goat pox are endemic in Africa north of the Equator, the Middle East and Asia, while some parts of
16 Europe have experienced outbreaks recently. See WAHIS (<https://wahis.woah.org/#/home>) for recent
17 information on distribution at the country level. ~~Countries that reported outbreaks of the disease between~~
18 ~~2010 and 2015 include Bulgaria, Chinese Taipei, Israel, Kazakhstan, Kyrgyzstan, Mongolia, Morocco,~~
19 ~~Greece and Russia, with Greece, Israel and Russia having experienced recurring incidences.~~

20 **Identification of the agent:** Laboratory confirmation of capripoxvirus is most rapid using the polymerase
21 chain reaction (PCR) method in combination with a clinical history consistent with generalised capripoxvirus
22 infection. Isolation of the virus is possible as capripoxviruses will grow on tissue culture of ovine, caprine or
23 bovine origin, although field isolates may require up to 14 days to grow or require one or more additional
24 tissue culture passage(s). The virus causes intracytoplasmic inclusions that can be clearly seen using
25 haematoxylin and eosin staining. The antigen can also be detected in tissue culture using specific sera and
26 immunoperoxidase or immunofluorescence techniques. Capripoxvirus antigen and inclusion bodies may be
27 seen in stained cryostat or paraffin sections of biopsy or post-mortem lesion material.

28 ~~An antigen detection enzyme-linked immunosorbent assay (ELISA) using a polyclonal detection serum~~
29 ~~raised against a recombinant immunodominant antigen of capripoxvirus has been developed.~~

30 **Serological tests:** The virus neutralisation test is the most specific serological test. The indirect
31 immunofluorescence test is less specific due to cross-reactions with antibody to other poxviruses. Western
32 blotting using the reaction between the P32 antigen of capripoxvirus with test sera is both sensitive and
33 specific, but is expensive and difficult to carry out. An enzyme-linked immunosorbent assay (ELISA) has
34 been developed and validated to detect antibodies to capripoxviruses, however it cannot differentiate
35 between SPPV, GTPV and LSDV.

36 ~~The use of this antigen, or other appropriate antigens expressed by a suitable vector, in an ELISA offers the~~
37 ~~prospect of an acceptable and standardised serological test in the future.~~

38 **Requirements for vaccines:** Live and inactivated vaccines have been used for the control of
39 capripoxviruses. All strains of capripoxvirus so far examined share a major neutralisation site and some will
40 cross protect. Inactivated vaccines give, at best, only short-term immunity.

41 A. INTRODUCTION

42 The *Capripoxvirus* genus, in the family *Poxviridae*, consists of three species – lumpy skin disease virus (LSDV), which
43 causes disease in cattle only (see Chapter 3.4.12), and sheeppox virus (SPPV) and goatpox virus (GTPV), which cause
44 sheep pox and goat pox, respectively. Sheep pox and goat pox are characterised by disseminated cutaneous nodules and
45 up to 100% mortality in fully susceptible breeds of sheep and goats. In indigenous animals, generalised disease and
46 mortality are less common, although they are seen where disease has been absent from an area or village for a period of
47 time, when intensive husbandry methods are introduced, or in association with other disease agents, such as peste des
48 petits ruminants virus or foot and mouth disease virus. Sheep pox and goat pox are major constraints to the introduction
49 of exotic breeds of sheep and goats to endemic areas, and to the development of intensive livestock production.

50 Strains of SPPV and GTPV can pass between sheep and goats, although most cause more severe clinical disease in only
51 one their homologous host species. SPPV and GTPV are transboundary diseases that regularly spread into adjacent, non-
52 endemic areas. Sheep pox and goat pox are endemic in Africa north of the Equator and parts of the Middle East and Asia
53 (see WAHIS for most up-to-date information on distribution: <https://wahis.woah.org/#/home>). Outbreaks have been
54 reported in non-endemic countries of Asia, Europe and the Middle East.

55 The incubation period of sheep pox and goat pox is between 8 and 13 days following contact between infected and
56 susceptible animals. It may be as short as 4 days following experimental infection by intradermal inoculation ~~or mechanical~~
57 ~~transmission by insects~~. Some breeds of European sheep, such as Soay, may die of acute infection before the
58 development of skin lesions. In other breeds there is an initial rise in rectal temperature to above 40°C, followed in 2–5
59 days by the development of, at first, macules – small circumscribed areas of hyperaemia, which are most obvious on
60 unpigmented skin – and then of papules – hard swellings of between 0.5 and 1 cm in diameter – which may cover the body
61 or be restricted to the groin, axilla and perineum. Papules may be covered by fluid-filled vesicles, but this is rare. Some
62 researchers have distinguished between a vesicular and nodular form of sheep pox and goat pox (Zro *et al.*, 2014b).

63 Within 24 hours of the appearance of generalised papules, affected animals develop rhinitis, conjunctivitis and enlargement
64 of all the superficial lymph nodes, in particular the prescapular lymph nodes. Papules on the eyelids cause blepharitis of
65 varying severity. As the papules on the mucous membranes of the eyes and nose ulcerate, so the discharge becomes
66 mucopurulent, and the mucosae of the mouth, anus, and prepuce or vagina become necrotic. Breathing may become
67 laboured and noisy due to pressure on the upper respiratory tract from the swollen retropharyngeal lymph nodes, due to
68 the developing lung lesions.

69 If the affected animal does not die in this acute phase of the disease, the papules start to become necrotic from ischaemic
70 necrosis following thrombi formation in the blood vessels at the base of the papule. In the following
71 5–10 days the papules form scabs, which persist for up to 6 weeks, leaving small scars. The skin lesions are susceptible
72 to fly strike, and secondary pneumonia is common. Anorexia is not usual unless the mouth lesions physically interfere with
73 feeding. Abortion is rare.

74 On post-mortem examination of the acutely infected animal, the skin lesions are often less obvious than on the live animal.
75 The mucous membranes appear necrotic and all the body lymph nodes are enlarged and oedematous. Papules, which
76 may be ulcerated, can usually be found on the abomasal mucosa, and sometimes on the wall of the rumen and large
77 intestine, on the tongue, hard and soft palate, trachea and oesophagus. Pale areas of approximately 2 cm in diameter may
78 occasionally be seen on the surface of the kidney and liver, and have been reported to be present in the testicles. Numerous
79 hard lesions of up to 5 cm in diameter are commonly observed throughout the lungs, but particularly in the diaphragmatic
80 lobes.

81 The clinical signs and post-mortem lesions vary considerably with breed of host and strain of capripoxvirus. Indigenous
82 breeds are less susceptible and frequently show only a few lesions, which could be confused with insect bites or contagious
83 pustular dermatitis. However, lambs that have lost their maternally derived immunity, animals that have been kept isolated
84 and animals brought into endemic areas from isolated villages, particularly if they have been subjected to the stress of
85 moving long distances and mixing with other sheep and goats, and their pathogens, can often be seen with generalised
86 and sometimes fatal capripoxvirus infections. Invariably there is high mortality in unprotected imported breeds of sheep
87 and goats following capripoxvirus infection. Capripoxvirus is not infectious to humans.

B. DIAGNOSTIC TECHNIQUES

Table 1. Test methods available for diagnosis of sheep pox and goat pox and their purpose

Method	Purpose					
	Population freedom from infection	Individual animal freedom from infection prior to movement	Contribute to eradication policies	Confirmation of clinical cases	Prevalence of infection – surveillance	Immune status in individual animals or populations post-vaccination
Identification of the agent^(a)						
Virus isolation	+	++	+	+++	+	–
Antigen detection	++	++	++	++	++	–
<u>IFAT</u>	<u>±</u>	<u>±</u>	<u>±</u>	<u>++</u>	<u>±</u>	<u>≡</u>
<u>IHC</u>	<u>±</u>	<u>±</u>	<u>±</u>	<u>++</u>	<u>±</u>	<u>≡</u>
PCR	++	+++	++	+++	++	–
Detection of immune response						
<u>VNT</u>	++	++	++	++	++	++
IFAT	+	+	+	+	+	+
<u>ELISA</u>	<u>++</u>	<u>++</u>	<u>++</u>	<u>++</u>	<u>++</u>	<u>++</u>

90

Key: +++ = recommended for this purpose; ++ recommended but has limitations;

91

+ = suitable in very limited circumstances; – = not appropriate for this purpose.

92

IFAT = indirect fluorescent antibody test; IHC = immunohistochemistry; PCR = polymerase chain reaction;

93

VNT = virus neutralisation; ELISA = enzyme-linked immunosorbent assay.

94

^(a)A combination of agent identification methods applied on the same clinical sample is recommended.

95

1. Identification of the agent

96

1.1. Specimen collection and submission

97

Material for virus isolation and antigen detection should be collected by biopsy or at post-mortem from skin papules, lung lesions or lymph nodes. Samples for virus isolation and antigen detection ~~enzyme-linked immunosorbent assay (ELISA)~~ should be collected within the first week of the occurrence of clinical signs, before the development of neutralising antibodies. Samples for genome detection by polymerase chain reaction (PCR) may be collected before or after the development of neutralising antibody responses. Buffy coat from blood collected into EDTA (ethylene diamine tetra-acetic acid) during the viraemic stage of capripoxvirus infection (before generalisation of lesions or within 4 days of generalisation), can also be used for virus isolation.

104

Samples for histology should include tissue from the surrounding area and should be placed immediately following collection into ten times the sample volume of 10% formalin or neutral buffered 10% formal saline. Tissues in formalin have no special transportation requirements.

105

106

107

Blood samples, for virus isolation from the buffy coat, should be collected in tubes containing anticoagulant, placed immediately on ice and processed as soon as possible. In practice, the blood samples may be kept at 4°C for up to 2 days prior to processing, but should not be frozen or kept at ambient temperatures. Tissues and dry scabs for virus isolation, antigen detection and genome detection should preferably be kept at 4°C, on ice or at –20°C. If it is necessary to transport samples over long distances without refrigeration, the medium should contain 10% glycerol; the samples should be of sufficient size that the transport medium does not penetrate the central part of the biopsy, which should be used for virus isolation/detection.

108

109

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114

1.2. Virus isolation

115 Lesion material for virus isolation and antigen detection is homogenised. The following is an example of one technique
116 for homogenisation: The tissue is minced using sterile scissors and forceps, and then macerated in a steel ball bearing
117 mixer mill or ground with a sterile pestle in a mortar with sterile sand and an equal volume of sterile phosphate
118 buffered saline (PBS) or serum-free Modified Eagle's Medium (MEM) containing sodium penicillin (1000 international
119 units [IU/ml), streptomycin sulphate (1 mg/ml), mycostatin (100 IU/ml) or fungizone (2.5 µg/ml) and neomycin
120 (200 IU/ml). The homogenised suspension is freeze–thawed three times and then partially clarified by centrifugation
121 using a bench centrifuge at 600 **g** for 10 minutes. In cases where bacterial contamination of the sample is expected
122 (such as when virus is isolated from skin samples), the supernatant can be filtered through a 0.45 µm pore size filter
123 after the centrifugation step, however, the amount of virus in the supernatant might be reduced. Buffy coats may be
124 prepared from 5–8 ml unclotted blood by centrifugation at 600 **g** for 15 minutes; the buffy coat is carefully removed
125 into 5 ml of cold double-distilled water using a sterile Pasteur pipette. After 30 seconds, 5 ml of cold double-strength
126 growth medium is added and mixed. The mixture is centrifuged at 600 **g** for 15 minutes, the supernatant is discarded
127 and the cell pellet is suspended in 5 ml of growth medium, such as Glasgow's modified Eagle's medium (GMEM).
128 After centrifugation at 600 **g** for a further 15 minutes, the resulting pellet is suspended in 5 ml of fresh GMEM.
129 Alternatively, the buffy coat may be separated from a heparinised sample using a density gradient.

130 Capripoxvirus will grow in tissue culture of bovine, ovine or caprine origin, although primary or secondary cultures of
131 lamb testis (LT) or lamb kidney (LK) cells are considered to be the most susceptible. Care needs to be taken to ensure
132 they are not contaminated with viruses such as bovine viral diarrhoea virus, particularly those derived from a wool
133 sheep breed (see chapter 1.1.9). Madin–Darby bovine kidney (MDBK) cells have been shown to be suitable for
134 capripoxvirus isolation (Fay *et al.*, 2020). The following is an example of an isolation technique: either 1 ml of buffy
135 coat cell suspension or 1 ml of clarified biopsy preparation supernatant is inoculated on to a 25 cm² tissue culture
136 flask of appropriate cells at 90% confluent LT or LK cells confluence, and the supernatant is allowed to adsorb for 1
137 hour at 37°C. The culture is then washed with warm PBS and covered with 10 ml of a suitable medium, such as
138 GMEM, containing antibiotics and 2% fetal calf serum. If available, tissue culture tubes ~~containing LT or LK cells and~~
139 ~~a, flying cover-slips~~, or tissue culture microscope slides, ~~are can~~ also be infected.

140 The flasks should be examined daily for 7–14 days for evidence of cytopathic effect (CPE). Contaminated flasks
141 should be discarded. Infected cells develop a characteristic CPE consisting of retraction of the cell membrane from
142 surrounding cells, and eventually rounding of cells and margination of the nuclear chromatin. At first only small areas
143 of CPE can be seen, sometimes as soon as 4 days after infection; over the following 4–6 days these expand to
144 involve the whole cell sheet. If no CPE is apparent by day 7, the culture should be freeze–thawed three times, and
145 clarified supernatant inoculated on to fresh ~~LT or LK cell~~ cultures. At the first sign of CPE in the flasks, or earlier if a
146 number of infected cover-slips are being used, a cover-slip should be removed, fixed in acetone and stained using
147 H&E. Eosinophilic intracytoplasmic inclusion bodies, which are variable in size but up to half the size of the nucleus
148 and surrounded by a clear halo, are indicative of poxvirus infection. Syncytia formation is not a feature of capripoxvirus
149 infection. If the CPE is due to capripoxvirus infection of the cell culture, it can be prevented or delayed by inclusion of
150 specific anti-capripoxvirus serum in the medium; this provides a presumptive identification of the agent. Some strains
151 of capripoxvirus have been adapted to grow on African green monkey kidney (Vero) cells, but these cells are not
152 recommended for primary isolation.

1.3. Electron microscopy

153 The characteristic poxvirus virion can be visualised using a negative-staining preparation technique followed by
154 examination with an electron microscope. There are many different negative-staining protocols, an example is given
155 below:
156

157 Material from the original tissue suspension is prepared for transmission electron microscope examination, prior to
158 centrifugation, by floating a 400-mesh hexagon electron microscope grid, with pili-form-carbon substrate activated by
159 glow discharge in pentylamine vapour, on to a drop of the suspension placed on parafilm or a wax plate. After 1
160 minute, the grid is transferred to a drop of Tris/EDTA buffer, pH 7.8, for 20 seconds and then to a drop of 1%
161 phosphotungstic acid, pH 7.2, for 10 seconds. The grid is drained using filter paper, air-dried and placed in the
162 electron microscope. The capripoxvirus virion is brick shaped, covered in short tubular elements and measures
163 approximately 290 × 270 nm. A host-cell-derived membrane may surround some of the virions, and as many as
164 possible should be examined to confirm their appearance (Kitching & Smale, 1986).

165 The virions of capripoxvirus are indistinguishable from those of orthopoxvirus, but, apart from *Vaccinia* virus, no
166 orthopoxvirus causes lesions in sheep and goats. However, capripoxvirus is distinguishable from the virions of
167 parapoxvirus, that cause contagious pustular dermatitis, as they are smaller, oval in shape, and each is covered in a
168 single continuous tubular element, which appears as striations over the virion.

169

1.4. Histopathology

170 Material for histopathology should be prepared by standard techniques. Following preparation, staining with
171 haematoxylin and eosin (H&E), and mounting of the formalin-fixed biopsy material, a number of sections should be
172 examined by light microscopy. On histological examination, the most striking aspects of acute-stage skin lesions are
173 a massive cellular infiltrate, vasculitis and oedema. Early lesions are characterised by marked perivascular cuffing.
174 Initially infiltration is by macrophages, neutrophils and occasionally eosinophils, and as the lesion progresses, by
175 more macrophages, lymphocytes and plasma cells. A characteristic feature of all capripoxvirus infections is the
176 presence of variable numbers of 'sheep pox cells' in the dermis. These sheep pox cells can also occur in other organs
177 where microscopic lesions of sheep and goat pox are present. These cells are large, stellate cells with eosinophilic,
178 poorly defined intracytoplasmic inclusions and vacuolated nuclei. Vasculitis is accompanied by thrombosis and
179 infarction, causing oedema and necrosis. Epidermal changes consist of acanthosis, parakeratosis and
180 hyperkeratosis. Changes in other organs are similar, with a predominant cellular infiltration and vasculitis. Lesions in
181 the upper respiratory tract are characterised by ulceration.

182

1.5. Immunological methods

183

1.5.1. Fluorescent antibody tests

184 Capripoxvirus antigen can also be identified on infected cover-slips or tissue culture slides using fluorescent
185 antibody tests. Cover-slips or slides should be washed and air-dried and fixed in cold acetone for 10 minutes.
186 The indirect test using immune sheep or goat sera is subject to high background colour and nonspecific
187 reactions. However, a direct conjugate can be prepared from sera from convalescent sheep or goats or from
188 rabbits hyperimmunised with purified *Capripoxvirus*. Uninfected tissue culture should be included as a
189 negative control because cross-reactions, due to antibodies to cell culture antigens, can cause problems. The
190 fluorescent antibody tissue section technique has also been used on cryostat-prepared slides.

191

1.6. Nucleic acid recognition methods

192 Amplification methods for detection of ~~the viral DNA genome are specific to the genus *Capripoxvirus*~~ DNA are ~~and~~
193 both specific and sensitive for ~~detection~~ throughout the course of disease, including before and after the emergence
194 of antibody responses. These methods include conventional PCR, real-time PCR, and most recently loop-mediated
195 isothermal amplification (LAMP). Nucleic acid recognition methods can be used to detect the *Capripoxvirus* genome
196 in biopsy, swab or tissue culture samples.

197

1.6.1. Conventional PCR methods

198 Several conventional PCR methods have been reported with varying specificity for capripoxviruses
199 in general, SPPV, or GTPV (Heine *et al.*, 1999; Ireland & Binopal, 1998; Zro *et al.*, 2014a). A
200 conventional PCR assay that differentiates GTPV and LSDV from SPPV has been described (Lamien
201 *et al.*, 2011a). Conventional PCR methods are particularly useful for obtaining sufficient genetic
202 material necessary for species identification by subsequent sequence and phylogenetic analysis (Le
203 Goff *et al.*, 2009).

204

The conventional gel-based PCR method described below is a simple, fast and sensitive method for
205 the detection of capripoxvirus genome in EDTA blood, semen or tissue culture samples (Tuppurainen
206 *et al.*, 2005).

207

Test procedure

208

The extraction method described below can be replaced using commercially available DNA extraction
209 kits.

210

i) Freeze and thaw 200 µl of blood in EDTA, semen or tissue culture supernatant and suspend in
211 100 µl of lysis buffer containing 5 M guanidine thiocyanate, 50 mM potassium chloride, 10 mM
212 Tris/HCl (pH 8); and 0.5 ml Tween 20.

213

ii) Cut skin and other tissue samples into fine pieces using a sterile scalpel blade and forceps.
214 Grind with a pestle in a mortar. Suspend the tissue samples in 800 µl of the above mentioned
215 lysis buffer.

216

iii) Add 2 µl of proteinase K (20 mg/ml) to blood samples and 10 µl of proteinase K (20 mg/ml) to
217 tissue samples. Incubate at 56°C for 2 hours or overnight, followed by heating at 100°C for
218 10 minutes. Add phenol:chloroform:isoamylalcohol (25:24:1 [v/v]) to the samples in a 1:1 ratio.
219 Vortex and incubate at room temperature for 10 minutes. Centrifuge the samples at 16,060 g

- 220 for 15 minutes at 4°C. Carefully collect the upper, aqueous phase (up to 200 µl) and transfer
221 into a clean 2.0 ml tube. Add two volumes of ice cold ethanol (100%) and 1/10 volume of 3 M
222 sodium acetate (pH 5.3). Place the samples at –20°C for 1 hour. Centrifuge again at 16,060 g
223 for 15 minutes at 4°C and discard the supernatant. Wash the pellets with ice cold 70% ethanol
224 (100 µl) and centrifuge at 16,060 g for 1 minute at 4°C. Discard the supernatant and dry the
225 pellets thoroughly. Suspend the pellets in 30 µl of nuclease-free water and store immediately at
226 –20°C (Tuppurainen *et al.*, 2005). Alternatively a column-based extraction kit may be used.
- 227 iv) The primers for this PCR assay were developed from the gene encoding the viral attachment
228 protein. The size of the expected amplicon is 192 bp (Ireland & Binepal, 1998). The primers
229 have the following gene sequences:
- 230 Forward primer 5'-TCC-GAG-CTC-TTT-CCT-GAT-TTT-TCT-TAC-TAT-3'
- 231 Reverse primer 5'-TAT-GGT-ACC-TAA-ATT-ATA-TAC-GTA-AAT-AAC-3'
- 232 v) DNA amplification is carried out in a final volume of 50 µl containing: 5 µl of 10 × PCR buffer,
233 1.5 µl of MgCl₂ (50 mM), 1 µl of dNTP (10 mM), 1 µl of forward primer, 1 µl of reverse primer,
234 1 µl of DNA template (~10 ng), 0.5 µl of Taq DNA polymerase and 39 µl of nuclease-free water.
235 The volume of DNA template required may vary and the volume of nuclease-free water must
236 be adjusted to the final volume of 50 µl.
- 237 vi) Run the samples in a thermal cycler as follows: 2 minutes at 95°C; then 45 seconds at 95°C,
238 50 seconds at 50°C and 1 minute at 72°C (34 cycles); 2 minutes at 72°C and hold at 4°C until
239 analysis.
- 240 vii) Mix 10 µl of each sample with loading dye and load onto a 1.5% agarose gel in TAE buffer
241 (Tris/acetate buffer containing EDTA). Load a parallel lane with a 100 bp DNA-marker ladder.
242 Electrophoretically separate the products using approximately 8–10 V/cm for 40–60 minutes
243 and visualise with a suitable DNA stain and transilluminator.

244 **1.6.2. Real-time PCR methods**

245 Several highly sensitive and specific fluorescent detection-based real-time PCR methods have been
246 developed and validated (Balinsky *et al.*, 2008; Bowden *et al.*, 2008; Das *et al.*, 2012; Stubbs *et al.*,
247 2012). Each test detects a small conserved genetic locus within the capripoxvirus genome, but these
248 methods do not discriminate between SPPV, GTPV or LSDV. Real-time PCR methods for direct
249 capripoxvirus genotyping species differentiation without the need for gene sequencing have been
250 described (Gelaye *et al.*, 2013; Lamien *et al.*, 2011b; Wolff *et al.*, 2021).

251 The real-time PCR method described below is a rapid, sensitive and specific method for the detection
252 of DNA from SPPV, GTPV or LSDV. This assay will not differentiate between capripoxvirus species.

253 **DNA extraction from blood and tissue**

254 A number of DNA extraction kits are commercially available for the isolation of template DNA for real-
255 time PCR. Manufacturer's instructions should always be consulted for guidance on the appropriate
256 method for the sample type being extracted. WOA Reference Laboratories can be contacted for
257 advice on suitable commercial kits.

258 **Real-time PCR**

- 259 i) The real-time PCR method outlined below uses the primers and probe described by Bowden *et*
260 *al.* (2008) and further validated by Stubbs *et al.* (2012). Cycling conditions and reagent
261 concentrations can be altered to ensure optimal performance in individual laboratories.
- 262 ii) Forward and reverse primers should be prepared at concentrations of 20 µM. A minor groove
263 binder (MGB) TaqMan probe should be prepared at a concentration of 10 µM.
- 264 iii) Forward primer: 5'-AAA-ACG-GTA-TAT-GGA-ATA-GAG-TTG-GAA-3'
- 265 iv) Reverse primer: 5'-AAA-TGA-AAC-CAA-TGG-ATG-GGA-TA-3'
- 266 v) Probe: 5'-FAM-TGG-CTC-ATA-GAT-TTC-CT-MGB-3'
- 267 vi) Mastermix is prepared by combining 10 µl of 2 × real-time PCR mastermix with 0.4 µl of forward
268 primer, 0.4 µl of reverse primer, 0.5 µl of probe and 6.7 µl of RNase free water per reaction.
- 269 vii) Add 2 µl of extracted DNA to 18 µl of mastermix in a 96-well PCR plate or PCR strip and perform
270 real-time PCR according to the example given below or similar method:

- 271 viii) 95°C for 10 minutes followed by 45 cycles of 95°C for 15 seconds, 60°C for 60 seconds.
272 Fluorescence detection should be performed at the end of each cycle.
- 273 ix) Following completion of the real-time PCR, a cycle threshold (C_T) should be set. Samples with
274 C_T values less than 35 are considered positive. Samples with a C_T value greater than 35 but
275 less than 45 are considered inconclusive and require further investigation. Samples which do
276 not yield a C_T value, i.e. the amplification curve does not cross the threshold, are considered
277 negative.

278 1.6.3. Isothermal genome amplification

279 Molecular tests using ~~loop-mediated isothermal amplification~~ (LAMP) to detect capripoxvirus
280 genomes are reported to provide sensitivity and specificity similar to real-time PCR with a simpler
281 method and at lower cost (Das *et al.*, 2012; Murray *et al.*, 2013). Field validation of the Das *et al.*
282 (2012) LAMP method has been further reported by (Omoga *et al.*, 2016) and a combination of this
283 universal capripoxvirus test with two additional LAMP assays was reported to show utility in
284 discriminating between GTPV and SPPV (Zhao *et al.*, 2014).

285 2. Serological tests

286 2.1. Virus neutralisation

287 A test serum can either be titrated against a constant titre of capripoxvirus (100 TCID₅₀ [50% tissue culture infective
288 dose]) or a standard capripoxvirus strain can be titrated against a constant dilution of test serum in order to calculate
289 a neutralisation index. Because of the variable sensitivity of tissue culture to capripoxvirus, and the consequent
290 difficulty of ensuring the use of 100 TCID₅₀, the neutralisation index is the preferred method, although it does require
291 a larger volume of test sera. The test is described using 96-well flat-bottomed tissue culture grade microtitre plates,
292 but it can be performed equally well in tissue culture tubes with the appropriate changes to the volumes used, although
293 it is more difficult to read an end-point in tubes. ~~The use of Vero cells in the virus neutralisation test has been reported~~
294 ~~to give more consistent results (Kitching & Taylor, 1985).~~

295 2.1.1. Test procedure

- 296 i) Test sera including a negative and a positive control are diluted 1/5 in Eagle's/HEPES (N-2-
297 hydroxyethylpiperazine, N-2-ethanesulphonic acid) and inactivated at 56°C for 30 minutes.
- 298 ii) Next, 50 µl of the first inactivated serum is added to columns 1 and 2, rows A to H of the
299 microtitre plate. The second serum is placed in columns 3 and 4, the third in columns 5 and 6,
300 the positive control serum is placed in columns 7 and 8, the negative control serum is placed in
301 columns 9 and 10, and 50 µl of Eagle's/HEPES without serum is placed in columns 11 and 12
302 and to all wells of row H.
- 303 iii) A reference strain of capripoxvirus, usually a vaccine strain known to grow well in tissue culture,
304 with a titre of over log₁₀ 6 TCID₅₀ per ml is diluted in Eagle's/HEPES in bijoux bottles to give a
305 log dilution series of log₁₀ 5.0; 4.0; 3.5; 3.0; 2.5; 2.0; 1.5 TCID₅₀ per ml (equivalent to log₁₀ 3.7;
306 2.7; 2.2; 1.7; 1.2; 0.7; 0.2 TCID₅₀ per 50 µl).
- 307 iv) Starting with row G and the most diluted virus preparation, 50 µl of virus is added to each well
308 in that row. This is repeated with each virus dilution, the highest titre virus dilution being placed
309 in row A.
- 310 v) The plates are covered and incubated for 1 hour at 37°C.
- 311 vi) ~~LT cells are~~ An appropriate cell suspension (such as MDBK cells) is prepared from pregrown
312 monolayers as a suspension of 10⁵ cells/ml in Eagle's medium containing antibiotics and 2%
313 fetal calf serum. Following incubation of the microtitre plates, 100 µl of cell suspension is added
314 to all the wells, except wells H11 and H12, which serve as control wells for the medium. The
315 remaining wells of row H are cell and serum toxicity controls.
- 316 vii) The microtitre plates are covered and incubated at 37°C for 9 days.
- 317 viii) Using an inverted microscope, the monolayers are examined daily starting at day 4 for evidence
318 of CPE. There should be no CPE in the cells of row H. Using the 0240 KSGP vaccine strain of
319 capripoxvirus, the final reading is taken on day 9, and the titre of virus in each duplicate titration
320 is calculated according to the Kärber method. If left longer, there is invariably a 'breakthrough'
321 of virus in which virus that was at first neutralised appears to disassociate from the antibody.
- 322 ix) *Interpretation of the results:* The neutralisation index is the log titre difference between the titre
323 of the virus in the negative serum and in the test serum. An index of ≥1.5 is positive. The test

324 can be made more sensitive if serum from the same animal is examined before and after
325 infection. Because immunity to capripoxvirus is predominantly cell mediated, a negative result,
326 particularly following vaccination in which the response is necessarily mild, does not imply that
327 the animal from which the serum was taken is not protected.

328 ~~A constant virus/varying serum method has been described using serum dilutions in the range~~
329 ~~1/5 to 1/500 and fetal calf muscle cells. Because these cells have a lower sensitivity to~~
330 ~~capripoxvirus than LT cells, the problem of virus 'breakthrough' is overcome.~~

331 2.2. Indirect fluorescent antibody test

332 Capripoxvirus-infected tissue culture grown on flying cover-slips or tissue culture microscope slides can be used for
333 the indirect fluorescent antibody test. Uninfected tissue culture control, and positive and negative control sera, should
334 be included in the test. The infected and control cultures are fixed in acetone at -20°C for 10 minutes and stored at
335 4°C . Dilutions of test sera are made in PBS, starting at 1/5, and positives are identified using an anti-sheep gamma-
336 globulin conjugated with fluorescein isothiocyanate (Davies & Otema, 1978). Cross-reactions can occur with orf,
337 bovine papular stomatitis virus and perhaps other poxviruses.

338 2.3. Western blot analysis

339 Western blotting of test sera against capripoxvirus-infected cell lysate provides a sensitive and specific system for
340 the detection of antibody to capripoxvirus structural proteins, although the test is expensive and difficult to carry out
341 (Chand *et al.*, 1994).

342 2.4. Enzyme-linked immunosorbent assay

343 ~~No validated ELISA is available for the serological diagnosis of SPP or GTP.~~

344 Both in-house and commercial enzyme-linked immunosorbent assay (ELISAs) are available, but these tests cannot
345 discriminate between antibodies to different capripoxviruses (LSD or SPP/GTP).

346 C. REQUIREMENTS FOR VACCINES

347 **[THIS SECTION IS UNDER REVIEW IN THE 2024/2025 REVIEW CYCLE]**

348 1. Background

349 1.1. Rationale and intended use of the product

350 A variety of attenuated live and inactivated capripoxvirus vaccines has been used to provide protection against
351 sheeppox and goatpox. All strains of capripoxvirus of ovine, caprine or bovine origin examined so far share a major
352 neutralising site, so that animals recovered from infection with one strain are resistant to infection with any other strain
353 (Capstick, 1961). Consequently, it is possible to use a single strain of capripoxvirus to protect both sheep and goats
354 against all field strains of virus, regardless of whether their origin was in Asia or Africa (Kitching *et al.*, 1986; Kitching
355 & Taylor, 1985). However, field evidence suggests some strains are quite host-specific and are used only in sheep
356 against SPPV and only in goat against GTPV.

357 A number of strains of capripoxvirus have had widespread use as live vaccines (Davies & Mbugwa, 1985), for
358 example the Romanian and RM-65 strains used mainly in sheep and the Mysore and Gorgan strains used in goats.
359 The real identity of the commonly used Kenyan sheep and goat pox vaccine virus (KSGP) 0240 was recently shown
360 to be actually LSDV (Tuppurainen *et al.*, 2014). Virus strain identity and attenuation properties must be ascertained
361 and taken into consideration when selecting vaccine strains for use in cattle, sheep and goats. The protective dose
362 depends on the vaccine strain used. Immunity in sheep and goats against capripoxvirus following vaccination with
363 the 0240 strain lasts over a year and the Romanian strain gave protection for at least 30 months.

364 Killed vaccines produced from tissue culture contain only the intracellular mature virion form of the virus, and lack the
365 less robust but biologically crucial extracellular enveloped virion form. As a result, the vaccine does not stimulate
366 immunity against the extracellular enveloped virion, resulting in poor protection. Killed capripoxvirus vaccines provide,
367 at best, only temporary protection.

368 2. Outline of production and minimum requirements for conventional vaccines

369 General requirements set for the facilities used for the production of vaccines and for the documentation and record keeping
370 throughout the whole manufacturing process are described in Chapter 1.1.8 *Principles of veterinary vaccine production*.
371 The documentation should include the standard operating procedures (SOP) for the method of manufacture and each step
372 for the testing of cells and reagents used in the process, each batches and the final product.

373 2.1. Characteristics of the seed

374 2.1.1. Biological characteristics

375 A strain of capripoxvirus used for vaccine production must be accompanied by a history describing
376 its origin and tissue culture or animal passage. It must be safe to use in all breeds of sheep and goats
377 for which it is intended, including pregnant and young animals. It must be non-transmissible, remain
378 attenuated after further tissue culture passage, and provide complete protection against challenge
379 with virulent field strains for a minimum of 1 year. A quantity of master seed vaccine virus should be
380 prepared and stored in order to provide a consistent working seed for regular vaccine production.

381 2.1.2. Quality criteria (sterility, purity, freedom from extraneous agents)

382 Each master seed must be tested to ensure its identity and shown to be free from adventitious
383 viruses, in particular pestiviruses, such as border disease and bovine viral diarrhoea virus, and free
384 from contamination with bacteria, fungi and/or mycoplasmas. The general procedures for sterility or
385 purity tests are described in chapter 1.1.9. The master seed must also be safe and produce no clinical
386 reaction in all breeds of sheep or goats when given by the recommended route and stimulate
387 complete immunity to capripoxvirus in all breeds of sheep and goats for at least 1 year. The necessary
388 safety and potency tests are described in Section C.2.2.4 *Final product batch tests*.

389 2.2. Method of manufacture

390 The method of manufacture should be documented as the Outline of Production.

391 2.2.1. Procedure

392 Vaccine seed should be lyophilised and stored in 2 ml vials at -20°C . It may be stored wet at -20°C ,
393 but when wet, is more stable at -70°C or lower. The virus should be cultured in primary or secondary
394 LT or LK cells of wool sheep origin for maximum yield. Vero cells may also be used with suitably
395 adapted strains.

396 Vaccine batches are produced on fresh monolayers of secondary LT or primary LK cells. A vial of
397 seed virus is reconstituted with GMEM or another appropriate medium and inoculated on to an LT or
398 LK monolayer that has been previously washed with warm PBS, and allowed to adsorb for 15 minutes
399 at 37°C before being overlaid with additional GMEM. After 4–6 days, there will be extensive (80–
400 90%) CPE. The culture should be examined for any evidence of nonspecific CPE, medium cloudiness
401 or change in medium pH. The culture is freeze–thawed three times, the suspension removed and
402 centrifuged at 600 **g** for 20 minutes. A second passage may be required to produce sufficient virus
403 for a production batch. Live vaccine may be produced on roller bottles.

404 The procedure is repeated and the harvests from individually numbered flasks are each mixed
405 separately with an equal volume of sterile and chilled 5% lactalbumin hydrolysate and 10% sucrose,
406 and transferred to individually numbered bottles for storage at -20°C . Prior to storage, 0.2 ml is
407 removed from each bottle for sterility control. An additional 0.2 ml is removed for virus titration; 2 ml
408 pools composed of 0.2 ml samples taken from ten bottles are used. A written record of all the
409 procedures must be kept for all vaccine batches.

410 Inactivated vaccines are produced, usually from unattenuated field strains of capripoxvirus, grown in
411 tissue culture as described above, inactivated with 0.03% formaldehyde, and mixed with an equal
412 volume of alhydrogel as adjuvant. Formaldehyde is no longer considered to be a suitable inactivant
413 for certain viral vaccines because its mode of action cannot be guaranteed to be totally effective in
414 inactivating all the live virus. This has not been fully investigated for capripoxvirus.

415	2.2.2. Requirements for substrate and media
416 417 418 419	The specification and source of all ingredients used in the manufacturing procedure should be documented and the freedom from extraneous agents: bacteria, fungi, mycoplasma and any other viruses should be tested. The detailed testing procedure is described in the chapter 1.1.9. The use of antibiotics must meet the requirements of the licensing authority.
420	2.2.3. In-process controls
421	i) Cells
422 423 424 425 426 427 428 429 430 431	Cells should be obtained from the testis or kidney of a healthy young lamb from a scrapie-free flock of a wool sheep breed. During cultivation, cells must be observed for any evidence of CPE, and for normal morphology (predominantly fibroblastic). They can usually be passaged successfully up to ten times. When used for vaccine production, uninfected control cultures should be grown in parallel and maintained for at least three additional passages for further observation. They should be checked for the presence of noncytopathic strains of bovine virus diarrhoea or border disease viruses by immunofluorescence or immunoperoxidase techniques. If possible, cells should be prepared and screened prior to vaccine production and stocked in 1–2 ml aliquots containing 2×10^7 cells/ml in sterile 10% DMSO (dimethyl sulphoxide) and 90% FBS (fetal bovine serum) solution stored in liquid nitrogen.
432	ii) Serum
433 434 435	Bovine serum used in the growth or maintenance medium must be free from transmissible spongiform encephalopathies (TSEs) and antibody to capripoxvirus, and tested for contamination with pestivirus or any other viruses, extraneous bacteria, mycoplasma or fungi.
436	iii) Medium
437 438	Medium must be tested free from contamination with pestivirus or any other viruses, extraneous bacteria, mycoplasma or fungi.
439	iv) Virus
440 441 442 443 444 445 446 447 448 449	Seed virus and final vaccine must be titrated in tissue culture tubes or microtitre plates. Vaccine samples must be examined for the presence of adventitious viruses including cytopathic and noncytopathic strains of pestivirus, and should be mixed with a high-titre capripoxvirus-immune serum that has tested negative for antibody to pestivirus to prevent the vaccine virus itself interfering with the test. The vaccine bulk can be held at -20°C or below until all sterility tests and titrations have been completed, at which time it should be freeze-dried in 1 ml aliquots in vials sufficient for 100 doses. The vaccine harvest diluted with lactalbumin hydrolysate and sucrose should have a minimum titre $\log_{10} 4.5$ TCID ₅₀ per ml after freeze-drying, equivalent to a field dose of $\log_{10} 2.5$ TCID ₅₀ . A further titration is carried out on five randomly chosen vials of the freeze-dried preparation to confirm the titre.
450	2.2.4. Final product batch tests
451	i) Sterility/purity
452 453	Tests for sterility and freedom from contamination of biological materials intended for veterinary use may be found in chapter 1.1.9.
454	ii) Safety
455 456 457 458 459	The safety studies should be demonstrated by statistically valid vaccination studies using seronegative young sheep and goats of known susceptibility to capripox virus. The procedure described is suitable for vaccine strains such as 0240 that are equally immunogenic in both sheep and goats. The choice of target animal should be adapted for strains with a more restricted host preference.
460	iii) Potency
461 462 463 464 465	Potency tests must be undertaken if the minimum immunising dose of the virus strain is not known. This is usually carried out by comparing the titre of a virulent challenge virus on the flanks of vaccinated and control animals. Following vaccination, the flanks of at least three animals and three controls are shaved of wool or hair. \log_{10} dilutions of the challenge virus are prepared in sterile PBS and six dilutions are inoculated intradermally (0.1 ml per inoculum) along the length of the flank; four

466 replicates of each dilution are inoculated down the flank. An oedematous swelling will develop at
467 possibly all 24 inoculation sites on the control animals, although preferably there will be little or no
468 reaction at the four sites of the most dilute inocula. The vaccinated animals should develop an initial
469 hypersensitivity reaction at sites of inoculation within 24 hours, which should quickly subside. Small
470 areas of necrosis may develop at the inoculation site of the most concentrated challenge virus. The
471 macule/papule is measured at between 8 and 10 days post-challenge. The titre of the challenge virus
472 is calculated for the vaccinated and control animals; a difference of \log_{10} titre > 2.5 is taken as
473 evidence of protection.

474 **2.3. Requirements for authorisation**

475 **2.3.1. Safety requirements**

476 i) Target and non-target animal safety

477 The vaccine must be safe to use in all breeds of sheep and goats for which it is intended, including
478 young and pregnant animals. It must also be non-transmissible, remain attenuated after further tissue
479 culture passage.

480 Safety tests should be carried out on the final product of each batch as described in Section C.2.2.4.

481 The safety of the vaccine in non-target animals must have been demonstrated using mice and
482 guinea-pigs as described in Section C.2.2.4. There should be no evidence of pathology caused by
483 the vaccine.

484 ii) Reversion-to-virulence for attenuated/live vaccines

485 The selected final vaccine should not revert to virulence during a further passages in target animals.

486 iii) Environmental consideration

487 Attenuated vaccine should not be able to perpetuate autonomously in cattle, sheep or goat
488 populations. Vaccines using the 0240 strain should not be used in *Bos taurus* breeds. Strains of
489 capripoxvirus are not a hazard to human health. There are no precautions other than those described
490 above for sterility and freedom from adventitious agents.

491 **2.3.2. Efficacy requirements**

492 i) For animal production

493 The efficacy of the vaccine must be demonstrated in vaccination challenge experiment under
494 laboratory conditions. As described in Section C.2.2.4.

495 Once the potency of the particular strain being used for vaccine production has been determined in
496 terms of minimum dose required to provide immunity, it is not necessary to repeat this on the final
497 product of each batch, provided the titre of virus present has been ascertained.

498 ii) For control and eradication

499 Vaccination is the only effective way to control the sheep pox and goat pox outbreaks in endemic
500 countries. Unfortunately, currently no marker vaccines allowing the differentiation of infected from
501 vaccinated animals are available.

502 Immunity to virulent field virus following vaccination of sheep or goats with the 0240 strain lasts over
503 1 year, and protection against generalised infection following intradermal challenge lasts at least
504 3 years and is effective lifelong. The duration of immunity produced by other vaccine strains should
505 be ascertained in both sheep and goats by undertaking controlled trials in an environment in which
506 there is no possibility of field strains of capripoxvirus confusing the results. The inactivated vaccines
507 provide immunity for less than 1 year, and for the reasons given at the beginning of this section, may
508 not give immunity to the form of capripoxvirus usually associated with natural transmission.

509 **2.3.3. Stability**

510 All vaccines are initially given a shelf-life of 24 months before expiry. Real-time stability studies are
511 then conducted to confirm the appropriateness of the expiry date. Multiple batches of the vaccine
512 should be re-titrated periodically throughout the shelf-life to determine the vaccine variability.

513 Properly freeze-dried preparations of capripox vaccine, particularly those that include a protectant,
514 such as sucrose and lactalbumin hydrolysate, are stable for over 25 years when stored at –20°C and
515 for 2–4 years when stored at 4°C. There is evidence that they are stable at higher temperatures, but
516 no long-term controlled experiments have been reported. The inactivated vaccines must be stored at
517 4°C, and their shelf- life is usually given as 1 year.

518 No preservatives other than a protectant, such as sucrose and lactalbumin hydrolysate, are required
519 for the freeze-dried preparation.

520 3. Vaccines based on biotechnology

521 3.1. Vaccines available and their advantages

522 Currently, no recombinant vaccines for capripoxviruses are commercially available. However, a new generation of
523 capripox vaccines is being developed that uses the capripoxvirus genome as a vector for the genes of other ruminant
524 pathogens such as peste des petits ruminants (PPR) virus (Berhe *et al.*, 2003; Tuppurainen *et al.*, 2014).

525 3.2. Special requirements for biotechnological vaccines, if any

526 Not applicable.

527 REFERENCES

528 BALINSKY C.A, DELHON G, SMOLIGA G, PRARAT M, FRENCH R.A, GEARY S.J, ROCK D.L & RODRIGUEZ L.L. (2008). Rapid
529 preclinical detection of sheep pox virus by a real-time PCR assay. *J. Clin. Microbiol.*, **46**, 438–442.

530 BERHE G., MINET C., LE GOFF C., BARRETT T., NGANGNOU A., GRILLET C., LIBEAU G., FLEMING M., BLACK D.N. & DIALLO A.
531 (2003). Development of a dual recombinant vaccine to protect small ruminants against peste-des-petits-ruminants virus
532 and capripoxvirus infections. *J. Virol.*, **77**, 1571–1577.

533 BOWDEN T.R, BABIUK S.L, PARKYN G.R., COPPS J.S. & BOYLE D.B. (2008). Capripox virus tissue tropism and shedding: A
534 quantitative study in experimentally infected sheep and goats. *Virology* , **371**, 380–393.

535 CAPSTICK P.B. (1961). Annual Report. Kenya Veterinary Department, Kenya, 45–47.

536 CHAND P., KITCHING R.P. & BLACK D.N. (1994). Western blot analysis of virus-specific antibody responses to capripoxvirus
537 and contagious pustular dermatitis infections in sheep. *Epidemiol. Infect.*, **113**, 377–385.

538 DAS A., BABIUK S. & MCINTOSH M.T. (2012). Development of a loop-mediated isothermal amplification assay for rapid
539 detection of capripoxviruses. *J. Clin. Microbiol.*, **50**, 1613–1620.

540 DAVIES F.G. & MBUGWA G. (1985). The alterations in pathogenicity and immunogenicity of a Kenya sheep and goat pox
541 virus on serial passage in bovine foetal muscle cell cultures. *J. Comp. Pathol.*, **95**, 565–576.

542 DAVIES F.G. & OTEMA C. (1978). The antibody response in sheep infected with a Kenyan sheep and goat pox virus. *J.*
543 *Comp. Pathol.*, **88**, 205–210.

544 FAY P.C., COOK C.G., WIJESIRIWARDANA N., TORE G., COMTET L., CARPENTIER A., SHIH B., FREIMANIS G., HAGA I.R. & BEARD
545 P.M. (2020). Madin–Darby bovine kidney (MDBK) cells are a suitable cell line for the propagation and study of the bovine
546 poxvirus lumpy skin disease virus. *J. Virol. Methods*, **285**, 113943. doi: 10.1016/j.jviromet.2020.113943.

547 GELAYE E., LAMIEN C.E., SILBER R., TUPPURAINEN E.S., GRABHERR R. & DIALLO A.(2013). Development of a cost-effective
548 method for capripoxvirus genotyping using snapback primer and dsDNA intercalating dye. *PLoS One*, **8** (10): e75971.

549 HEINE H.G., STEVENS M.P., FOORD A.J. & BOYLE D.B. (1999). A capripoxvirus detection PCR and antibody ELISA based on
550 the major antigen P32, the homolog of the vaccinia virus H3L gene. *J. Immunol. Methods*, **227**, 187–196.

551 IRELAND D.C. & BINEPAL Y.S. (1998). Improved detection of capripoxvirus in biopsy samples by PCR. *J. Virol. Methods*, **74**,
552 1–7.

- 553 KITCHING R.P., HAMMOND J.M. & TAYLOR W.P. (1986). A single vaccine for the control of capripox infection in sheep and
554 goats. *Res. Vet. Sci.*, **42**, 53–60.
- 555 KITCHING R.P. & SMALE C. (1986). Comparison of the external dimensions of capripoxvirus isolates. *Res. Vet. Sci.*, **41**, 425–
556 427.
- 557 KITCHING R.P. & TAYLOR W.P. (1985). Clinical and antigenic relationship between isolates of sheep and goat pox viruses.
558 *Trop. Anim. Health Prod.*, **17**, 64–74.
- 559 LAMIEN C.E., GOFF C.L., SILBER R., WALLACE D.B., GULYAZ V., TUPPURAINEN E., MADANI H., CAUFOUR P., ADAM T., EL HARRAK
560 M., LUCKINS A.G., ALBINA E. & DIALLO A. (2011a). Use of the Capripoxvirus homologue of Vaccinia virus 30kDa RNA
561 polymerase subunit (RPO30) gene as a novel diagnostic and genotyping target: development of a classical PCR method
562 to differentiate Goat poxvirus from Sheep poxvirus. *Vet. Microbiol.*, **149**, 30–39. doi: 10.1016/j.vetmic.2010.09.038.
- 563 LAMIEN C.E., LELENTA M., GOGER W., SILBER R., TUPPURAINEN E., MATIJEVIC M., LUCKINS A.G. & DIALLO A. (2011b). Real time
564 PCR method for simultaneous detection, quantitation and differentiation of capripoxviruses. *J. Virol. Methods*, **171**, 134–
565 140.
- 566 LE GOFF C., LAMIEN C.E., FAKHFAFH E., CHADEYRAS A., ABU-ADULUGBAD E., LIBEAU G., TUPPURAINEN E., WALLACE D., ADAM T.,
567 SILBER R., GULYAZ V., MADANI H., CAUFOUR P., HAMAMMI S., DIALLO A. & ALBINA E. (2009). Capripoxvirus G-protein-coupled
568 chemokine receptor, a host-range gene suitable for virus-animal origin discrimination. *J. Gen. Virol.*, **90**, 67–77.
- 569 MURRAY L., EDWARDS L., TUPPURAINEN E.S., BACHANEK-BANKOWSKA K., OURA C.A., MIOULET V. & KING D.P. (2013). Detection
570 of capripoxvirus DNA using a novel loop-mediated isothermal amplification assay. *BMC Vet. Res.*, **9**, 90.
- 571 OMOGA D.C.A., MACHARIA M., MAGIRI E., KINYUA J., KASIITI J. & HOLTON T. (2016) Molecular based detection, validation of a
572 LAMP assay and phylogenetic analysis of capripoxvirus in Kenya. *J. Adv. Biol. Biotech.*, **7**, 1–12.
- 573 STUBBS S., OURA C.A., HENSTOCK M., BOWDEN T.R., KING D.P. & TUPPURAINEN E.S. (2012). Validation of a high-throughput
574 real-time polymerase chain reaction assay for the detection of capripoxviral DNA. *J. Virol. Methods*, **179**, 419–422.
- 575 TUPPURAINEN E.S.M., PEARSON C.R., BACHANEK-BANKOWSKA K., KNOWLES N.J., AMAREEN S., FROST L., HENSTOCK M.R.,
576 LAMIEN C.E., DIALLO A. & MERTENS P.P.C. (2014). Characterization of sheep pox virus vaccine for cattle against lumpy skin
577 disease virus. *Antiviral Res.*, **109**, 1–6.
- 578 TUPPURAINEN E.S.M., VENTER E.H. & COETZER J.A.W. (2005). The detection of lumpy skin disease virus in samples of
579 experimentally infected cattle using different diagnostic techniques. *Onderstepoort J. Vet. Res.*, **72**, 153–164.
- 580 WOLFF J. & BEER M. & Hoffmann B. (2021). Probe-Based Real-Time qPCR Assays for a Reliable Differentiation of Capripox
581 Virus Species. *Microorganisms*, **9**, 765. <https://doi.org/10.3390/microorganisms9040765>
- 582 ZHAO Z., FAN B., WU G., YAN X., LI Y., ZHOU X., YUE H., DAI X., ZHU H., TIAN B., LI J. & ZHANG Q. (2014) Development of loop-
583 mediated isothermal amplification assay for specific and rapid detection of differential goat Pox virus and Sheep Pox virus.
584 *BMC Microbiol.*, **14**, 1–10.
- 585 ZRO K., AZELMAT S., BENDOURO Y., KUHN J.H., EL FAHIME E. & ENNAJI M.M. (2014a). PCR-based assay to detect sheeppox
586 virus in ocular, nasal, and rectal swabs from infected Moroccan sheep. *J. Virol. Methods*, **204**, 38–43.
- 587 ZRO K., ZAKHAM F., MELLOUL M., EL FAHIME E. & MUSTAPHA M. (2014b). A sheeppox outbreak in Morocco: isolation and
588 identification of virus responsible for the new clinical form of disease. *BMC Vet Res.*, **10**, 31.
- 589 *
590 * *

591 **NB:** There are WOA Reference Laboratories for sheep pox and goat pox (please consult the WOA Web site:
592 <https://www.woah.org/en/what-we-offer/expertise-network/reference-laboratories/#ui-id-3>).
593 Please contact the WOA Reference Laboratories for any further information on
594 diagnostic tests, reagents and vaccines for sheep pox and goat pox

595 **NB:** FIRST ADOPTED IN 1989. MOST RECENT UPDATES ADOPTED IN 2017.

2 MEETING OF THE BIOLOGICAL STANDARDS COMMISSION

3 Paris, 4–8 September 2023

4
5 SECTION 3.9.

6 SUIDAE

7 CHAPTER 3.9.1.

8 AFRICAN SWINE FEVER
9 (INFECTION WITH AFRICAN SWINE FEVER VIRUS)

10 SUMMARY

11 *African swine fever (ASF) is an infectious disease of domestic and wild pigs of all breeds and ages, caused*
12 *by ASF virus (ASFV). The clinical syndromes vary from peracute, acute, subacute to chronic, depending on*
13 *the virulence of the virus. Acute disease is characterised by high fever, haemorrhages in the*
14 *reticuloendothelial system, and a high mortality rate. Soft ticks of the Ornithodoros genus, especially O.*
15 *moubata and O. erraticus, have been shown to be both reservoirs and transmission vectors of ASFV. The*
16 *virus is present in tick salivary glands and passed to new hosts (domestic or wild suids) when feeding. It can*
17 *be transmitted sexually between ticks, transovarially to the eggs, or transtadially throughout the tick's life.*

18 *ASFV is the only member of the Asfarviridae family, genus Asfivirus.*

19 *Laboratory diagnostic procedures for ASF fall into two groups: detection of the virus and serology. The*
20 *selection of the tests to be carried out depends on the disease situation and laboratory diagnostic capacity*
21 *in the area or country.*

22 **Identification of the agent:** *Laboratory diagnosis must be directed towards isolation of the virus by*
23 *inoculation of pig leukocyte or bone marrow cultures, the detection of antigen in smears or cryostat sections*
24 *of tissues by fluorescent antibody test and/or the detection of genomic DNA by the polymerase chain reaction*
25 *(PCR) or real-time PCR. The PCRs are excellent, highly sensitive, specific and rapid techniques for ASFV*
26 *detection and are very useful under a wide range of circumstances. They are especially useful if the tissues*
27 *are unsuitable for virus isolation and antigen detection. In doubtful cases, the material is passaged in*
28 *leukocyte cell cultures and the procedures described above are repeated.*

29 **Serological tests:** *Pigs that survive natural infection usually develop antibodies against ASFV from 7–10*
30 *days post-infection and these antibodies persist for long periods of time. Where the disease is endemic, or*
31 *where a primary outbreak is caused by a strain of low or moderate virulence, the investigation of new*
32 *outbreaks should include the detection of specific antibodies in serum or extracts of the tissues submitted.*
33 *A variety of methods such as the enzyme-linked immunosorbent assay (ELISA), the indirect fluorescent*
34 *antibody test (IFAT), the indirect immunoperoxidase test (IPT), and the immunoblotting test (IBT) is available*
35 *for antibody detection.*

36 **Requirements for vaccines: ~~At present, there is no vaccine for ASF.~~ Commercially produced modified live**
37 **virus vaccines are available and licenced in some countries.**

38 A. INTRODUCTION

39 The current distribution of African swine fever (ASF) extends across more than 50 countries in three continents (Africa,
40 Asia and Europe). Several incursions of ASF out of Africa were reported between the 1960s and 1970s. In 2007, ASF was
41 introduced into Georgia, from where it spread to neighbouring countries including the Russian Federation. From there ASF
42 spread to eastern European countries extending westwards and reaching the European Union in 2014. Further westward
43 and southern spread in Europe has occurred since that time. In all these countries, both hosts – domestic pig and wild
44 boar – were affected by the disease. In August 2018, the People’s Republic of China reported its first outbreak of ASF and
45 further spread in Asia has occurred.

46 ASF virus (ASFV) is a complex large, enveloped DNA virus with icosahedral morphology. It is currently classified as the
47 only member of the *Asfviridae* family, genus *Asfivirus* (Dixon *et al.*, 2005). More than 60 structural proteins have been
48 identified in intracellular virus particles (200 nm) (Alejo *et al.*, 2018). More than a hundred infection-associated proteins
49 have been identified in infected porcine macrophages, and at least 50 of them react with sera from infected or recovered
50 pigs (Sánchez-Vizcaíno & Arias, 2012). The ASFV double-stranded linear DNA genome comprises between 170 and
51 193 kilobases (kb) and contains between 150 and 167 open reading frames with a conserved central region of about 125
52 kb and variable ends. These variable regions encode five multigene families that contribute to the variability of the virus
53 genome. The complete genomes of several ASFV strains have been sequenced (Bishop *et al.*, 2015; Chapman *et al.*,
54 2011; de Villiers *et al.*, 2010; Portugal *et al.*, 2015). Different strains of ASFV vary in their ability to cause disease, but at
55 present there is only one recognised serotype of the virus detectable by antibody tests.

56 The molecular epidemiology of the disease is investigated by sequencing of the 3’ terminal end of the B646L open reading
57 frame encoding the p72 protein major capsid protein, which differentiates up to 24 distinct genotypes (Achenbach *et al.*,
58 2017; Boshoff *et al.*, 2007; Quembo *et al.* 2018). To distinguish subgroups among closely related ASFV, sequence analysis
59 of the tandem repeat sequences (TRS), located in the central variable region (CVR) within the B602L gene (Gallardo *et al.*,
60 2009; Lubisi *et al.*, 2005; Nix *et al.*, 2006) and in the intergenic region between the I73R and I329L genes, at the right
61 end of the genome (Gallardo *et al.*, 2014), is undertaken. Several other gene regions such as the E183L encoding p54
62 protein, the CP204L encoding p30 protein, and the protein encoded by the EP402R gene (CD2v), have been proved as
63 useful tools to analyse ASFVs from different locations and hence track virus spread.

64 ASF viruses produce a range of syndromes varying from peracute, acute to chronic disease and subclinical infections.
65 Pigs are the only domestic animal species that is naturally infected by ASFV. European wild boar and feral pigs are also
66 susceptible to the disease, exhibiting clinical signs and mortality rates similar to those observed in domestic pigs. In contrast
67 African wild pigs such as warthogs (*Phacochoerus aethiopicus*), bush pigs (*Potamochoerus porcus*) and giant forest hogs
68 (*Hylochoerus meinertzhageni*) are resistant to the disease and show few or no clinical signs. These species of wild pig act
69 as reservoir hosts of ASFV in Africa (Costard *et al.*, 2013; Sánchez-Vizcaíno *et al.*, 2015).

70 The incubation period is usually 4–19 days. The more virulent strains produce peracute or acute haemorrhagic disease
71 characterised by high fever, loss of appetite, haemorrhages in the skin and internal organs, and death in 4–10 days,
72 sometimes even before the first clinical signs are observed. Case fatality rates may be as high as 100%. Less virulent
73 strains produce mild clinical signs – slight fever, reduced appetite and depression – which can be readily confused with
74 many other conditions in pigs and may not lead to suspicion of ASF. Moderately virulent strains are recognised that induce
75 variable disease forms, ranging from acute to subacute. Low virulence, non-haemadsorbing strains can produce subclinical
76 non-haemorrhagic infection and seroconversion, but some animals may develop discrete lesions in the lungs or on the
77 skin in areas over bony protrusions and other areas subject to trauma. Animals that have recovered from either acute,
78 subacute or chronic infections may potentially become persistently infected, acting as virus carriers. The biological basis
79 for the persistence of ASFV is still not well understood, nor it is clear what role persistence plays in the epidemiology of
80 the disease.

81 ASF cannot be differentiated from classical swine fever (CSF) by either clinical or post-mortem examination, and both
82 diseases should be considered in the differential diagnosis of any acute febrile haemorrhagic syndrome of pigs. Bacterial
83 septicaemias may also be confused with ASF and CSF. Laboratory tests are essential to distinguish between these
84 diseases.

85 In countries free from ASF but suspecting its presence, the laboratory diagnosis must be directed towards isolation of the
86 virus by the inoculation of pig leukocyte or bone marrow cultures, the detection of genomic DNA by polymerase chain
87 reaction (PCR) or the detection of antigen in smears or cryostat sections of tissues by direct fluorescent antibody test
88 (FAT). Currently the PCR is the most sensitive technique and can detect ASFV DNA from a very early stage of infection in
89 tissues, ethylene diamine tetra-acetic acid (EDTA)-blood and serum samples. The PCR is particularly useful if samples

90 submitted are unsuitable for virus isolation and antigen detection because they have undergone putrefaction. Pigs that
91 have recovered from acute, subacute or chronic infections usually exhibit a viraemia for several weeks making the PCR
92 test a very useful tool for the detection of ASFV DNA in pigs infected with low or moderately virulent strains. Virus isolation
93 by the inoculation of pig leukocyte or bone marrow cultures and identification by haemadsorption tests (HAD) are
94 recommended as a confirmatory test when ASF is positive by other methods, particularly in the event of a primary outbreak
95 or a case of ASF.

96 ~~As no vaccine is available, the presence of ASFV antibodies is indicative of previous infection and, as antibodies are~~
97 ~~produced from the first week of infection and persist for long periods, they are a good marker for the diagnosis of the~~
98 ~~disease, particularly in subacute and chronic forms.~~

99 Vaccines should be prepared in accordance with Chapter 1.1.8 *Principles of veterinary vaccine production*. ASF modified
100 live virus (MLVs) vaccines are based on the live virus that have been naturally attenuated or attenuated by targeted genetic
101 recombination through cell cultures (Gladue & Borca, 2022). MLV production is based on a seed-lot system consistent with
102 the *European Pharmacopoeia* (11th edition) and that has been validated with respect to virus identity, sterility, purity,
103 potency, safety, non-transmissibility, stability and immunogenicity. ASF MLV first generation vaccines – defined as those
104 for which peer-reviewed publications are in the public domain – should meet or exceed the minimum standards as
105 described below. Paramount demonstration of acceptable safety and efficacy against the epidemiologically relevant ASFV
106 field strain(s) where the vaccine is intended for use are required. At the present time, acceptable efficacy should be shown
107 against the B646L (p72) genotype II pandemic virus lineage currently circulating widely in domestic pigs and wild boar.

108 ASF MLV first generation vaccines allowing the differentiation of infected animals from vaccinated animals (DIVA) by
109 suitable methods (e.g. serology-based tests) are preferred. Demonstration of MLV safety and efficacy in breeding-age
110 boars, gilts and pregnant sows, and onset and duration of protective immunity, are also preferred but are not required to
111 meet the minimum standard.

112 ASF epidemiology is complex with different epidemiological patterns of infection occurring in Africa and Europe. ASF
113 occurs through transmission cycles involving domestic pigs, wild boar, wild African suids, and soft ticks (Sánchez-Vizcaíno
114 *et al.*, 2015). In regions where *Ornithodoros* soft-bodied ticks are present, the detection of ASFV in these reservoirs of
115 infection contributes to a better understanding of the epidemiology of the disease. This is of major importance in
116 establishing effective control and eradication programmes (Costard *et al.*, 2013).

117 ASF is not a zoonotic disease and does not affect public health (Sánchez-Vizcaíno *et al.*, 2009).

118 ASFV should be handled with an appropriate level of bio-containment, determined by risk analysis in accordance with
119 Chapter 1.1.4 *Biosafety and biosecurity: Standard for managing biological risk in the veterinary laboratory and animal*
120 *facilities*.

121 . . .

122 C. REQUIREMENTS FOR VACCINES

123 ~~At present there is no commercially available vaccine for ASF.~~

124 1. Background

125 The ASF p72 genotype II strain (ASFV Georgia 2007/1 lineage) (NCBI, 2020) is recognised to be the current highest global
126 threat for domestic pig production worldwide (Penrith *et al.*, 2022).

127 Guidelines for the production of veterinary vaccines are given in Chapter 1.1.8 *Principles of Veterinary Vaccine Production*.
128 Varying additional requirements relating to quality (including purity and potency), safety, and efficacy will apply in particular
129 countries or regions for manufacturers to comply with local regulatory requirements.

130 Wherever live, virulent ASFV or ASF MLVs are stored, handled and disposed, the appropriate biosecurity level, procedures
131 and practices should be used. The ASF MLV vaccine production facility should meet the requirements for containment
132 outlined in Chapter 1.1.4 *Biosafety and biosecurity: Standard for managing biological risk in the veterinary laboratory and*
133 *animal facilities*.

134 An optimal ASF MLV first generation vaccine for the target host should have the following general characteristics (minimum
135 standards):

-
- 136 • Safe: demonstrate absence of fever and clinical signs of acute or chronic ASF in vaccinated and in-contact animals,
137 minimal and ideally no vaccine virus transmission, and absence of an increase in virulence (genetic and phenotypic
138 stability);
- 139 • Efficacious: protects against mortality, reduces acute disease (fever accompanied by the appearance of clinical signs
140 caused by ASF) and reduces vertical (boar semen and placental) and horizontal disease transmission;
- 141 • Quality – purity: free from wild-type ASFV and extraneous microorganisms that could adversely affect the safety,
142 potency or efficacy of the product;
- 143 • Quality – potent: the log₁₀ virus titre maintained throughout the vaccine shelf life that guarantees the efficacy
144 demonstrated by the established minimum immunising (protective) dose.
- 145 • Identity: based on the capacity to protect against the ASFV B646L (p72) genotype II pandemic strain or other p72
146 genotypes of recognised epidemiologic importance.
- 147 Vaccine production should be carried out using a validated, controlled and consistent manufacturing process.
- 148 ASF MLV first generation vaccines must be safe (i.e. an acceptable safety profile) for non-target species and the
149 environment in general.
- 150 Ideally, ASF MLV first generation vaccines that meet the minimum standards should also fulfil the following additional
151 general characteristics: i) prevents acute and persistent (carrier state) disease; ii) prevents horizontal and vertical disease
152 transmission; iii) induces rapid protective immunity (e.g. < 2 weeks); and iv) confers stable, life-long immunity.
- 153 Furthermore, ASF MLV second and future generation vaccines should meet the minimum safety and efficacy standards
154 as ASF MLV first generation vaccines, and ideally provide additional product profile benefits, including but not limited to: i)
155 contain a negative marker allowing the differentiation of infected from vaccinated animals (DIVA) by reliable discriminatory
156 tests such as serology-based tests; and ii) confer broad range of protection against other p72 genotype field strains of
157 varying virulence (low, moderate, and high).
- 158 The majority of ASF global vaccine research groups and companies are currently focused on ASF MLV first generation
159 vaccine candidates that are safe and efficacious against ASF viruses belonging to the ASFV p72 genotype II pandemic
160 strain (ASFV Georgia 2007/1 lineage) (NCBI, 2020).
- 161 Currently, two gene deleted MLV recombinant vaccines (ASFV-G-ΔI177L and ASFV-G-ΔMGF) have been licenced for
162 field use in Vietnam following supervised field testing to evaluate the safety and effectiveness of several vaccine batches.
- 163 There are numerous, promising ASF MLV vaccine candidates targeting the p72 genotype II pandemic strain under
164 development, including:
- 165 • A naturally attenuated field strain (Lv17/WB/Rei1) (Barasona *et al.*, 2019) being developed as an oral bait vaccine for
166 wild boars;
- 167 • A laboratory thermo-attenuated field strain (ASFV-989) (Bourry *et al.*, 2022);
- 168 • Single gene-deleted, recombinant viruses (e.g. SY18ΔI226R, ASFV-G-ΔA137R) (Gladue *et al.*, 2021; Zhang *et al.*,
169 2021);
- 170 • Double gene-deleted, recombinant viruses (e.g. ASFV-G-Δ9GL/ΔUK; ASFV-SY18-ΔCD2v/UK; Arm-ΔCD2v-ΔA238L)
171 (O'Donnell *et al.*, 2016; Pérez-Núñez *et al.*, 2022; Teklue *et al.*, 2020);
- 172 • Multiple gene-deleted, recombinant viruses (ASFV-G-ΔI177L/ΔLVR; ASFV-G-ΔMGF; BA71ΔCD2; HLJ/18-7GD;
173 ASFVGZΔI177LΔCD2vΔMGF) (Borca *et al.*, 2021; Chen *et al.*, 2020; Liu *et al.*, 2023; Monteagudo *et al.*, 2017;
174 O'Donnell *et al.*, 2015).
- 175 Information regarding many of these MLV vaccine candidates can be found in a recent review publication (Brake, 2022).
- 176 Different DIVA strategies using serological methods (e.g. ELISA) or genome detection methods (e.g. differential real-time
177 PCR) are not widely available for these ASF MLV first generation vaccine candidates. Therefore, there is still room for
178 improvement with respect to marker vaccines and their companion diagnostic tests.
- 179 Inactivated (non-replicating) whole virus vaccines are not presently available and may be difficult to develop to meet
180 minimum efficacy standards. Recombinant vectored, subunit vaccine candidates that can be produced in scalable vaccine
181 platform expression systems and mRNA-based ASF vaccines are being evaluated in ongoing laboratory research, testing
182 and evaluation in experimental challenge models. The publicly available *Center of Excellence for African Swine Fever*
-

183 Genomics (ASFV Genomics, 2022⁴³) that provides the structural protein predictions for all 193 ASFV proteins may help
184 accelerate ASF first and second generation vaccine research and development.

185 Fit-for-purpose vaccine use scenarios matched to the intended use in a domestic pig specific type of production system
186 may require different vaccine product profiles or may influence the focus of essential versus ideal vaccine requirements.
187 As with any MLV vaccine, all ASF MLV vaccines should be used according to the label instructions, under the strict control
188 of the country's Regulatory Authority.

189 The minimum standards given here and in chapter 1.1.8 are intended to be general in nature and may be supplemented
190 by national, regional, and veterinary international medicinal product harmonised requirements. Minimum data requirements
191 for an authorisation in exceptional circumstances should be considered where applicable.

192 **2. Outline of production and minimum requirements for vaccines**

193 **2.1. Characteristics of the seed**

194 **2.1.1. Biological characteristics of the master seed**

195 MLVs are produced from ASFV field strains derived from naturally attenuated field isolates or using
196 DNA homologous (genetically targeted) recombination techniques in cell cultures to delete one or
197 more ASFV genes or gene families. These molecular techniques typically involve replacement of the
198 targeted ASFV gene(s) with one or more positive, marker fluorescent (e.g. BFP, eGFP, mCherry) or
199 enzyme-based (e.g. β -glucuronidase) ASFV promoter-reporter gene systems that allow the use of
200 imaging microscopy or flow cytometry to visualise, select, and clone gene-deleted, recombinant, ASF
201 MLVs. MLV production is carried out in cell cultures based on a seed-lot system.

202 Master seed viruses (MSVs) for MLVs should be selected and produced based on their ease of
203 growth in cell culture, virus yield (\log_{10} infectious titre) and genetic stability over multiple cell
204 passages. Preferably, a continuous well-characterised cell line (e.g. ZMAC-4; PIPEC; IPKM) (Borca
205 *et al.*, 2021; Masujin *et al.*, 2021; Portugal *et al.*, 2020) is used to produce a master cell bank (MCB)
206 on which the MSV and MSV-derived working seed virus (WSV) can be produced. The exact source
207 of the underlying ASFV isolate, the whole genome sequence, and the passage history must be
208 recorded.

209 **2.1.2. Quality criteria (sterility, purity, freedom from extraneous agents)**

210 Only MSVs that have been established as sterile, pure (free of wild-type parental virus and free of
211 extraneous agents as described in Chapter 1.1.9 *Tests for sterility and freedom from contamination*
212 *of biological materials intended for veterinary use*, and those listed by the appropriate licensing
213 authorities) and immunogenic, should be used as the vaccine virus (WSV and vaccine batch
214 production). Live vaccines must be shown not to cause disease or other adverse effects in target
215 animals in accordance with chapter 1.1.8, Section 7.1 *Safety tests* (for live attenuated MSVs), that
216 includes target animal safety tests, increase in virulence tests, assessing the risk to the environment)
217 and if possible, no transmission to other animals.

218 Identity of the MSV must be confirmed using appropriate methods (e.g. through the use of vaccine
219 strain-specific whole genome detection methods such as next generation sequencing).

220 Demonstration of MSV stability over several cell passages is necessary, typically through at least five
221 passages (e.g. MSV+5). For those MLV vaccines for which attenuation is linked to specific
222 characteristics (gene deletion, gene mutations, etc.), genetic stability of attenuation throughout the
223 production process should be confirmed using suitable methods. Suitable techniques to demonstrate
224 genetic stability may include but are not limited to: genome sequencing, biochemical, proteomic,
225 genotypic (e.g. detection of genetic markers) and phenotypic strain characterisation. If final product
226 yields (infectious titres) are relatively low, genetic stability at a minimum of MSV+10 should be
227 demonstrated to allow more flexibility in the outline of production. For example, if MSV+8 is the
228 maximum passage for use in final product manufacturing, demonstration of genetic stability to at least
229 MSV+10 is warranted.

43 <http://asfvgenomics.com>. Accessed 4/4/2023.

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2.1.3. Validation as a vaccine strain

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232

The vaccine derived from the MSV must be shown to be satisfactory with respect to safety and efficacy.

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Even if pigs are not known for susceptibility to transmissible spongiform encephalopathy (TSE) agents, consideration should also be given to minimising the risk of TSE transmission by ensuring that animal origin materials from TSE-relevant species, if no alternatives exist for vaccine virus propagation, comply with the measures on minimising the risk of transmission of TSE.

237
238

Ideally, the vaccine virus in the final product should generally not differ by more than five passages from the master seed lot.

239

ASF vaccine should be presented in a suitable pharmaceutical form (e.g. lyophilisate or liquid form).

240

2.2. Method of manufacture

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2.2.1. Procedure

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The MLV virus is used to infect swine primary cell cultures obtained from specific-pathogen free pigs, the requirements for which are defined in specific monographs (Chapter 2.3.3 *Minimum requirements for the organisation and management of a vaccine manufacturing facility*, Section 2.4.2). Compared with primary cell cultures, use of a continuous cell line generally allows for more consistency, higher serial volumes in manufacturing and aligns better with a seed lot system. Thus, preferably a master cell bank based established, continuous cell line shown to support genetically stable ASFV replication and acceptable titres over several passages should be used.

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Cell cultures shall comply with the requirements for cell cultures for production of veterinary vaccines in chapter 1.1.8. Regardless of the production method, the substrate should be harvested under aseptic conditions and may be subjected to appropriate methods to release cell-associated virus (e.g. freeze-thaw cycles, detergent lysis). The harvest can be further processed by filtration and other purification methods. A stabiliser or other excipients may be added as appropriate. The vaccine is homogenised to ensure a uniform batch/serial.

255

2.2.2. Requirements for ingredients

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All ingredients used for vaccine production should be in line with requirements in chapter 1.1.8.

257

2.2.3. In-process controls

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In-process controls will depend on the protocol of production: they include virus titration of bulk antigen and sterility tests.

260

2.2.4. Final product batch tests

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i) Sterility

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Tests for sterility and freedom from contamination of biological materials intended for veterinary use may be found in chapter 1.1.9.

264

ii) Identity

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Appropriate methods such as specific genome detection methods (e.g. specific differential real-time PCR) should be used for confirmation of the identity of the vaccine virus.

267

iii) Purity

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269

Appropriate methods should be used to ensure that the final product batch does not contain any residual wild-type ASFV.

270

iv) Safety

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272
273

Batch safety testing is to be carried out unless consistent safety of the product is demonstrated and approved in the registration dossier and the production process is approved for consistency in accordance with the standard requirements referred to in chapter 1.1.8.

274 v) Batch/serial potency
275 Virus titration is a reliable indicator of vaccine potency once a relationship has been established
276 between the vaccine minimum immunising dose (MID) (minimum protective dose) and titre of the
277 modified live vaccine *in vitro*. In the absence of a demonstrated correlation between the virus titre
278 and protection, an efficacy test will be necessary (Section C.2.3.3 *Efficacy requirements*, below).

279 vi) Residual humidity/residual moisture
280 The test should be carried out consistent with VICH⁴⁴ GL26 (*Biologicals: Testing of Residual*
281 *Moisture*, 2003⁴⁵). Required for MLV vaccines presented as lyophilisates for suspension for injection.

282 **2.3. Requirements for authorisation/registration/licensing**

283 **2.3.1. Manufacturing process**

284 For regulatory approval of a vaccine, all relevant details concerning history of the pre-MSV,
285 preparation of MSV, manufacture of the vaccine and quality control testing (Sections C.2.1
286 *Characteristics of the seed* and C.2.2 *Method of manufacture*) should be submitted to the authorities.

287 Information shall be provided from three consecutive vaccine batches originating from the same MSV
288 and representative of routine production, with a volume not less than 1/10, and more preferably with
289 a volume not less than 1/3 of the typical industrial batch volume. The in-process controls are part of
290 the manufacturing process.

291 **2.3.2. Safety requirements**

292 For the purpose of gaining regulatory approval, the following safety tests should be performed
293 satisfactorily.

294 As a minimum standard, vaccines should be tested for any pathogenic effects on healthy domestic
295 pigs of the target age intended for use. Additional demonstration of MLV safety in breeding age gilts
296 and pregnant sows is preferred but not required as a minimum standard.

297 i) Safety in young animals

298 Carry out the test by each recommended route of administration using, in each case, piglets a
299 minimum of 6-weeks old and not older than 10-weeks old.

300 The test is conducted using no fewer than eight healthy piglets, and preferably no fewer than ten
301 healthy piglets.

302 Use vaccine virus at the least attenuated passage level that will be present in a batch of the vaccine.

303 Administer to each piglet a quantity of the vaccine virus equivalent to not less than ten times the
304 maximum virus titre (e.g. 50% haemadsorption dose [HAD₅₀], 50% tissue culture infective dose
305 [TCID₅₀], quantitative PCR, etc.) (maximum release dose) likely to be contained in one dose of the
306 vaccine. To obtain individual and group mean baseline temperatures, the body temperature of each
307 vaccinated piglet is measured on at least the 3 consecutive days preceding administration of the
308 vaccine.

309 To confirm the presence or absence of fever accompanied by acute and chronic disease, observe
310 the piglets 4 hours after vaccination and then at least once daily for at least 45 days, preferably 60
311 days post-vaccination. Carry out the daily observations for signs of acute and chronic disease using
312 a quantitative clinical scoring system adding the values for multiple clinical signs (e.g. Gallardo *et al.*,
313 2015a). These clinical signs should include fever, anorexia, recumbency, skin haemorrhage or
314 cyanosis, joint swelling and necrotic lesions around the joints, respiratory distress and digestive
315 findings).

316 At a minimum of 45 days post-vaccination, humanely euthanise all vaccinated piglets. Conduct gross
317 pathology on spleen, lung, tonsil, and kidney tissue samples and at least three different lymph nodes

⁴⁴ VICH: International Cooperation on Harmonisation of Technical Requirements for Registration of Veterinary Medical Products

⁴⁵ https://www.ema.europa.eu/en/documents/scientific-guideline/vich-gl26-biologicals-testing-residual-moisture-step-7_en.pdf

318 (which should include lymph node closest to site of inoculation, gastrohepatic and submandibular
319 nodes).

320 The vaccine complies with the test if:

321 • No piglet shows abnormal (local or systemic) reactions, reaches the pre-determined humane
322 endpoint defined in the clinical scoring system or dies from causes attributable to the vaccine;

323 • The average body temperature increase for all vaccinated piglets (group mean) for the
324 observation period does not exceed 1.5°C above baseline; and no individual piglet shows a
325 temperature rise above baseline greater than 2.5°C for a period exceeding 3 days.

326 • No vaccinated pigs show notable signs of disease by gross pathology

327 ii) Safety test in pregnant sows and test for transplacental transmission

328 There is currently an absence of published information on ASFV pathogenesis in breeding-age gilts
329 and in pregnant sows associated with ASFV transplacental infection and fetus abortion/stillbirth. If a
330 label claim is pursued for use in breeding age gilts and sows, then a safety study in line with VICH
331 GL44 (Guidelines on Target Animal Safety for Veterinary Live and Inactivated Vaccines, Section 2.2.
332 Reproductive Safety Test, 2009⁴⁶) should be completed.

333 iii) Horizontal transmission

334 The test is conducted using no fewer than 12 healthy piglets, a minimum of 6-weeks old and not older
335 than 10-weeks old and of the same origin, that do not have antibodies against ASFV, and blood
336 samples are negative on real-time PCR. All piglets are housed together from day 0 and the number
337 of vaccinated animals is the same as the number of naïve, contact animals. Co-mingle equal numbers
338 of vaccinated and naïve, contact piglets in the same pen or room.

339 Use vaccine virus at the least attenuated passage level that will be present between the master seed
340 lot and a batch of the vaccine. Administer by each recommended route of administration to no fewer
341 than six piglets a quantity of the vaccine virus equivalent to not less than the maximum virus titre
342 (maximum release dose) likely to be contained in 1 dose of the vaccine.

343 To obtain individual and group mean baseline temperatures, the body temperature of each naïve,
344 contact piglet is measured on at least the 3 consecutive days preceding co-mingling with vaccinated
345 piglets. The body temperature of each naïve, contact piglet is then measured daily for at least 45
346 days, preferably 60 days.

347 To confirm the presence or absence of fever accompanied by disease, observe the naïve, contact
348 piglets daily for at least 45 days, preferably 60 days. Carry out the daily observations for signs of
349 acute and chronic clinical disease using a quantitative clinical scoring system adding the values for
350 multiple clinical signs (e.g. Gallardo *et al.*, 2015a). These clinical signs should include fever, anorexia,
351 recumbency, skin haemorrhage or cyanosis, joint swelling and necrotic lesions around the joints,
352 respiratory distress and digestive findings.

353 In addition, blood should be taken from the naïve contact piglets at least twice a week for the first 21
354 days post-vaccination and then on a weekly basis. From the blood samples, determine infectious
355 virus titres by quantitative virus isolation (HAD₅₀/ml or TCID₅₀/ml) and using a real-time PCR test. If
356 the vaccine virus is non-haemadsorbing or does not cause cytopathic effects, a real-time PCR test
357 only may be used.

358 Collect blood (serum) samples from the naïve contact pigs at least at day 21 and day 28 days and
359 carry out an appropriate test to detect vaccine virus antibodies. At a minimum of 45 days, humanely
360 euthanise all naïve, contact piglets. Conduct gross pathology on spleen, lung, tonsil, and kidney
361 tissue samples and at least three different lymph nodes. Determine virus titres in all collected samples
362 by quantitative virus isolation (HAD₅₀/mg or TCID₅₀/mg) and real-time(RT)-PCR (see Section B.1.
363 Identification of the agent). If the vaccine virus is non-haemadsorbing or does not cause cytopathic
364 effects, a real-time PCR test or other appropriate method (e.g. titration using IPT or FAT detection)
365 may be used.

46 https://www.ema.europa.eu/en/documents/scientific-guideline/vich-gl44-target-animal-safety-veterinary-live-inactivated-vaccines-step-7_en.pdf.

366 The vaccine complies with the test if:

367 • No vaccinated or naïve contact piglet shows abnormal (local or systemic) reactions, reaches the
368 predetermined humane endpoint defined in the clinical scoring system or dies from causes
369 attributable to the vaccine;

370 • The average body temperature increase for all naïve, contact piglets (group mean) for the
371 observation period does not exceed 1.5°C above baseline; and no individual piglet shows a
372 temperature rise above baseline greater than 2.5°C for a period exceeding 3 days;

373 • No naïve, contact piglet shows notable signs of disease by gross pathology and no virus is
374 detected in their blood or tissue samples

375 • No naïve contact pigs test positive for antibodies to the vaccine virus.

376 iv) Post-vaccination kinetics of viral replication (MLV blood and tissue dissemination) study

377 Prior to the reversion to virulence study (Section C2.3.2.v. below), a minimum of one study should be
378 performed to determine the post-vaccination kinetics of virus replication in the blood (viremia), tissues
379 and viral shedding.

380 The test consists of the administration of the vaccine virus from the master seed lot to no fewer than
381 eight healthy piglets, and preferably ten healthy piglets, a minimum of 6-weeks old and not older than
382 10-weeks old and of the same origin, that do not have antibodies against ASFV, and blood samples
383 are negative on real-time PCR.

384 Administer to each piglet, using the recommended route of administration most likely to result in
385 spread (such as the intramuscular route or intranasal route), a quantity of the master seed vaccine
386 virus equivalent to not less than the maximum virus titre (maximum release dose) likely to be
387 contained in 1 dose of the vaccine.

388 Record daily body temperatures and observe inoculated animals daily for clinical disease for at least
389 45 days, preferably 60 days.

390 Carry out the daily observations for signs of acute and chronic clinical disease using a quantitative
391 clinical scoring system adding the values for multiple clinical signs (e.g. Gallardo *et al.* (2015a). These
392 clinical signs should include fever, anorexia, recumbency, skin haemorrhage or cyanosis, joint
393 swelling and necrotic lesions around the joints, respiratory distress and digestive findings.

394 Collect blood samples from all the piglets at least two times per week from 3 days post-vaccination
395 for the first 2 weeks, then weekly for the duration of the test. Determine vaccine virus titres by
396 quantitative virus isolation (HAD₅₀/ml or TCID₅₀/ml) and using a real-time PCR test. If the vaccine
397 virus is non-haemadsorbing or does not cause cytopathic effects, a real-time PCR test only may be
398 used.

399 Determine which blood timepoint(s) should be used in the design of the reversion to virulence study
400 (Section C2.3.2.v. below). Collect oral, nasal and faecal swab samples (preferably devoid of blood to
401 minimise assay interference) at least two times per week from 3-days post-vaccination for the first
402 2 weeks, then weekly for the duration of the test. Test the swabs for the presence of vaccine virus.
403 Determine virus titres in all collected samples by quantitative virus isolation (HAD₅₀/ml or TCID₅₀/ml)
404 and using a real-time PCR test. If the vaccine virus is non-haemadsorbing or does not cause
405 cytopathic effects, a real-time PCR test or other appropriate method (e.g. titration using IPT or FAT
406 detection) may be used.

407 Euthanise at least two piglets on days 7, 14, 21, and preferably on day 28 (±2 days at each timepoint)
408 and collect spleen, lung, tonsil, kidney tissue samples and at least three different lymph nodes (which
409 should include lymph node closest to site of inoculation, gastrohepatic and submandibular nodes).
410 Determine virus titres in all collected samples by quantitative virus isolation (HAD₅₀/mg or TCID₅₀/mg)
411 and using real-time PCR test. If the vaccine virus is non-haemadsorbing or does not cause cytopathic
412 effects, a real-time PCR test or other appropriate method (e.g. titration using IPT or FAT detection)
413 may be used.

414 Determine which tissue(s) and timepoint(s) should be used to aid in the design of the reversion to
415 virulence study (Section C.2.3.2.v) for example, specific tissues at specific timepoints which show
416 the highest titres should be considered for selection and use in the reversion to virulence study.

417 v) Reversion to virulence

418 The test should be carried out consistent with VICH GL41 (Examination of live veterinary vaccines in
419 target animals for absence of reversion to virulence, 2008⁴⁷).

420 The test for increase in virulence consists of the administration of the vaccine master seed virus to
421 healthy piglets of an age (e.g. between 6-weeks and 10-weeks old) suitable for recovery of the strain
422 and of the same origin, that do not have antibodies against ASFV, and blood samples that are
423 negative on real-time PCR. This protocol is typically repeated five times.

424 First pass (p1)

425 Administer to no fewer than two piglets, and preferably no fewer than four piglets using the intended
426 route of administration for the final product, a quantity of the master seed vaccine virus equivalent to
427 not less than the maximum virus titre (maximum release dose) likely to be contained in 1 dose of the
428 vaccine. Observe inoculated animals daily for the appearance of at least two and preferably at least
429 three clinical signs and record daily body temperatures.

430 Based on results from at least one completed vaccine shed and spread (virus blood and tissue
431 dissemination study, Section C.2.3.2.iv above) collect an appropriate quantity of blood from each
432 piglet on the predetermined single timepoint (day 5–13). Determine virus titres in individual blood
433 samples by quantitative virus isolation (HAD₅₀/ml or TCID₅₀/ml) and by real-time PCR. If the vaccine
434 virus is non-haemadsorbing or does not cause cytopathic effects, a real-time PCR test or other
435 appropriate method (e.g. titration using IPT or FAT detection) may be used. Identify the individual
436 blood sample(s) with the highest infectious titre and reserve for the subsequent *in-vivo* passage
437 (second pass, p2).

438 Based on results from at least one completed vaccine virus blood and tissue distribution
439 dissemination study, Section C.2.3.2.iv above) euthanise piglets on the predetermined timepoint (i.e.
440 day 7, 14, 21, or 28). Determine infectious virus titres in individual tissue samples by quantitative
441 virus isolation (HAD₅₀/ml or TCID₅₀/ml). If the vaccine virus is non-haemadsorbing or does not cause
442 cytopathic effects, a real-time PCR test or other appropriate method (e.g. titration using IPT or FAT
443 detection) may be used. Identify individual tissue sample(s) with the highest infectious titre. Pool the
444 tissues from different organs from all animals with the highest titres and prepare at least a 10%
445 suspension in PBS, pH 7.2 kept at 4°C or at –70°C for longer storage. Test each blood and tissue
446 pool used for inoculation by PCR to confirm the absence of potential viral agent contaminants (i.e.
447 CSEV, FMDV, PRRS, PCV2). Blood and pooled tissue (p1) are used to inoculate 2 ml of positive
448 material using the intended route of administration for the final product to each of least two and ideally
449 at least four further pigs of the same age and origin.

450 Second pass (p2)

451 If no virus is found (p1), repeat the administration by the intended route once again with the same
452 pooled material (blood and pooled tissue, p1) in another ten healthy piglets of the same age and
453 origin.

454 If no virus is found at this point, end the process here. If, however, virus is found, carry out a second
455 series of passages by administering 2 ml of positive material using the intended route of
456 administration for the final product to each of no fewer than two piglets, and preferably no fewer than
457 four piglets of the same age and origin. Observe inoculated animals daily for the appearance of at
458 least two and preferably at least three clinical signs and record daily body temperatures.

459 Third and fourth pass (p3 and p4)

460 If no virus (p2), repeat the intramuscular administration once again with the same pooled material
461 (blood and pooled tissue, p2) in another eight healthy piglets of the same age and origin.

462 If no virus is found at this point, end the process here. If, however, virus is found, carry out this
463 passage operation no fewer than two additional times (p3 and p4) (to each of no fewer than two
464 piglets, and preferably no fewer than four piglets of the same age and origin) and verifying the
465 presence of the virus at each passage in blood and tissues. Observe inoculated animals daily for the

47 https://www.ema.europa.eu/en/documents/scientific-guideline/vich-gl41-target-animal-safety-examination-live-veterinary-vaccines-target-animals-absence-reversion_en.pdf.

466 appearance of at least two and preferably at least three clinical signs and record daily body
467 temperatures.

468 *Fifth pass (p5)*

469 Administer 2 ml of the blood and pooled tissue (4) to each of at least eight healthy piglets of the same
470 age and origin. Observe inoculated animals daily for at least 28 days post-inoculation for the
471 appearance of at least two and preferably at least three clinical signs, and daily body temperature.

472 The vaccine virus complies with the test if:

- 473 • No piglet shows abnormal local or systemic reaction, reaches the pre-determined humane end
474 point defined in the clinical scoring system or dies from causes attributable to the vaccine; and
- 475 • There is no indication of increasing virulence (as monitored by daily body temperature
476 accompanied by clinical sign observations) of the maximally passaged virus compared with the
477 master seed virus.

478 At a minimum, a safe MLV vaccine shall demonstrate ALL the following features (minimal standards):

- 479 • Absence of fever (defined as average body temperature increase for all vaccinated piglets (group
480 mean) for the observation period does not exceed 1.5°C above baseline; and no individual piglet
481 shows a temperature rise above baseline greater than 2.5°C for a period exceeding 3 days);
- 482 • Absence of chronic and acute clinical signs and gross pathology over the entire test period or
483 minimal chronic clinical signs (defined as mild swollen joints with a low clinical score that resolve
484 within 1 week).
- 485 • Minimal (defined as no naïve, contact piglet shows notable signs of disease by clinical signs and
486 gross pathology and no or a low percentage of contact piglets test both real-time PCR positive
487 and seropositive) or no vaccine virus transmission (defined as no naïve, contact piglet shows
488 notable signs of disease by clinical signs and gross pathology and no contact piglets test both
489 real-time PCR positive and seropositive) over the entire test period;
- 490 • Absence of an increase in virulence (genetic and phenotypic stability) (complies with the reversion
491 to virulence test).

492 In addition, the vaccines in their commercial presentation before being authorised for general use
493 should be tested for safety in the field (see chapter 1.1.8 Section 7.2.3). Additional field safety
494 evaluation studies may include but are not limited to: environmental persistence (e.g. determination
495 of virus recovery from bedding or other surfaces), assessment of immunosuppression, and negative
496 impacts on performance.

497 **2.3.3. Efficacy requirements**

498 i) Protective dose

499 Vaccine efficacy is estimated in immunised animals directly, by evaluating their resistance to live
500 virus challenge. The test consists of a vaccination/challenge trial in piglets a minimum of 6-weeks old
501 and not more than 10-weeks old, free of antibodies to ASFV, and negative blood samples by real-
502 time PCR. The test is conducted using no fewer than 15 and preferably no fewer than 24 vaccinated
503 pigs, and no fewer than five non-vaccinated control piglets.

504 The test is conducted to determine the minimal immunising dose (MID) (also referred to as the
505 minimal protective dose [MPD] or protective fraction); using at least three groups of no fewer than
506 five and preferably not fewer than eight vaccinated piglets per group, and one additional group of no
507 fewer than five non-vaccinated piglets of the same age and origin as controls. Use vaccine containing
508 virus at the highest passage level that will be present in a batch of vaccine.

509 Each group of piglets, except the control group, is immunised with a different vaccine virus content
510 in the same vaccine volume. In at least one vaccinated group, piglets are immunised with a vaccine
511 dose containing not more than the minimum virus titre (minimum release dose) likely to be contained
512 in one dose of the vaccine as stated on the label.

513 Twenty-eight days (±2 days) after the single injection of vaccine (or if using two injections of the
514 vaccine then 28 days [±2 days] following the second injection), challenge all the piglets by the
515 intramuscular route. If previous studies have demonstrated acceptable efficacy using IM challenge,

516 then a different challenge route (e.g. direct contact, oral or oronasal) may be used. Challenged,
517 vaccinated piglets may be housed in one or more separate pens in the same room or in different
518 rooms. Challenged, naïve controls can be housed in one or more rooms that are separate from
519 challenged, vaccinated piglets.

520 Carry out the test using an ASFV representative strain of the epidemiologically relevant field strain(s)
521 where the vaccine is intended for use (e.g. ASFV B646L [p72] genotype II pandemic strain and other
522 p72 virulent genotype of recognised epidemiologic importance). For gene deleted, recombinant MLV
523 viruses, if neither challenge virus type is available, then carry out the test with the parental, virulent
524 virus used to generate the MLV recombinant virus. Use a 10e3–10e4 HAD₅₀ (or TCID₅₀ for non-HAD
525 viruses) challenge dose sufficient to cause death or meet the humane endpoint in 100% of the
526 nonvaccinated piglets in less than 21 days. Higher or lower challenge doses can be considered if
527 appropriately justified.

528 The rectal temperature of each vaccinated piglet is measured on at least the 3 days preceding
529 administration of the challenge virus, at the time of challenge, 4 hours after challenge, and then daily
530 for at least 28 days, preferably 35 days. Observe the piglets at least daily for at least 28 days,
531 preferably 35 days. Carry out the daily observations for signs of acute and chronic clinical disease
532 using a quantitative clinical scoring system adding the values for multiple clinical signs (e.g. Gallardo
533 *et al.*, 2015). These clinical signs should include fever, anorexia, recumbency, skin haemorrhage or
534 cyanosis, joint swelling and necrotic lesions around the joints, respiratory distress and digestive
535 findings.

536 Collect blood samples from the vaccinated challenged piglets at least two times per week from 3 days
537 post-challenge for at least 28, preferably 35 days. From the blood samples, determine infectious virus
538 titres by quantitative virus isolation (HAD₅₀/ml or TCID₅₀/ml) and using a real-time PCR test. If the
539 vaccine virus is non-haemadsorbing or does not cause cytopathic effects, a real-time PCR test only
540 may be used.

541 At the end of the test period, humanely euthanise all vaccinated challenged piglets. Conduct gross
542 pathology on spleen, lung, tonsil, and kidney tissue samples and at least three different lymph nodes,
543 (which should include lymph node closest to site of inoculation, gastrohepatic and submandibular
544 nodes). Determine virus titres in all collected samples by quantitative virus isolation (HAD₅₀/mg or
545 TCID₅₀/mg) and real-time PCR (see Section B.1. Identification of the agent). If the vaccine virus is
546 non-haemadsorbing or does not cause cytopathic effects, a real-time PCR test or other appropriate
547 method (e.g. titration using IPT or FAT detection) may be used.

548 The test is invalid if fewer than 100% of control piglets die or reach a humane endpoint.

549 The vaccine (or a specific vaccine virus dose if conducting a vaccine dose titration study) complies
550 with the test if:

- 551 • No vaccinated challenged piglet shows abnormal (local or systemic) reactions, reaches the
552 humane endpoint or dies from causes attributable to ASF;
- 553 • The average body temperature increase for all vaccinated challenged piglets (group mean) for
554 the observation period does not exceed 2.0°C above baseline; and no individual piglet shows a
555 temperature rise above baseline greater than 2.0°C;
- 556 • The vaccinated challenged piglets display a reduction or absence of typical acute clinical signs of
557 disease and gross pathology and a reduction or absence of challenge virus levels in blood and
558 tissues.

559 ii) Assessment for horizontal transmission (challenge virus shed and spread study)

560 The ASF basic reproduction number, R₀, can be defined as the average number of secondary ASF
561 disease cases caused by a single ASFV infectious pig during its entire infectious period in a fully
562 susceptible population (Hayes *et al.*, 2021). In general, if the ASFV effective reproduction number
563 Re=R₀ × (S/N) (S= susceptible pigs; N= total number of pigs in a given population) is greater than
564 1.0, disease is predicted to spread. Ideally, ASF vaccination should reduce Re to less than 1.0 by
565 reducing the number of susceptible, naïve, contact pigs exposed to vaccinated, infected pigs.

566 To evaluate ASF vaccine impact on ASF disease transmission, the test consists of a
567 vaccination/challenge trial in piglets a minimum of 6-weeks old and not older than 10-weeks old, free
568 of antibodies to ASFV, and negative blood samples by real-time PCR.

569 The test is conducted using no fewer than 15 healthy piglets at a ratio comprising twice the number
570 of vaccinated piglets to naïve piglets (e.g. ten vaccinated and five naïve). Use vaccine containing
571 virus at the highest passage level that will be present in a batch of the vaccine.

572 The quantity of vaccine virus administered to each pig is equivalent to be not more than the minimum
573 virus titre (minimum dose) likely to be contained in one dose of the vaccine as stated on the label.
574 Following immunisation, vaccinated and naïve piglets should continue to be co-mingled.

575 Twenty-eight days [±2 days] after the single injection of vaccine (or if using two injections of the
576 vaccine then 28 days [± 2 days] following the second injection), temporarily separate [into different
577 pen(s) or room(s)] all vaccinated piglets from naïve piglets. Challenge all vaccinated piglets by the
578 intramuscular or other previously verified route. Carry out the challenge using an ASFV
579 representative strain of the epidemiologically relevant field strain(s) where the vaccine is intended for
580 use (e.g. ASFV B646L [p72] genotype II pandemic strain and other p72 virulent genotype of
581 recognised epidemiological importance). For gene deleted, recombinant MLV viruses, if neither
582 challenge virus type is available, then carry out the test with the parental, virulent virus used to
583 generate the MLV recombinant virus. Use a 10e3–10e4 HAD₅₀ (or TCID₅₀ for non-HAD viruses
584 challenge dose sufficient to cause death or met the humane endpoint in 100% of the nonvaccinated
585 piglets in less than 21 days. Higher or lower challenge doses can be considered if appropriately
586 justified.

587 Approximately 18-24 hours later, re-introduce naïve piglets to vaccinated, challenged piglets and
588 allow for direct nose to nose contact exposure with vaccinated, challenged piglets. Allow for
589 continuous contact exposure by co-mingling both groups through the end of the study. If more than
590 one pen or room is used for co-housing, following reintroduction initially maintain a ratio of 2:1 of
591 challenged, vaccinated piglets to contact exposed, naïve piglets.

592 The rectal temperature of each contact piglet is measured on at least the 3 days preceding
593 administration of the challenge virus to vaccinated pigs, immediately prior to direct contact exposure,
594 4 hours post-contact exposure, and then daily for at least 28, preferably 35 days. Observe all contact
595 exposed piglets at least daily for at least 28 days, and preferably for at least 35 days.

596 Carry out the daily observations in each contact piglet for signs of acute and chronic clinical disease
597 using a quantitative clinical scoring system adding the values for multiple clinical signs (e.g. Gallardo
598 *et al.*, 2015a). These clinical signs should include fever, anorexia, recumbency, skin haemorrhage or
599 cyanosis, joint swelling and necrotic lesions around the joints, respiratory distress and digestive
600 findings.

601 In addition, blood should be taken from the naïve contact piglets at least twice a week from 3 days
602 post-contact exposure for the duration of the test period. From the blood samples, determine
603 infectious challenge virus titres by quantitative virus isolation (HAD₅₀/ml or TCID₅₀/ml) and using a
604 real-time PCR test. If the vaccine virus is non-haemadsorbing or does not cause cytopathic effects,
605 a real-time PCR test only may be used.

606 Collect blood (serum) samples from the naïve contact pigs at least at day 21 and day 28 (±2 days),
607 and at the end of the test period, and carry out an appropriate test to detect vaccine virus antibodies.

608 Collect oral, nasal and faecal swab samples (preferably devoid of blood to minimise assay
609 interference) from all contact-exposed naïve piglets at least two times per week from 3-days post-
610 contact exposure for the first 2 weeks, then weekly for the duration of the test and test swabs for the
611 presence of challenge virus. Determine virus titres in all collected samples by quantitative virus
612 isolation (HAD₅₀/ml or TCID₅₀/ml) and using a real-time PCR test. If the vaccine virus is non-
613 haemadsorbing or does not cause cytopathic effects, a real-time PCR test or other appropriate
614 method (e.g. titration using IPT or FAT detection) may be used.

615 At the end of the test period, humanely euthanise all contact piglets. Conduct gross pathology on
616 spleen, lung, tonsil, and kidney tissue samples and at least three different lymph nodes, (which should
617 include lymph node closest to site of inoculation, gastrohepatic and submandibular nodes).
618 Determine virus titres in all collected samples by quantitative virus isolation (HAD₅₀/mg or TCID₅₀/mg)
619 and real-time PCR (see Section B.1. Identification of the agent). If the vaccine virus is non-
620 haemadsorbing or does not cause cytopathic effects, a real-time PCR test or other appropriate
621 method (e.g. titration using IPT or FAT detection) may be used.

622 The test is invalid if the vaccine fails to comply with the compliance criteria described for the protected
623 dose test in vaccinated pigs (Section C.2.3.3.i above).

624 The vaccine complies with the test for a reduction in horizontal disease transmission if:

- 625 • No naïve, contact exposed piglet shows abnormal (local or systemic) reactions, reaches the
626 defined humane endpoint or dies from causes attributable to ASF;
- 627 • No naïve, contact exposed piglet displays fever accompanied by typical signs of disease,
628 including gross pathology.
- 629 • Naïve contact pigs show a reduction or absence of challenge virus levels in blood and tissues.
- 630 • None of or a reduced number of naïve contact exposed pigs test positive for antibodies to the
631 challenge virus.

632 At a minimum, an efficacious MLV vaccine shall demonstrate ALL the following features (minimal
633 standards):

- 634 • Protects against mortality;
- 635 • Reduces acute disease (fever accompanied by a reduction of typical clinical and pathological
636 signs of acute disease)
- 637 • Reduces horizontal disease transmission (no naïve, contact exposed piglet shows abnormal
638 [local or systemic] reactions, reaches the humane endpoint or dies from causes attributable to
639 ASF, and displays fever accompanied by typical acute disease signs caused by ASF)
- 640 • Reduces levels of viral shedding and viraemia.

641 In addition, the vaccines in their commercial presentation before being authorised for general use
642 should be tested for efficacy in the field (see chapter 1.1.8 Section 7.2.3). Additional field efficacy
643 evaluation studies may include but are not limited to: onset of immunity, duration of immunity, and
644 impact on disease transmission.

645 **2.3.4. Duration of immunity**

646 Although not included in the guidance for ASF MLV first generation vaccines, manufacturers are
647 encouraged as part of the authorisation procedure, to demonstrate the duration of immunity of a given
648 vaccine by evaluation of potency at the end of the claimed period of protection.

649 **2.3.5. Stability**

650 Stability of the vaccine should be demonstrated over the shelf life recommended for the product.
651 Although not included in the standards for first generation MLV ASF vaccines, manufacturers are
652 encouraged, as part of the authorisation procedure, to generate data supporting the period of validity
653 of a lyophilised or other pharmaceutical form of the ASF vaccine as part of the authorisation
654 procedure.

655 **REFERENCES**

656 ACHENBACH J.E., GALLARDO C., NIETO-PELEGRÍN E., RIVERA-ARROYO B., DEGEFA-NEGI T., ARIAS M., JENBERIE S., MULISA D.D.,
657 GIZAW D., GELAYE E., CHIBSSA T.R., BELAYE A., LOITSCH A., FORSA M., YAMI M., DIALLO A., SOLER A., LAMIEN C.E. & SÁNCHEZ-
658 VIZCAÍNO J.M. (2017). Identification of a New Genotype of African Swine Fever Virus in Domestic Pigs from Ethiopia.
659 *Transbound. Emerg. Dis.*, **64**, 1393–1404.

660 AGÜERO M., FERNÁNDEZ J., ROMERO L., SANCHEZ C., ARIAS M. & SÁNCHEZ-VIZCAÍNO J.M. (2003). Highly sensitive PCR assay
661 for the routine diagnosis of African swine fever virus in clinical samples, *J. Clin. Microbiol.*, **41**, 4431–4434.

662 AGÜERO M., FERNÁNDEZ J., ROMERO L., ZAMORA M.J., SANCHEZ C., BELÁK S., ARIAS M. & SÁNCHEZ-VIZCAÍNO J.M. (2004). A
663 highly sensitive and specific gel-based multiplex RT-PCR assay for the simultaneous and differential diagnosis of African
664 swine fever and Classical swine fever. *Vet. Res.*, **35**, 1–13.

665 ALEJO A., MATAMOROS T., GUERRA M. & ANDRÉS G. (2018). A Proteomic Atlas of the African Swine Fever Virus Particle. *J.*
666 *Viro.*, **92**, pii: e01293-18. doi: 10.1128/JVI.01293-18.

- 667 BARASONA J.A., GALLARDO C., CADENAS-FERNÁNDEZ E., JURADO C., RIVERA B., RODRÍGUEZ-BERTOS A., ARIAS M. & SÁNCHEZ-
668 VIZCAÍNO J.M. (2019). First oral vaccination of Eurasian wild boar against African swine fever virus genotype II. *Front. Vet.*
669 *Sci.*, **6**, 137. [https://doi: 10.3389/fvets.2019.00137](https://doi.org/10.3389/fvets.2019.00137).
- 670 BASTO A.P., PORTUGAL R.S., NIX R.J., CARTAXEIRO C., BOINAS F., DIXON L.K., LEITAO A. & MARTINS C. (2006). Development of
671 a nested PCR and its internal control for the detection of African swine fever virus (ASFV) in *Ornithodoros erraticus*. *Arch.*
672 *Viro.*, **151**, 819–826
- 673 BISHOP R.P., FLEISCHAUER C., DE VILLIERS E.P., OKOTH E.A., ARIAS M., GALLARDO C. & UPTON C. (2015). Comparative analysis
674 of the complete genome sequences of Kenyan African swine fever virus isolates within p72 genotypes IX and X. *Virus*
675 *Genes*, **50**, 303–309.
- 676 BORCA M.V., RAI A., RAMÍREZ-MEDINA E., SILVA E., VELÁZQUEZ-SALINAS L., VUONO E., PRUITT S., ESPINOZA N. & GLADUE D.P.
677 (2021). A Cell Culture-Adapted Vaccine Virus against the Current African Swine Fever Virus Pandemic Strain. *J. Virol.*, **95**,
678 e0012321. [https://doi: 10.1128/JVI.00123-21](https://doi.org/10.1128/JVI.00123-21).
- 679 BOSHOF C.I., BASTOS A.D., GERBER L.J. & VOSLOO W. (2007). Genetic characterisation of African swine fever viruses from
680 outbreaks in southern Africa (1973–1999). *Vet. Microbiol.*, **121**, 45–55.
- 681 BOURRY O., HUTET E., LE DIMNA M., LUCAS P., BLANCHARD Y., CHASTAGNER A., PABOEUF F. & LE POTIER M.F. (2022). Oronasal
682 or Intramuscular Immunization with a Thermo-Attenuated ASFV Strain Provides Full Clinical Protection against Georgia
683 2007/1 Challenge. *Viruses*, **14**, 2777. doi: 10.3390/v14122777
- 684 BRAKE D.A. (2022). African Swine Fever Modified Live Vaccine Candidates: Transitioning from Discovery to Product
685 Development through Harmonized Standards and Guidelines. *Viruses*, **14**, 2619. doi: 10.3390/v14122619
- 686 CADENAS-FERNÁNDEZ E., SÁNCHEZ-VIZCAÍNO J.M., KOSOWSKA A., RIVERA B., MAYORAL-ALEGRE F., RODRÍGUEZ-BERTOS A., YAO
687 J., BRAY J., LOKHANDWALA S., MWANGI W. & BARASONA J.A. (2020). Adenovirus-vectored African Swine Fever Virus Antigens
688 Cocktail Is Not Protective against Virulent Arm07 Isolate in Eurasian Wild Boar. *Pathogens*, **9**, 171. doi:
689 10.3390/pathogens9030171.
- 690 CHAPMAN D.A., DARBY A.C., DA SILVA M., UPTON C., RADFORD A.D. & DIXON L.K. (2011). Genomic analysis of highly virulent
691 Georgia 2007/1 isolate of African swine fever virus. *Emerg. Infect. Dis.*, **17**, 599–605.
- 692 CHEN W., ZHAO D., HE X., LIU R., WANG Z., ZHANG X., LI F., SHAN D., CHEN H., ZHANG J., WANG L., WEN Z., WANG X., GUAN Y.,
693 LIU J. & BU Z. (2020). A seven-gene-deleted African swine fever virus is safe and effective as a live attenuated vaccine in
694 pigs. *Sci. China Life Sci.*, **63**, 623. [https://doi: 10.1007/s11427-020-1657-9](https://doi.org/10.1007/s11427-020-1657-9).
- 695 COSTARD S., MUR L., LUBROTH J., SANCHEZ-VIZCAINO J.M. & PFEIFFER D.U. (2013). Epidemiology of African swine fever virus.
696 *Virus Res.*, **173**, 191–197.
- 697 DE LEÓN P., BUSTOS M.J. & CARRASCOSA A.L. (2013). Laboratory methods to study African swine fever virus. *Virus Res.*,
698 **173**, 168–179.
- 699 DE VILLIER E.P., GALLARDO C., ARIAS M., DA SILVA M., UPTON C., MARTIN R. & BISHOP R.P. (2010). Phylogenomic analysis of
700 11 complete African swine fever virus genome sequences. *Virology*, **400**, 128–136.
- 701 DIXON L.K., ESCRIBANO J.M., MARTINS C., ROCK D.L., SALAS M.L. & WILKINSON P.J. (2005). In: Virus Taxonomy, VIIIth Report
702 of the ICTV, Fauquet C.M., Mayo M.A., Maniloff J, Desselberger U. & Ball L.A., eds. Elsevier/Academic Press, London, UK,
703 135–143.
- 704 ESCRIBANO J.M., PASTOR M.J. & SANCHEZ VIZCAINO J.M. (1989). Antibodies to bovine serum albumin in swine sera:
705 implications for false positive reactions in the sero diagnosis of African swine fever. *Am. J. Vet. Res.*, **50**, 1118–1122.
- 706 FERNÁNDEZ-PACHECO P., NIETO R., SIMÓN A., GARCÍA CASTEY T.A., MARTÍN E., ARIAS M. & GALLARDO C. (2016). Comparative
707 evaluation of the performance of six ELISA tests for the detection of antibodies against African swine fever virus (ASFV).
708 EPIZONE 10th Annual Meeting, Madrid, Spain, 27–29 September 2016, p. [https://www.epizone-](https://www.epizone.eu.net/en/Home/Downloads.htm)
709 [eu.net/en/Home/Downloads.htm](https://www.epizone.eu.net/en/Home/Downloads.htm)
- 710 FERNÁNDEZ-PINERO J., GALLARDO C., ELIZALDE M., RASMUSSEN T.B., STAHL K., LOEFFEN W., BLOME S., BATTEN C., CROOKE H.,
711 LE POTIER M.F., UTTENTHAL Á., LEBLANC N., ALBINA E., KOWALCZYK A., MARKOWSKA-DANIEL I., TIGNON M., DE MIA G.M.,
712 GIAMMARIOLI M., ARIAS M. & HOFFMANN B. (2010). EPIZONE ring trial on ASFV real-time PCR. Annual Meeting of National
713 African swine fever Laboratories, 18 May 2010, Pulawy, Poland.

- 714 FERNÁNDEZ-PINERO J., GALLARDO C., ELIZALDE M., ROBLES A., GÓMEZ C., BISHOP R., HEATH L., COUACY-HYMMAN E., FASINA
715 F.O., PELAYO V., SOLER A & ARIAS M. (2013). Molecular diagnosis of African Swine Fever by a new real-time PCR using
716 universal probe library. *Transbound. Emerg. Dis.*, **60**, 48–58.
- 717 GALLARDO C., FERNÁNDEZ-PINERO J., PELAYO V., GAZAEV I., MARKOWSKA-DANIEL I., PRIDOTKAS G., NIETO R., FERNÁNDEZ-
718 PACHECO P., BOKHAN S., NEVOLKO O., DROZHYZHE Z., PÉREZ C., SOLER A., KOLVASOV D. & ARIAS M. (2014). Genetic variation
719 among African swine fever genotype II viruses, eastern and central Europe. *Emerg. Infect. Dis.*, **20**, 1544–1547.
- 720 GALLARDO C., MWAENGO D.M., MACHARIA J.M., ARIAS M., TARACHA E.A., SOLER A., OKOTH E., MARTÍN E., KASITI J. & BISHOP
721 RP. (2009). Enhanced discrimination of African swine fever virus isolates through nucleotide sequencing of the p54, p72,
722 and pB602L (CVR) genes. *Virus Genes*, **38** 85–95.
- 723 GALLARDO C., NIETO R., SOLER A., PELAYO V., FERNÁNDEZ-PINERO J., MARKOWSKA-DANIEL I., PRIDOTKAS G., NURMOJA I.,
724 GRANTA R., SIMÓN A., PÉREZ C., MARTÍN E., FERNÁNDEZ-PACHECO P. & ARIAS M. (2015b). Assessment of African swine fever
725 diagnostic techniques as a response to the epidemic outbreaks in Eastern European Union countries: How to improve
726 surveillance and control programs. *J. Clin. Microbiol.*, **53**, 2555–2565.
- 727 GALLARDO C., SOLER A., NIETO R., CARRASCOSA A.L., DE MIA G.M., BISHOP R.P., MARTINS C., FASINA F.O., COUACY-HYMMAN
728 E., HEATH L., PELAYO V., MARTIN E., SIMON A., MARTIN R., OKURUT A.R., LEKOLOL I., OKOTH E. & ARIAS M. (2013). Comparative
729 evaluation of novel African swine fever virus (ASF) antibody detection techniques derived from specific ASF viral genotypes
730 with the OIE internationally prescribed serological tests. *Vet. Microbiol.*, **162**, 32–43.
- 731 GALLARDO C., SOLER A., NIETO R., SÁNCHEZ M.A.S., MARTINS E., PELAYO V., CARRASCOSA A., REVILLA Y., SIMON A., BRIONES
732 V., SÁNCHEZ-VIZCAÍNO J.M. & ARIAS M. (2015a). Experimental Transmission of African Swine Fever (ASF) Low Virulent
733 Isolate NH/P68 by Surviving Pigs. *Transbound. Emerg. Dis.*, **62**, 612–622.
- 734 GLADUE D.P. & BORCA M.V. (2022). Recombinant ASF Live Attenuated Virus Strains as Experimental Vaccine Candidates.
735 *Viruses*, **14**, 878. <http://doi:10.3390/v14050878>.
- 736 GLADUE D.P., RAMIREZ-MEDINA E., VUONO E., SILVA E., RAI A., PRUITT S., ESPINOZA N., VELAZQUEZ-SALINAS L. & BORCA M.V.
737 (2021). Deletion of the A137R Gene from the Pandemic Strain of African Swine Fever Virus Attenuates the Strain and
738 Offers Protection against the Virulent Pandemic Virus. *J. Virol.*, **95** (21):e0113921. doi: 10.1128/JVI.01139-21. Epub 2021
739 Aug 18. PMID: 34406865; PMCID: PMC8513468.
- 740 HAINES F.J., HOFMANN M.A., KING D.P., DREW T.W. & CROOKE H.R. (2013). Development and validation of a multiplex, real-
741 time RT PCR assay for the simultaneous detection of classical and African swine fever viruses. *PLoS One*, **8** (7).
- 742 HAYES B.H., ANDRAUD M., SALAZAR L.G., ROSE N. & VERGNE T. (2021). Mechanistic modelling of African swine fever: A
743 systematic review. *Prev. Vet. Med.*, **191**, 105358. doi: 10.1016/j.prevetmed.2021.105358.
- 744 KING K., CHAPMAN D., ARGILAGUET J.M., FISHBOURNE E., HUTET E., CARIOLET R., HUTCHINGS G., OURA C.A., NETHERTON C.,
745 MOFFAT K., TAYLOR G., LE POTIER M.-F., DIXON L.K. & TAKAMATSU H.-H. (2011). Protection of European domestic pigs from
746 virulent African isolates of African swine fever virus by experimental immunisation. *Vaccine*, **29**, 4593–4600. [https://doi:](https://doi:10.1016/j.vaccine.2011.04.052)
747 10.1016/j.vaccine.2011.04.052
- 748 KING D.P., REID S.M., HUTCHINGS G.H., GRIERSON S.S., WILKINSON P.J., DIXON L.K., BASTOS A.D.S. & DREW T.W. (2003).
749 Development of a TaqMan® PCR assay with internal amplification control for the detection of African swine fever virus. *J.*
750 *Virol. Methods*, **107**, 53–61.
- 751 LIU Y., XIE Z., LI Y., SONG Y., DI D., LIU J., GONG L., CHEN Z., WU J., YE Z., LIU J., YU W., LV L., ZHONG Q., TIAN C., SONG Q.,
752 WANG H. & CHEN H. (2023). Evaluation of an I177L gene-based five-gene-deleted African swine fever virus as a live
753 attenuated vaccine in pigs. *Emerg. Microbes Infect.*, **12**, 2148560. doi: 10.1080/22221751.2022.2148560. PMID:
754 36378022; PMCID: PMC9769145.
- 755 LUBISI B.A., BASTOS A.D., DWARKA R.M. & VOSLOO W. (2005). Molecular epidemiology of African swine fever in East Africa.
756 *Arch Virol.*, **150**, 2439–2452.
- 757 MASUJIN K., KITAMURA K., KAMEYAMA K.I., OKADERA K., NISHI T., TAKENOUCI T., KITANI H. & KOKUHO T. (2021). An
758 immortalized porcine macrophage cell line competent for the isolation of African swine fever virus. *Sci. Rep.*, **11**, 4759.
759 doi.org/10.1038/s41598-021-84237-2.
- 760 MONTEAGUDO P.L., LACASTA A., LOPEZ L., BOSCH J., COLLADO J., PINA-PEDRERO S., CORREA-FIZ F., ACCENSI F., NAVAS M.J.,
761 VIDAL E., BUSTOS M.J., RODRIGUEZ J.M., GALLEI A., NIKOLIN V., SALAS M.L. & RODRIGUEZ F. (2017). BA71deltaCD2: A new

- 762 recombinant live attenuated African swine fever virus with cross-protective capabilities. *J. Virol.*, **91**, e1058–e1117.
763 [https://doi: 10.1128/JVI.01058-17](https://doi:10.1128/JVI.01058-17).
- 764 NCBI (NATIONAL CENTER FOR BIOTECHNOLOGY INFORMATION) (2020). <https://www.ncbi.nlm.nih.gov/nuccore/FR682468>.
765 Accessed 4/4/2023.
- 766 Nix R.J., GALLARDO C., HUTCHINGS G., BLANCO E. & DIXON L.K. (2006). Molecular epidemiology of African swine fever virus
767 studied by analysis of four variable genome regions. *Arch. Virol.*, **151**, 2475–244.
- 768 O'DONNELL V., HOLINKA L.G., GLADUE .DP., SANFORD B., KRUG P.W., LU X., ARZT J., REESE B., CARRILLO C., RISATTI G.R. &
769 BORCA M.V. (2015). African swine fever virus Georgia isolate harboring deletions of MGF360 and MGF505 genes is
770 attenuated in swine and confers protection against challenge with virulent parental virus. *J. Virol.*, **89**, 6048. [https://doi:](https://doi:10.1128/JVI.00554-15)
771 [10.1128/JVI.00554-15](https://doi:10.1128/JVI.00554-15).
- 772 O'DONNELL V., RISATTI G.R., HOLINKA L.G., KRUG P.W., CARLSON J., VELAZQUEZ-SALINAS L., AZZINARO P.A., GLADUE D.P. &
773 BORCA M.V. (2016). Simultaneous Deletion of the 9GL and UK Genes from the African Swine Fever Virus Georgia 2007
774 Isolate Offers In-creased Safety and Protection against Homologous Challenge. *J. Virol.*, **91**, e01760-16. [https://doi:](https://doi:10.1128/JVI.01760-16)
775 [10.1128/JVI.01760-16](https://doi:10.1128/JVI.01760-16).
- 776 PASTOR M.J., ARIAS M. & ESCRIBANO J.M. (1990). Comparison of two antigens for use in an enzyme-linked immunosorbent
777 assay to detect African swine fever antibody. *Am. J. Vet. Res.*, **51**, 1540–1543.
- 778 PASTOR M.J., LAVIADA M.D., SANCHEZ VIZCAINO J.M. & ESCRIBANO J.M. (1989). Detection of African swine fever virus
779 antibodies by immunoblotting assay. *Can. J. Vet. Res.*, **53**, 105–107.
- 780 PENRITH M.L., VAN HEERDEN J., HEATH L., ABWORO E.O. & BASTOS A.D.S. (2022). Review of the Pig-Adapted African Swine
781 Fever Viruses in and Outside Africa. *Pathogens*, **11**, 1190. doi: 10.3390/pathogens11101190.
- 782 PÉREZ-NÚÑEZ D., SUNWOO S.-Y., GARCÍA-BELMONTE R., KIM C., VIGARA-ASTILLERO G., RIERA E., KIM D.-M., JEONG J., TARK D.,
783 KO Y.-S., YOU Y.-K. & REVILLA Y. (2022). Recombinant African Swine Fever Virus Arm/07/CBM/c2 Lacking CD2v and A238L
784 Is Attenuated and Protects Pigs against Virulent Korean Paju Strain. *Vaccines*, **10**, 1992.
785 <https://doi.org/10.3390/vaccines10121992>.
- 786 PORTUGAL R., COELHO J., HÖPER D., LITTLE N.S., SMITHSON C., UPTON C., MARTINS C., LEITÃO A. & KEIL G.M. (2015). Related
787 strains of African swine fever virus with different virulence: genome comparison and analysis. *J. Gen. Virol.*, **96** (Pt 2), 408–
788 419.
- 789 PORTUGAL R., GOATLEY L.C., HUSMANN R., ZUCKERMANN F.A. & DIXON L.K. (2020). A porcine macrophage cell line that
790 supports high levels of replication of OURT88/3, an attenuated strain of African swine fever virus. *Emerg. Microbes Infect.*,
791 **9**, 1245–1253. doi.org/10.1080/22221751.2020.1772675.
- 792 QUEMBO C.J., JORI F., VOSLOO W. & HEATH L. (2018). Genetic characterization of African swine fever virus isolates from soft
793 ticks at the wildlife/domestic interface in Mozambique and identification of a novel genotype. *Transbound. Emerg. Dis.*, **65**,
794 420–431.
- 795 SÁNCHEZ-VIZCAÍNO J.M. (1987). African swine fever diagnosis. In: African Swine Fever, Becker Y., ed. Martinus Nijhoff,
796 Boston, USA, 63–71.
- 797 SÁNCHEZ-VIZCAÍNO J.M. & ARIAS M. (2012). African swine fever. In: Diseases of Swine, tenth Edition, Straw B., D'Allaire S.,
798 Mengeling W., Taylor D., eds. Iowa State University, USA, pp.396–404.
- 799 SÁNCHEZ-VIZCAÍNO J.M., MARTINEZ-LÓPEZ B., MARTINEZ-AVILÉS M., MARTINS C., BOINAS B., VIAL L., MICHAUD V., JORI F., ETTER
800 E., ALBINA E. & ROGER F. (2009). Scientific Review on African swine fever. CFP/EFSA/AHAW/2007/02, pp: 1–141.
- 801 SÁNCHEZ-VIZCAÍNO J.M., MUR L., GOMEZ-VILLAMANDOS J.C. & CARRASCO L. (2015). An update on the epidemiology and
802 pathology of African swine fever. *J. Comp. Pathol.*, **152**, 9–21.
- 803 TEKLUE T., WANG T., LUO Y., HU R., SUN Y. & QIU H.J. (2020). Generation and Evaluation of an African Swine Fever Virus
804 Mutant with Deletion of the CD2v and UK Genes. *Vaccines*, **8**, 763. <https://doi:10.3390/vaccines8040763>.

805 TIGNON M., GALLARDO C., ISCARO C., HUTET E., VAN DER STEDE Y., KOLBASOV D., DE MIA G.M., LE POTIER M.F., BISHOP R.P.,
806 ARIAS M. & KOENEN F. (2011). Development and inter-laboratory validation study of an improved new real-time PCR assay
807 with internal control for detection and laboratory diagnosis of African swine fever virus. *J. Virol. Methods*, **178**, 161–167.

808 WANG N., ZHAO D., WANG J., ZHANG Y., WANG M., GAO Y., LI F., WANG J., BU Z., RAO Z. & WANG X. (2019). Architecture of
809 African swine fever virus and implications for viral assembly. *Science*, **366**, 640–644. doi: 10.1126/science.aaz1439. Epub
810 2019 Oct 17

811 ZHANG Y., KE J., ZHANG J., YANG J., YUE H., ZHOU X., QI Y., ZHU R., MIAO F. & LI Q. (2021). African Swine Fever Virus Bearing
812 an I226R Gene Deletion Elicits Robust Immunity in Pigs to African Swine Fever. *J. Virol.*, **95**, e0119921. [https://doi:](https://doi:10.1128/JVI.01199-21)
813 [10.1128/JVI.01199-21](https://doi:10.1128/JVI.01199-21).

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816 **NB:** There are WOA Reference Laboratories for African swine fever
817 (please consult the WOA Web site:
818 <https://www.woah.org/en/what-we-offer/expertise-network/reference-laboratories/#ui-id-3>).
819 Please contact the WOA Reference Laboratories for any further information on
820 diagnostic tests and reagents for African swine fever

821 **NB:** FIRST ADOPTED IN 1990. MOST RECENT UPDATES ADOPTED IN 2021.

822

823 **Appendix 1 to Annex 16 of the Report of the Biological Standards Commission meeting**
824 **4–8 September 2023**

825 **Draft Standards for African Swine Fever (ASF) Modified Live Virus (MLV)**
826 **Vaccines for Domestic and Wild Pigs**
827



Annex16_3.09.01_ap
pendix1_GL_ASF_MLV

828

2 **MEETING OF THE BIOLOGICAL STANDARDS COMMISSION**

3 **Paris, 4–8 September 2023**

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5 **CHAPTER 3.10.4.**

6 **INFECTION WITH**
7 ***CAMPYLOBACTER JEJUNI* AND *C. COLI***

8 **SUMMARY**

9 **Description of the disease:** *Campylobacter jejuni* (*C. jejuni*) and *Campylobacter coli* (*C. coli*) can colonise
10 the intestinal tract of most mammals and birds and are the most frequently isolated *Campylobacter* species
11 in humans with gastroenteritis. Although poultry is the main reservoir of *Campylobacter*, transmission to
12 humans is only partly through handling and consumption of poultry meat; other transmission routes are also
13 considered to be important. This chapter focuses on *C. jejuni* and *C. coli* in primary livestock production with
14 regard to food safety.

15 *Campylobacter jejuni* and *C. coli* do not normally cause clinical disease in adult animals except for sporadic
16 cases of abortion in ruminants ~~and very rare cases of hepatitis in ostriches~~. The faecal contamination of
17 meat (especially poultry meat) during processing is considered to be an important source of human food-
18 borne disease. In humans, extraintestinal infections, including bacteraemia, can occur and some sequelae
19 of infection, such as polyneuropathies, though rare, can be serious.

20 **Identification of the agent:** In mammals and birds, detection of intestinal colonisation is based on the
21 isolation of the organism from faeces, rectal swabs or caecal contents, or the use of polymerase chain
22 reaction (PCR). *Campylobacter jejuni* and *C. coli* are thermophilic, Gram-negative, highly motile bacteria
23 that, for optimal growth, require microaerobic environment and incubation temperatures of 37–42°C. Agar
24 media containing selective antibiotics are required to isolate these bacteria from faecal/intestinal samples.
25 Alternatively, their high motility can be exploited using filtration techniques for isolation. Enrichment
26 techniques to detect intestinal colonisation are not routinely used. Preliminary confirmation of isolates can
27 be made by examining the morphology and motility using a light microscope. The organisms in the log growth
28 phase are short and S-shaped in appearance, while coccoid forms predominate in older cultures. Under
29 phase-contrast microscopy the organisms have a characteristic rapid corkscrew-like motility. Phenotypic
30 identification is based on reactions under different growth conditions. Biochemical and molecular tests,
31 including PCR and MALDI-TOF (matrix assisted laser desorption ionisation–time of flight) mass
32 spectrometry can be used to identify *Campylobacter* strains at species level. PCR assays can also be used
33 for the direct detection of *C. jejuni* and *C. coli*.

34 **Serological tests:** serological assays are not routinely in use for the detection of colonisation by *C. jejuni*
35 and *C. coli*.

36 **Requirements for vaccines:** There are no effective vaccines available for the prevention of enteric
37 *Campylobacter* infections in birds or mammals.

A. INTRODUCTION

1. Disease

Campylobacter jejuni and *C. coli* are generally considered commensals of livestock, domestic pet animals and birds. Large numbers of *Campylobacter* have been isolated from young livestock with enteritis, including piglets, lambs and calves, but the organisms are also found in healthy animals. One specific *C. jejuni* clone has been associated with abortion in sheep (Tang *et al.*, 2017). Outbreaks of avian hepatitis have been reported, but although *C. jejuni* is associated with the disease, it is not the causative agent (Jennings *et al.*, 2011). Recently, a new *Campylobacter* was isolated as the causative agent of spotty liver disease in layers (Crawshaw *et al.*, 2015). *Campylobacter jejuni* and *C. coli* are of interest mainly from the point of view food safety. *Campylobacter* is the main cause of human bacterial intestinal disease identified in many industrialised countries (Havelaar *et al.*, 2013; Scallan *et al.*, 2011; CDC, 2022; EFSA, 2021), and *C. jejuni* and *C. coli* together account for more than 90% of all human campylobacteriosis cases. Over 80% of cases are caused by *C. jejuni* and about 10% of cases are caused by *C. coli*. In humans, *C. jejuni/C. coli* infection is associated with acute enteritis and abdominal pain lasting for 7 days or more. Although such infections are generally self-limiting, complications can arise and may include bacteraemia, Guillain–Barré syndrome, reactive arthritis, and abortion (WHO, 2013). Attribution Studies have shown that the majority of campylobacteriosis cases in humans can be attributed to poultry and a smaller fraction to cattle (Mughini-Gras *et al.*, 2012) is the main reservoir of *Campylobacter* and responsible for between 50 and 80% of the human infections. In the European Union (EU), an estimated 30–40% of the human infections are associated with handling and consumption of poultry meat while up to 80% of the strains infecting humans have their origin in the poultry reservoir (EFSA, 2010). A considerable proportion of the poultry-derived strains has a non-poultry meat transmission route, e.g. via environmental contamination surface water (EFSA, 2010b; Mulder *et al.*, 2020). Contact with pets and livestock, the consumption of contaminated water or raw milk and travelling in high-prevalence areas are also considered risks factors in human disease (Domingues *et al.*, 2012; Mughini-Gras *et al.*, 2021). The control of *Campylobacter* in the food chain has now become a major target of agencies responsible for food safety world-wide.

Laboratory manipulations should be performed with appropriate biosafety and containment procedures as determined by biorisk analysis (see Chapter 1.1.4 *Biosafety and biosecurity: standard for managing biological risk in the veterinary diagnostic laboratory and animal facilities*).

2. Taxonomy

There are currently 34–43 *Campylobacter* species recognised (July 2023), but with the improved diagnostic techniques and genomic analysis, this number is expected to increase over time (cf-List of prokaryotic names with standing in nomenclature: (<https://lpsn.dsmz.de/genus/campylobacter> - <http://www.bacterio.net/index.html>). Members of the genus *Campylobacter* are typically Gram-negative, non-spore-forming, S-shaped or spiral shaped bacteria (0.2–0.8–0.5 µm wide and 0.5–5–8 µm long), with single polar flagella at one or both ends, conferring a characteristic corkscrew-like motility. These bacteria *Campylobacter* requires microaerobic conditions, but some strains also grow aerobically or anaerobically. They neither ferment nor oxidise carbohydrates. Some species, particularly *C. jejuni*, *C. coli* and *C. lari*, are thermophilic, growing optimally at 42°C. They can colonise mucosal surfaces, usually the intestinal tract, of most mammalian and avian species tested. The species *C. jejuni* includes two subspecies (*C. jejuni* subsp. *jejuni* and *C. jejuni* subsp. *doylei*) that can be discriminated on the basis of several phenotypic tests, but this subspeciation has no added value for epidemiological or intervention purposes (nitrate reduction, selenite reduction, sodium fluoride, and safranin) and growth at 42°C (subsp. *doylei* does not grow at 42°C) (Garrity, 2005). Subspecies *jejuni* is much more frequently isolated than subspecies *doylei*.

B. DIAGNOSTIC TECHNIQUES

Table 1. Test methods available for the diagnosis of *Campylobacter jejuni* and *C. coli* and their purpose

Method	Purpose ^(a)					
	Population freedom from infection	Individual animal freedom from infection prior to movement	Contribute to eradication policies	Confirmation of clinical cases	Prevalence of infection – surveillance	Immune status in individual animals or populations post-vaccination
Agent identification^(b)						
Isolation	+++	–	≡ +++	+++	+++	–
MALDI-TOF	+++	–	+++	+++	+++	–

Method	Purpose ^(a)					
	Population freedom from infection	Individual animal freedom from infection prior to movement	Contribute to eradication policies	Confirmation of clinical cases	Prevalence of infection – surveillance	Immune status in individual animals or populations post-vaccination
Antigen detection	++	–	≡ **	–	+++ _≡	–
16S rRNA sequencing	**	–	**	**	**	–
Real-time PCR	+++ _≡	–	≡ **	++	+++ _≡	–
Detection of immune response: n/a for <i>Campylobacter jejuni</i> and <i>C. coli</i>						

Key: +++ = recommended for this purpose; ++ recommended but has limitations; + = suitable in very limited circumstances; – = not appropriate for this purpose.

MALDI-TOF = matrix assisted laser desorption ionisation–time of flight; PCR = polymerase chain reaction.

^(a)Regarding the control of the agent: *Campylobacter jejuni* and *C. coli* are endemic globally and very rarely cause disease. These species are of interest from the point of view of food safety. There is no eradication programme. For broiler flocks there are worldwide efforts to try to prevent colonisation with *C. jejuni* and *C. coli* to prevent contamination of the carcasses during slaughter. Therefore, only the columns 'population freedom' (= broiler flock) and prevalence of infection surveillance are filled in where "infection" should be read as "colonisation".

^(b)A combination of agent identification methods applied on the same clinical sample is recommended.

1. Isolation and identification of the agent

Two ISO (International Organization for Standardization) procedures for detection of *Campylobacter* exist. ISO 10272 describes a horizontal method for detection and enumeration of thermotolerant *Campylobacter* spp. (ISO 10272) in food and animal feeding stuffs with 2 parts: (part 1 detection method (ISO 10272-1:2017) and part 2 colony count technique (ISO 10272-2:2017)). Both parts of the ISO are under revision and will be published in 2017. The revised standard will include methods for the isolation of *Campylobacter* from live animals, and a procedure for ISO 17995 concerns water quality, with detection and enumeration of thermotolerant *Campylobacter* spp. from water (ISO, 2005 – last reviewed in 2014).

1.1. Collection of specimens

1.1.1. Poultry at the farm

Poultry is frequently colonised with *C. jejuni* (65–95%), less often with *C. coli* and rarely with other *Campylobacter* species (Newell & Wagenaar, 2000; Wagenaar et al., 2023). Colonisation rates in broiler chickens are age-related. Most flocks are negative until 2 weeks of age. Once *Campylobacter* colonisation occurs in a broiler flock, transmission, via exposure to faecal contamination, is extremely rapid and up to 100% of birds within a flock can become colonised within a few days. Samples from live birds, destined for the food chain, should therefore be taken as close to slaughter as possible (Newell & Wagenaar, 2000; Wagenaar et al., 2023). The majority of birds shed large numbers of organisms (>10⁶ colony-forming units/g faeces). *Campylobacter* can be isolated from fresh faeces/caecal droppings or cloacal swabs. For reliable detection of *Campylobacter* by culture, freshly voided faeces (preferably without traces of urine) should be collected. **Such samples must be prevented from drying out before culturing.** When swabs are used, a transport medium such as Cary Blair, Amies, or Stuart must be used. Sampling strategy in primary poultry has been reviewed (Vidal et al., 2013) and is normally based on boot-swab samples, faecal/caecal droppings or cloacal swabs.

1.1.2. Cattle, sheep and pigs at the farm

*Campylobacter*s are frequent colonisers of the intestine of livestock such as cattle, sheep and pigs; data have been reviewed by Newell et al., (in press 2017). Cattle and sheep are found to be colonised mainly with *C. jejuni*, *C. coli*, *C. hyointestinalis*, and *C. fetus*, whereas pigs are predominantly colonised by *C. coli*. In young animals, the numbers are higher than in older animals. In older animals, the organisms can be intermittently detected in faeces, probably due to low numbers or due to

118 intermittent shedding. Fresh samples have to be taken (rectal samples if possible) and **they should**
119 **be prevented from drying out**. When swabs are used, a transport medium (like Cary Blair, Amies,
120 or Stuart) must be used.

1.1.3. At slaughter

122 In poultry, the caecal contents are usually used for the detection of *Campylobacter*. ~~They~~ Caeca can
123 be cut with sterile scissors from the remaining part of the intestines and submitted intact to the
124 laboratory in a suitable container.

125 Samples from cattle, sheep and pigs are collected from the intestines by aseptically opening the gut
126 wall or by taking guarded rectal swabs.

127 At all stages from collecting the samples until they are processed in the laboratory, utmost attention
128 should be given to make sure that campylobacters do not die. Follow the instructions for
129 transportation and shipment carefully.

1.2. Transportation and treatment of specimens

1.2.1. Transport

132 *Campylobacters* are sensitive to environmental conditions, including dehydration, atmospheric
133 oxygen, sunlight and elevated temperature. Transport to the laboratory and subsequent processing
134 should therefore be as rapid as possible preferably the same day, ~~but~~ It is recommended to process
135 the samples within 72 hours, but if not possible, storage of samples is accepted up to 96 hours (Tast-
136 Lahti et al., 2022) within at least 3 days. The samples must be protected from light, extreme
137 temperatures and desiccation.

138 No recommendation on the ideal temperature for transportation can be made, but it is clear that
139 freezing or high temperatures can reduce viability. If possible, samples should be maintained at a
140 temperature of 4°C (±2°C). High temperatures (>20°C), low temperatures (<0°C) and fluctuations in
141 temperature must be avoided. When the time between sampling and processing is longer than 48
142 hours, storage at 4°C (±2°C) is advised.

1.2.2. Transport media

144 *Swabs*: When samples are collected on boot-swabs or rectal swabs, the use of commercially
145 available transport tubes, containing a medium, such as Cary Blair or Amies, is recommended. This
146 medium may be plain agar or charcoal-based. The function of the medium is not for growth of
147 *Campylobacter* spp., but to protect the swab contents from drying and the toxic effects of oxygen.

148 When only small amounts of faecal/caecal samples can be collected and transport tubes are not
149 available, shipment of the specimen in transport medium is recommended. Several transport media
150 have been described: Amies, Cary-Blair, modified Cary-Blair, modified Stuart medium, Campy-
151 thioglycolate medium, alkaline peptone water and semisolid motility test medium. ~~Good recovery~~
152 ~~results have been reported using Cary Blair (Luechtefeld et al., 1981; Sjogren et al., 1987).~~

1.2.3. Maintenance of samples

154 On arrival at the laboratory, samples should be processed as soon as possible, preferably on the day
155 of arrival. It is recommended to process the samples within 72 hours, but if not possible, storage of
156 samples is accepted up to 96 hours, whereby *C. coli* is more sensitive for long storage times than *C.*
157 *jejuni* but no longer than 3 days after collecting the samples (Tast-Lahti et al., 2022). To avoid
158 temperature variation, samples should only be refrigerated when they cannot be processed on the
159 same day, otherwise they should be kept at room temperature when processed the same day. When
160 samples are submitted or kept in the laboratory at 4°C, they should be allowed to equilibrate to room
161 temperature before processing to avoid temperature shock.

1.3. Isolation of *Campylobacter*

163 For the isolation of *Campylobacter* from faecal/caecal or intestinal samples, no pre-treatment is needed;
164 samples can be plated on selective medium or the filtration method on non-selective agar can be used. In the
165 case of caecal samples, caeca are aseptically opened by cutting the end with a sterile scissors and squeezing
166 out the material to be processed. ~~Enrichment is recommended~~ can be considered to enhance the culture
167 sensitivity of ~~potentially environmentally stressed organisms or in the case of~~ low levels of organisms in faeces

168 (ISO, 2017), for example from cattle, sheep or pigs. However, enrichment of faecal samples is usually subject
169 to overgrowth by competing bacteria and is not carried out routinely. There is no need to use enrichment
170 media to isolate *Campylobacter* from poultry caeca.

171 1.3.1. Selective media for isolation

172 Many media can be used in the recovery of *Campylobacter* spp. The selective medium modified
173 charcoal, cefoperazone, desoxycholate agar (mCCDA), is the most commonly recommended
174 medium and is prescribed in the ISO standard, although alternative media may be used (ISO, 2017).
175 A detailed description on *Campylobacter* detection by culture and the variety of existing media is
176 given by Corry *et al.* (1995; 2003). The selective media can be divided into two main groups: blood-
177 based media and charcoal-based media. Blood components and charcoal serve to remove toxic
178 oxygen derivatives. Most media are commercially available. The selectivity of the media is
179 determined by the antibiotics used. Cephalosporins (generally cefoperazone) are used, sometimes in
180 combination with other antibiotics (e.g. vancomycin, trimethoprim). ~~Cycloheximide (actidione) and~~
181 ~~more recently Amphotericin B or cycloheximide~~ are used to inhibit yeasts and molds (Martin *et al.*,
182 2002). The main difference between the media is the degree of inhibition of contaminating flora. All
183 the selective agents allow the growth of both *C. jejuni* and *C. coli*. There is no medium available that
184 allows growth of *C. jejuni* and inhibits *C. coli* or vice versa. To some extent, other *Campylobacter*
185 species (e.g. *C. lari*, *C. upsaliensis*, *C. helveticus*, *C. fetus* and *C. hyointestinalis*) will grow on most
186 media, especially at the less selective temperature of 37°C.

187 Examples of selective blood-containing solid media:

- 188 i) Preston agar
- 189 ii) Skirrow agar
- 190 iii) Butzler agar
- 191 iv) Campy-cefex

192 Examples of charcoal-based solid media:

- 193 i) mCCDA (modified charcoal cefoperazone deoxycholate agar), slightly modified version of the
194 originally described CCDA (Bolton *et al.*, 1984; 1988)
- 195 ii) Karmali agar or CSM (charcoal-selective medium) (Karmali *et al.*, 1986)
- 196 iii) CAT agar (cefoperazone, amphotericin and teicoplanin), facilitating growth of *C. upsaliensis*
197 (Aspinall *et al.*, 1993).

198 1.3.2 Enrichment

199 The ISO standard describes the isolation of *Campylobacter* from samples with low numbers of
200 *Campylobacter* and high numbers of background flora by using Preston enrichment medium (ISO,
201 2017). This can be considered for samples from pigs, cattle and sheep. Samples are added to
202 Preston broth with a 1 in 10 dilution (e.g. 10 g faecal sample with 90 ml broth) and incubated under
203 microaerobic conditions for 24 hours at 41.5°C.

204 After enrichment, campylobacters can be isolated on selective media as described before with plating
205 one loop (10 µl) to solid media.

206 1.3.3. Passive filtration

207 Passive filtration, a method developed by Steele & McDermott (1984) obviates the need for selective
208 media; thus it is very useful for the isolation of antimicrobial-sensitive *Campylobacter* species. As the
209 method does not use expensive selective media, it may be used in laboratories with fewer resources.
210 For passive filtration, faeces are mixed with PBS (approximately 1/10 dilution) to produce a
211 suspension. Approximately ~~10–15 drops~~ 100 µl of this suspension are then carefully layered on to a
212 0.45-~~or~~ 0.65 µm sterile cellulose acetate filter, which has been previously placed on top of a non-
213 selective blood agar plate. Care must be taken not to allow the inoculum to spill over the edge of the
214 filter. The bacteria are allowed to migrate through the filter for 30–45 minutes at 37°C ~~or room~~
215 ~~temperature~~ (microaerobic conditions are not required) and the filter is then removed. The plate is
216 incubated microaerobically at 37°C or 42°C.

-
- 217 **1.3.4. Incubation**
- 218 i) Atmosphere
- 219 Microaerobic atmospheres of 5–10% oxygen, 5–10% carbon dioxide are required for optimal growth
220 (Corry *et al.*, 2003; Vandamme, 2000). Appropriate atmospheric conditions may be produced by a
221 variety of methods. In some laboratories, (repeated) gas jar evacuations followed by atmosphere
222 replacement with bottled gasses are used. Gas generator kits are available from commercial sources.
223 Variable atmosphere incubators are more suitable if large numbers of cultures are undertaken.
- 224 ii) Temperature
- 225 Media may be incubated at 37°C or 42°C, but it is common practice to incubate at 42°C to minimise
226 growth of contaminants and to select for optimal growth of *C. jejuni* and *C. coli*. The fungistatic agents
227 cycloheximide or amphotericin B or cycloheximide are added in order to prevent growth of yeasts
228 and mould at 37°C (Bolton *et al.*, 1988). In some laboratories, incubation takes place at 41.5°C to
229 harmonise with *Salmonella* and *Escherichia coli* O157 isolation protocols (ISO, 2006).
- 230 iii) Time
- 231 *Campylobacter jejuni* and *C. coli* usually show growth on solid media within 24–48 hours at 37–42°C.
232 As the additional number of positive samples obtained by prolonged incubation is very low, 48 hours
233 of incubation is recommended for routine diagnosis (Bolton *et al.*, 1988).

234 **1.4. Confirmation**

235 A pure culture is required for confirmatory tests, but a preliminary confirmation can be obtained by direct microscopic
236 examination of suspect colony material.

237 **1.4.1. Identification on solid medium**

238 On Skirrow or other blood-containing agars, characteristic *Campylobacter* colonies are slightly pink,
239 round, convex, smooth and shiny, with a regular edge. On charcoal-based media such as mCCDA,
240 the characteristic colonies are greyish, flat and moistened, with a tendency to spread, and may have
241 a metal sheen.

242 **1.4.2. Microscopic examination of morphology and motility**

243 Material from a suspect colony is suspended in saline and evaluated, preferably by a phase-contrast
244 microscope, for characteristic, spiral or curved slender rods with a corkscrew-like motility. Older
245 cultures show less motile coccoid forms.

246 **1.4.3. Detection of oxidase**

247 Take material from a suspect colony and place it on to a filter paper moistened with oxidase reagent.
248 The appearance of a violet or deep blue colour within 10 seconds is a positive reaction. If a
249 commercially available oxidase test kit is used, follow the manufacturer's instructions.

250 **1.4.4. Aerobic growth at 25°C**

251 Inoculate the pure culture on to a non-selective blood agar plate and incubate at 25°C in an aerobic
252 atmosphere for 48 hours.

253 **1.4.5. Latex agglutination tests**

254 *Latex agglutination tests* for confirmation of pure cultures of *C. jejuni* and *C. coli* (often also including
255 *C. lari*) are commercially available.

256 **1.5. Biochemical identification of *Campylobacter* to the species level**

257 Among the *Campylobacter* spp. growing at 42°C, the most frequently encountered species from samples of animal
258 origin are *C. jejuni* and *C. coli*. However, low frequencies of other species, including *Helicobacter* species, have been
259 described. Generally, *C. jejuni* can be differentiated from other *Campylobacter* species on the basis of the hydrolysis
260 of hippurate as this is the only hippurate-positive species isolated from veterinary or food samples. The presence of
261 hippurate-negative *C. jejuni* strains has been reported (Steinhauserova *et al.*, 2001). Table 2 gives some basic
262 classical phenotypic characteristics of the most important thermophilic *Campylobacter* species (ISO, 2006–2017).

263 More extensive speciation schemes have been described in the literature (On, 1996; Vandamme, 2000). Speciation
264 results should be confirmed using defined positive and negative controls.

265 Biochemical speciation may be supplemented or replaced with MALDI-TOF mass spectrometry. MALDI-TOF can be
266 used to identify *Campylobacter* isolates rapidly and efficiently at the genus and species level (Bessede et al., 2011).

267 **Table 2. Basic phenotypic characteristics of selected thermophilic *Campylobacter* species**

Characteristics	<i>C. jejuni</i>	<i>C. coli</i>	<i>C. lari</i>
Hydrolysis of hippurate	+	–	–
Hydrolysis of indoxyl acetate	+	+	–

Key: + = positive; – = negative; *not all strains.

268 The confirmatory tests for the presence of thermophilic campylobacters and the interpretation (ISO, 2006–2017) are
269 given in Table 3. Confirm results of confirmation tests using positive and negative controls.

270 **Table 3. Confirmatory tests for thermophilic *Campylobacter***

Confirmatory test	Result for thermophilic <i>Campylobacter</i>
Morphology	Small curved bacilli
Motility	Characteristic (highly motile and cork-screw like)
Oxidase	+
Aerobic growth at 25°C	–

271 1.5.1. Detection of hippurate hydrolysis

272 Suspend a loopful of growth from a suspect colony in 400 µl of a 1% sodium hippurate solution (care
273 should be taken not to incorporate agar). Incubate aerobically at 37°C for 2 hours, then slowly add
274 200 µl 3.5% ninhydrin solution to the side of the tube to form an overlay. Re-incubate at 37°C for 40
275 15–30 minutes, and read the reaction. Positive reaction: dark purple/blue. Negative reaction: clear or
276 grey. If commercially available hippurate hydrolysis test disks are used, follow the manufacturer's
277 instructions. The hippurate hydrolysis test is not very robust and the test is often replaced by
278 molecular tests (see below).

279 1.5.2. Detection of indoxyl acetate hydrolysis

280 Place a suspect colony on an indoxyl acetate disk and add a drop of sterile distilled water. If indoxyl
281 acetate is hydrolysed a colour change to dark blue occurs within 5–10 minutes. No colour change
282 indicates hydrolysis has not taken place. If commercially available indoxyl acetate hydrolysis test
283 disks are used, follow the manufacturer's instructions.

284 ~~Biochemical speciation may be supplemented or replaced with molecular methods or MALDI-TOF mass~~
285 ~~spectrometry. MALDI-TOF can be used to identify *Campylobacter* isolates rapidly and efficiently at the genus and~~
286 ~~species level (Bessede et al., 2011). A variety of DNA probes and polymerase chain reaction (PCR) based~~
287 ~~identification assays has been described for the identification of *Campylobacter* species (On, 1996; Vandamme,~~
288 ~~2000). On & Jordan (2003) evaluated the specificity of 11 PCR-based assays for *C. jejuni* and *C. coli* identification.~~
289 ~~A fast method to differentiate *C. jejuni* and *C. coli* strains is a duplex real time PCR, targeting gene *mapA* for *C. jejuni*~~
290 ~~identification and gene *CouE* for *C. coli* identification (Best et al., 2003). Another real-time PCR method commonly~~
291 ~~used to identify and differentiate between *C. jejuni*, *coli* and *lari* is described by Mayr et al. (2010). A gel based method~~
292 ~~that is commonly used differentiates between *C. jejuni*, *C. coli*, *C. lari* and *C. upsaliensis* (Wang et al., 2002).~~
293 ~~*Campylobacter* isolates can also be molecular identified at species level with 16S rRNA sequencing (Gorkiewicz et~~
294 ~~al., 2003).~~

295 **1.6. Molecular detection and identification of Campylobacter**

296 Multiple PCR-based methods for the detection of Campylobacter in animal faecal samples and enriched meat
297 samples have been extensively described in the literature (Bang et al., 2001; Lund et al., 2003; Olsen et al., 1995).
298 Lund et al. describe a real-time PCR method to detect Campylobacter spp. in chicken faecal samples using magnetic
299 bead DNA isolation followed by a real-time PCR targeting the 16S rRNA gene (Lund et al., 2003; 2004). For food
300 samples, a combined method is described of Bolton broth enrichment and multiplex real-time PCR targeting gene
301 mapA for C. jejuni, gene ceuE for C. coli and a ATP-binding protein for both C. jejuni and C. coli (Lanzl et al., 2022).
302 Many molecular tests are available to identify Campylobacter species, but there is not a specific recommended one.
303 Campylobacter isolates can be identified at species level with 16S rRNA sequencing (Gorkiewicz et al., 2003).
304 Inclusion of positive and negative reference strains and process controls to detect inhibition of the PCR reaction by
305 the sample matrix are required for all molecular Campylobacter detection methods.

306 A variety of DNA probes and PCR-based identification assays has been described for the identification of
307 Campylobacter species (Ferrari et al., 2023; Jribi et al., 2017). On & Jordan (2003) evaluated the specificity of
308 11 PCR-based assays for C. jejuni and C. coli identification. A fast method to differentiate C. jejuni and C. coli strains
309 is a duplex real-time PCR, targeting gene mapA for C. jejuni identification and gene ceuE for C. coli identification
310 (Best et al., 2003). Another real-time PCR method commonly used to identify and differentiate between C. jejuni, C.
311 coli and C. lari is described by Mayr et al. (2010). Campylobacter isolates can also be identified at species level with
312 16S rRNA sequencing (Gorkiewicz et al., 2003).

313 **1.7. Antigen-capture-based tests**

314 Enzyme immunoassays are available for the detection of Campylobacter in human and animal stool samples (Ricke
315 et al., 2019). Some are of the lateral flow format. While antigen tests are convenient to use, in an evaluation study
316 where human stool samples were tested with four commercial Campylobacter antigen tests, it was shown that no
317 stool antigen test offered the necessary combination of high sensitivity, high specificity, and moderate to high positive
318 predictive value needed in a standalone diagnostic test (Fitzgerald et al., 2016). By using antigen-capture-based
319 tests, the sensitivity and specificity should be critically evaluated through an in-house validation.

320 **2. Serological tests**

321 There are no serological assays in routine use for the detection of colonisation of *C. jejuni* or *C. coli* in livestock.

322 **C. REQUIREMENTS FOR VACCINES AND DIAGNOSTIC BIOLOGICALS**

323 There are no vaccines specifically developed for *C. jejuni* or *C. coli* in animals or birds.

324 **REFERENCES**

325 ASPINALL S.T., WAREING D.R.A., HAYWARD P.G. & HUTCHINSON D.N. (1993). Selective medium for thermophilic
326 campylobacters including *Campylobacter upsaliensis*. *J. Clin. Pathol.*, **46**, 829–831.

327 BANG D.D., PEDERSEN K. & MADSEN M. (2001). Development of a PCR assay suitable for *Campylobacter* spp. mass
328 screening programs in broiler production. *J. Rapid Methods Autom. Microbiol.*, **9**, 97–113.

329 BESSEDE E., SOLECKI O., SIFRE E., LABADI L. & MEGRAUD F. (2011). Identification of *Campylobacter* species and related
330 organisms by matrix assisted laser desorption ionization–time of flight (MALDI-TOF) mass spectrometry. *Clin. Microbiol.*
331 *Infect.*, **17**, 1735–1739.

332 BEST E.L., POWEL E.J., SWIFT C., KATHLEEN A.G. & FROST J.A. (2003). Applicability of a rapid duplex real-time PCR assay
333 for speciation of *Campylobacter jejuni* and *Campylobacter coli* directly from culture plates. *FEMS Microbiol.*, **229**, 237–241.

334 BOLTON F.J., HUTCHINSON D.N. & COATES D. (1984). Blood-free selective medium for isolation of *Campylobacter jejuni* from
335 faeces. *J. Clin. Microbiol.*, **19**, 169–171.

336 BOLTON F.J., HUTCHINSON D.N. & PARKER G. (1988). Reassessment of selective agars and filtration techniques for isolation
337 of *Campylobacter* species from faeces. *Eur. J. Clin. Microbiol. Infect. Dis.*, **7**, 155–160.

- 338 CDC (CENTRES FOR DISEASE CONTROL AND PREVENTION [OF THE USA]) (2022) FoodNet Homepage, CDC,
339 <https://www.cdc.gov/foodnet/index.html>. Accessed 4 July 2023
- 340 CORRY J.E.L., ATABAY H.I., FORSYTHE S.J. & MANSFIELD L.P. (2003). Culture media for the isolation of campylobacters,
341 helicobacter and arcobacters. *In: Handbook of Culture Media for Food Microbiology*, Second Edition, Corry J.E.L., Curtis
342 G.D.W. & Baird R.M. eds. Elsevier, Amsterdam, The Netherlands, 271–315.
- 343 CORRY J.E.L., POST D.E., COLIN P. & LAISNEY M.J. (1995). Culture media for the isolation of campylobacters. *Int. J. Food*
344 *Microbiol.*, **26**, 43–76.
- 345 CRAWSHAW T.R., CHANTER J.I., YOUNG S.C., CAWTHRAW S., WHATMORE A.M., KOYLASS M.S., VIDAL A.B., SALGUERO F.J. &
346 IRVINE R.M. (2015). Isolation of a novel thermophilic *Campylobacter* from cases of spotty liver disease in laying hens and
347 experimental reproduction of infection and microscopic pathology. *Vet. Microbiol.*, **179**, 315–321.
- 348 DOMINGUES A.R., PIRES S.M., HALASA T. & HALD T. (2012). Source attribution of human campylobacteriosis using a meta-
349 analysis of case-control studies of sporadic infections. *Epidemiol. Infect.*, **140**, 970–981.
- 350 EFSA (EUROPEAN FOOD SAFETY AUTHORITY) (2010). Scientific Opinion on Quantification of the risk posed by broiler meat to
351 human campylobacteriosis in the EU. EFSA Panel on Biological Hazards (BIOHAZ). *EFSA J.*, **8**, 1437. [89 pp.].
- 352 EFSA (EUROPEAN FOOD SAFETY AUTHORITY) (2021). The European Union one health 2020 Zoonoses report. *EFSA J.*, **19**,
353 <https://doi.org/10.2903/J.EFSA.2021.6971>
- 354 FERRARI S., ÁSTVALDSSON A., JERNBERG T., STINGL K., MESSELHÄUßER U. & SKARIN H. (2023). Validation of PCR methods for
355 confirmation and species identification of thermotolerant *Campylobacter* as part of EN ISO 10272 – Microbiology of the
356 food chain – Horizontal method for detection and enumeration of *Campylobacter* spp. *Int. J. Food Microbiol.*, **388**, 110064.
357 doi: 10.1016/j.ijfoodmicro.2022.110064.
- 358 FITZGERALD C., PATRICK M., GONZALEZ A., AKIN J., POLAGE C.R., WYMORE K., GILLIM-ROSS L., XAVIER K., SADLOWSKI J.,
359 MONAHAN J., HURD S., DAHLBERG S., JERRIS R., WATSON R., SANTOVENIA M., MITCHELL D., HARRISON C., TOBIN-D'ANGELO M.,
360 DEMARTINO M., PENTELLA M., RAZEQ J., LEONARD C., JUNG C., ACHONG-BOWE R., EVANS Y., JAIN D., JUNI B., LEANO F.,
361 ROBINSON T., SMITH K., GITTELMAN R.M., GARRIGAN C. & NACHAMKIN I. (2016). Multicenter Evaluation of Clinical Diagnostic
362 Methods for Detection and Isolation of *Campylobacter* spp. from Stool. *J. Clin. Microbiol.*, **54**, 1209–1215. doi:
363 10.1128/JCM.01925-15.
- 364 GARRITY G.M. (Editor in Chief) (2005). *Bergey's Manual of Systematic Bacteriology, Second Edition*. Springer-Verlag, New
365 York, USA.
- 366 GORKIEWICZ G., FEIERL G., SCHOBER C., DIEBER F., KÖFER J., ZECHNER R. & ZECHNER E.L. (2003). Species-specific
367 identification of *Campylobacter*s by partial 16S rRNA gene sequencing. *J. Clin. Microbiol.*, **41**, 2537–2546.
- 368 HAVELAAR A.H., IVARSSON S., LÖFDAHL M. & NAUTA M.J. (2013). Estimating the true incidence of campylobacteriosis and
369 salmonellosis in the European Union, 2009. *Epidemiol. Infect.*, **141**, 293–302.
- 370 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO) (2005). ISO 17995:2005. Water quality — Detection and
371 enumeration of thermophilic *Campylobacter* species. International Organisation for Standardisation (ISO), ISO Central
372 Secretariat, 1 rue de Varembé, Case Postale 56, CH – 1211, Geneva 20, Switzerland.
- 373 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO) (2017-2006). ISO 10272-1: 2017-2006 AND ISO/TS 10272-2: 2017
374 2006. Microbiology of food and animal feeding stuffs – Horizontal method for the detection and enumeration of
375 *Campylobacter* spp. Part 1: Detection method; Part 2: Colony count technique. International Organisation for
376 Standardisation (ISO), ISO Central Secretariat, 1 rue de Varembé, Case Postale 56, CH - 1211, Geneva 20, Switzerland.
- 377 JENNINGS J.L., SAIT L.C., PERRETT C.A., FOSTER C., WILLIAMS L.K., HUMPHREY T.J. & COGAN T.A. (2011). *Campylobacter jejuni*
378 is associated with, but not sufficient to cause vibriotic hepatitis in chickens. *Vet. Microbiol.*, **149**, 193–199.
- 379 JRIBI H., SELLAMI H., MARIAM S., SMAOUI S., GHORBEL A., HACHICHA S., BENEJAT L., MESSADI-AKROUT F., MÉGRAUD F. & GDOURA
380 R. (2017). Isolation and Identification of *Campylobacter* spp. from Poultry and Poultry By-Products in Tunisia by
381 Conventional Culture Method and Multiplex Real-Time PCR. *J. Food Prot.*, **80**, 1623–1627.
- 382 KARMALI M.A., SIMOR A.E., ROSCOE M., FLEMING P.C., SMITH S.S. & LANE J. (1986). Evaluation of a blood-free, charcoal-
383 based, selective medium for the isolation of *Campylobacter* organisms from feces. *J. Clin. Microbiol.*, **23**, 456–459.

- 384 LANZL M.I., ZWIETERING M.H., ABEE A. & DEN BESTEN H.M.W. (2022). Combining enrichment with multiplex real-time PCR
385 leads to faster detection and identification of *Campylobacter* spp. in food compared to ISO 10272–1:2017. *Food Microbiol.*
386 **108**, 104117.
- 387 LUECHTEFELD N.W., WANG W.L., BLASER M.J. & RELLER L.B. (1981). Evaluation of transport and storage techniques for
388 isolation of *Campylobacter fetus* subsp. *jejuni* from turkey cecal specimens. *J. Clin. Microbiol.*, **13**, 438–443.
- 389 LUND M., NORDENTOFT S., PEDERSEN K. & MADSEN M. (2004). Detection of *Campylobacter* spp. in chicken fecal samples by
390 real-time PCR. *J. Clin. Microbiol.*, **42**, 5125–5132.
- 391 LUND M., WEDDERKOPP A., WAINO M., NORDENTOFT S., BANG D.D., PEDERSEN K. & MADSEN M. (2003). Evaluation of PCR for
392 detection of *Campylobacter* in a national broiler surveillance programme in Denmark. *J. Appl. Microbiol.*, **94**, 929–935.
- 393 MARTIN K.W., MATTICK K.L., HARRISON M. & HUMPHREY T.J. (2002). Evaluation of selective media for *Campylobacter* isolation
394 when cycloheximide is replaced with amphotericin B. *Let. Appl. Microbiol.*, **34**, 124–129.
- 395 MAYR A.M., LICK S., BAUER J., THARIGEN D., BUSCH U. & HUBER I. (2010). Rapid detection and differentiation of *Campylobacter*
396 *jejuni*, *Campylobacter coli* and *Campylobacter lari* in food, using multiplex real-time PCR. *J. Food Prot.*, **73**, 241–250.
- 397 MUGHINI-GRAS L., PIJNACKER R., COIPAN C., MULDER A.C., VELUDO A.F., DE RIJK S., VAN HOEK A.H.A.M., BUIJ R., MUSKENS G.,
398 KOENE M., VELDMAN K., DUIM B., VAN DER GRAAF-VAN BLOOIS L., VAN DER WEIJDEN C., KUILING S., VERBRUGGEN A., VAN DER
399 GIESSEN J., OPSTEEGH M., VAN DER VOORT M., CASTELIJN G.A.A., SCHETS F.M., BLAAK H., WAGENAAR J.A., ZOMER A.L. & E.
400 FRANZ (2021). Sources and transmission routes of campylobacteriosis: A combined analysis of genome and exposure data.
401 *J. Infect.*, **82**, 216–226. <https://doi.org/10.1016/J.JINF.2020.09.039>
- 402 MUGHINI-GRAS L., SMID J.H., WAGENAAR J.A., DE BOER A.G., HAVELAAR A.H., FRIESEMA I.H., FRENCH N.P., BUSANI L. & VAN
403 PELT W. (2012). Risk factors for campylobacteriosis of chicken, ruminant, and environmental origin: a combined case-
404 control and source attribution analysis. *PLoS One*, **7**(8):e42599. doi: 10.1371/journal.pone.0042599.
- 405 MULDER A.C., FRANZ E., DE RIJK S., VERSLUIS M.A.J., COIPAN C., BUIJ R., MUSKENS G., KOENE M., PIJNACKER R., DUIM B., VAN
406 DER GRAAF-VAN BLOOIS L., VELDMAN K., WAGENAAR J.A., ZOMER A.L., SCHETS F.M., BLAAK H. & MUGHINI-GRAS L. (2020).
407 Tracing the animal sources of surface water contamination with *Campylobacter jejuni* and *Campylobacter coli*. *Water Res.*
408 **187**, 116421. doi: 10.1016/j.watres.2020.116421.
- 409 NEWELL D.G., MUGHINI-GRAS L., KALUPAHANA R.S. & WAGENAAR J.A. (2017). *Campylobacter* epidemiology – sources and
410 routes of transmission for human infection. *Campylobacter: Features, Detection, and Prevention of Foodborne Disease*,
411 **85-110**. Elsevier, Amsterdam, Netherlands.
- 412 NEWELL D.G. & WAGENAAR J.A. (2000). Poultry infections and their control at the farm level. In: *Campylobacter*, Second
413 Edition, Nachamkin I. & M.J. Blaser, eds. ASM Press, Washington DC, USA, 497–509.
- 414 OLSEN J.E., ABO S., HILL W., NOTERMANS S., WERNARS K., GRANUM P.E., POPVIC T., RASMUSSEN H.N. & OLSEVIK O. (1995).
415 Probes and polymerase chain reaction for the detection of food-borne bacterial pathogens. *Int. J. Food Microbiol.* **28**, 1–
416 78.
- 417 ON S.L.W. (1996). Identification methods for *Campylobacters*, *Helicobacters*, and Related organisms. *Clin. Microbiol. Rev.*,
418 **9**, 405–422.
- 419 ON S.L.W. & JORDAN P.J. (2003). Evaluation of 11 PCR assays for species-level identification of *Campylobacter jejuni* and
420 *Campylobacter coli*. *J. Clin. Microbiol.*, **41**, 330–336.
- 421 RICKE S.C., FEYE K.M., CHANEY W.E., SHI Z., PAVLIDIS H. & YANG Y. (2019). Developments in Rapid Detection Methods for
422 the Detection of Foodborne *Campylobacter* in the United States. *Front Microbiol.*, **9**, 3280. doi: 10.3389/fmicb.2018.03280.
- 423 SCALLAN E., HOEKSTRA R.M., ANGULO F.J., TAUXE R.V., WIDDOWSON M.A., ROY S.L., JONES J.L., GRIFFIN P.M. (2011).
424 Foodborne illness acquired in the United States—major pathogens. *Emerg. Infect. Dis.*, **17**, 7–15.
- 425 SJOCREN E., LINDBLOM G.B. & KAUSER B. (1987). Comparison of different procedures, transport media, and enrichment
426 media for isolation of *Campylobacter* species from healthy laying hens and humans with diarrhea. *J. Clin. Microbiol.*, **25**,
427 1966–1968.

- 428 STEELE T.W. & McDERMOTT S.N. (1984). The use of membrane filters applied directly to the surface of agar plates for the
429 isolation of *Campylobacter jejuni* from feces. *Pathology*, **16**, 263–265.
- 430 STEINHAUSEROVA I., CESKOVA J., FOJTIKOVA K. & OBROVSKA I. (2001). Identification of thermophilic *Campylobacter* spp. by
431 phenotypic and molecular methods. *J. Appl. Microbiol.*, **90**, 470–475.
- 432 TANG Y., MEINERSMANN R.J., SAHIN O., WU Z., DAI L., CARLSON J., PLUMBLEE LAWRENCE J., GENZLINGER L., LEJEUNE J.T. &
433 ZHANG Q. (2017). Wide but Variable Distribution of a Hypervirulent *Campylobacter jejuni* Clone in Beef and Dairy Cattle in
434 the United States. *Appl. Environ. Microbiol.*, **83**. <https://doi.org/10.1128/AEM.01425-17>
- 435 TAST-LAHTI E., ROSENDAL T., JERNBERG T. & SKARIN H. (2022). Optimal detection of *Campylobacter* spp. in swine caecal
436 contents – the impact of selective media, time between sampling and start of analysis and the number of colonies
437 confirmed. Abstract book FoodMicro2022, 27th International ICFMH (International Committee on Food Microbiology and
438 Hygiene) Conference, Athens, Greece.
- 439 VANDAMME P. (2000). Taxonomy of the family Campylobacteraceae. In: *Campylobacter*, Second Edition, Nachamkin I. &
440 M.J. Blaser, eds. ASM Press, Washington DC, USA, 3–26.
- 441 VIDAL A.B., RODGERS J., ARNOLD M. & CLIFTON-HADLEY F. (2013). Comparison of different sampling strategies and laboratory
442 methods for the detection of *C. jejuni* and *C. coli* from broiler flocks at primary production. *Zoonoses Public Health*, **60**,
443 412–425.
- 444 WAGENAAR J.A., NEWELL D.G., KALUPAHANA R.S. & MUGHINI-GRAS L. (2023). *Campylobacter*: Animal Reservoirs, Human
445 Infections, and Options for Control. In: Zoonoses: Infections Affecting Humans and Animals, Sing A., eds. Springer, Cham.
446 https://doi.org/10.1007/978-3-030-85877-3_6-1
- 447 WANG G., CLARK C.G., TAYLOR T.M., PUCKNELL C., BARTON C., PRICE L., WOODWARD D.L. & RODGERS F.G. (2002). Colony
448 multiplex PCR assay for identification and differentiation of *Campylobacter jejuni*, *C. coli*, *C. lari*, *C. upsaliensis*, and *C.*
449 *fetus* subsp. *fetus*. *J. Clin. Microbiol.*, **40**, 4744–4747.
- 450 WORLD HEALTH ORGANIZATION (WHO) (2013). The global view of campylobacteriosis: report of an expert consultation,
451 Utrecht, Netherlands, 9–11 July 2012, WHO, Food and Agriculture Organization of the United Nations, World Organisation
452 for Animal Health, eds. WHO, Geneva, Switzerland.
453 <http://www.who.int/iris/handle/10665/80751>
- 454 *
- 455 * *
- 456 **NB:** There is a WOA Reference Laboratory for campylobacteriosis
457 (please consult the WOA Web site for the most up-to-date list:
458 <https://www.woah.org/en/what-we-offer/expertise-network/reference-laboratories/#ui-id-3>).
- 459 Please contact the WOA Reference Laboratories for any further information on
460 diagnostic tests and reagents for campylobacteriosis
- 461 **NB:** FIRST ADOPTED IN 2004. MOST RECENT UPDATES ADOPTED IN 2017.

2 MEETING OF THE BIOLOGICAL STANDARDS COMMISSION

3 Paris, 4–8 September 2023

4

5 CHAPTER 3.10.8.

6 TOXOPLASMOSIS

7 SUMMARY

8 *Toxoplasmosis is a zoonotic infection of animals caused by the protozoan parasite Toxoplasma gondii. This*
9 *parasite has the potential to infect all warm-blooded animals. Although infection does not result in clinical*
10 *illness in the majority of animal species, in some it causes acute life-threatening disease. In some animals,*
11 *particularly small ruminants, Toxoplasma infection may manifest itself as a disease of pregnancy by*
12 *multiplying in the placenta and fetus. In these animals it can result in abortion or the birth of weak offspring.*
13 *Human infections are generally asymptomatic, but they can cause abortion in pregnant women, ocular*
14 *disease, hydrocephalus or intracranial calcifications in congenitally infected children, ocular toxoplasmosis*
15 *in immunocompetent individuals, and serious symptoms and even death in severely immunocompromised*
16 *patients.*

17 *Toxoplasma gondii is an obligate intracellular parasite that has a sexual cycle in Felidae and a two-stage*
18 *asexual cycle in all warm-blooded animals. Globally the T. gondii population structure is diverse and the*
19 *various genotypes are associated with the extent of virulence in particular hosts. In the acute phase of*
20 *infection, tachyzoites multiply in host cells to cause varying degrees of tissue destruction. With the onset of*
21 *an immune response, tachyzoites transform into bradyzoites that multiply slowly in cells to produce tissue*
22 *cysts.*

23 **Detection of the agent:** *In aborted fetuses and placenta, T. gondii is often difficult to find histologically, but*
24 *is more likely to be seen in tissue sections of brain and placenta. Parasitic stages can be identified by*
25 *immunohistochemistry, while nucleic acid-based assays might be used to confirm presence of parasite DNA*
26 *in tissues and may allow genotyping of the parasite in biological specimens. In-vitro isolation of T. gondii*
27 *from host samples is expensive, time consuming and rarely used.*

28 *The sexual part of the life-cycle of T. gondii takes place exclusively in epithelial cells of the feline intestine*
29 *and can result in the excretion of large numbers of oocysts in the faeces. Oocysts may remain viable in the*
30 *environment for many months. Oocysts of T. gondii morphologically resemble those from Hammondia*
31 *hammondi, a related but non-virulent parasite that also uses cats as definitive hosts. Nucleic acid-based*
32 *molecular tests are available to distinguish between these related parasites.*

33 **Serological tests:** *Among the easy-to-perform serological tests, the indirect fluorescent antibody test (IFAT)*
34 *and the direct agglutination test (DAT) allow the titration of sera and the establishment of appropriate cut-*
35 *offs to ensure diagnostic sensitivity and specificity. The IFAT can be used to differentiate IgM and IgG*
36 *antibodies. The DAT is fast and requires no complex laboratory facilities. Enzyme-linked immunosorbent*

37 assays (ELISA) require more sophisticated laboratory equipment but can process large numbers of samples
38 and are easier to standardise.

39 **Requirements for vaccines:** A vaccine composed of live *T. gondii* tachyzoites is available commercially for
40 use in sheep in certain countries. The vaccine is supplied as a concentrated suspension of tachyzoites with
41 an approved diluent and delivery system. The vaccine must be handled strictly according to the
42 manufacturer's instructions as it can be hazardous to the user and has a very short shelf life.

43 A. INTRODUCTION

44 *Toxoplasma gondii* is a zoonotic, obligate intracellular protozoan parasite with the capacity to infect all warm-blooded
45 animals, including birds. Although clinical toxoplasmosis seldom occurs in the majority of animal species, acute life-
46 threatening disease has been reported in some animals. In small ruminants, in particular, it manifests itself as a disease
47 of pregnancy by multiplying in the placenta and fetus. Acute, potentially fatal, infections have been recorded from a range
48 of wild or zoo animals (Dubey, 2022). Infected humans often show no symptoms, but congenital toxoplasmosis, postnatally
49 acquired ocular toxoplasmosis in immunocompetent individuals, or toxoplasmosis in severely immunocompromised
50 patients represent serious threats (EFSA, 2018).

51 *Toxoplasma gondii* has a two-stage asexual cycle in warm-blooded animals and a sexual cycle in Felidae. A systematic
52 review and meta-analysis have reported a global seroprevalence of 38% in domestic cats and 64% wild felids (Hatam-
53 Nahavandi *et al.*, 2021). The genetic diversity of *T. gondii* is complicated; three archetypal clonal lineages (I, II, and III)
54 prevail in Europe and North America; in South America, Asia, and Africa, much greater genetic diversity is apparent and,
55 furthermore, fewer clonal and non-clonal lineages have been genotyped (Lorenzi *et al.*, 2016). Transport between
56 continents via animal migration, including birds, and human activity such as trade may have contributed to the genetic
57 population structures of *T. gondii* in different geographical regions (Shwab *et al.*, 2018).

58 In the asexual part of the lifecycle, the two developmental stages are the rapidly multiplying tachyzoite and the slowly
59 multiplying bradyzoite. In acute infection, tachyzoites actively penetrate host cells where they multiply, causing the cell to
60 rupture and release organisms locally and into the circulation. As the host develops immunity, the parasite retains its overall
61 size and shape, but transforms into the bradyzoite stage and multiplies more slowly within tissue cysts to establish a
62 persistent infection. These microscopic tissue cysts occur most frequently in brain and skeletal muscle and represent the
63 quiescent stage of the parasite within the host. Viable tissue cysts within muscle (meat) are a significant source of human
64 infection, and ingestion of bradyzoites in prey is probably the main route of infection to predators, including the felid
65 definitive host. In animals that succumb to acute infection, tachyzoites may be demonstrated in ascitic fluid or in lung
66 impression smears, as well as in tissue sections of the liver and other affected organs.

67 Abortions in sheep and goats due to *T. gondii* are of particular veterinary importance. Toxoplasmosis in small ruminants
68 must be differentiated from diseases caused by other infectious agents, including infections with *Chlamydomphila abortus*
69 (see Chapter 3.8.5 *Enzootic abortion of ewes*), *Coxiella burnetii* (see Chapter 3.1.17 *Q fever*), *Brucella melitensis* (see
70 Chapter 3.1.4 *Brucellosis* [*Brucella abortus*, *B. melitensis* and *B. suis*]), *Campylobacter foetus* (see Chapter 3.4.4 *Bovine*
71 *genital campylobacteriosis*), *Salmonella* spp. (see Chapter 3.10.7 *Salmonellosis*), and the viruses that cause border
72 disease (see Chapter 3.8.1 *Border disease*), bluetongue (see Chapter 3.1.3), Wesselsbron's disease, and Akabane
73 disease (see Chapter 3.10.1). In pigs, *Brucella suis* (see Chapter 3.1.4) may also cause fetal death, mummification, and
74 abortion.

75 The sexual part of the lifecycle occurs in enteroepithelial cells of the feline definitive host, and results in the production of
76 *T. gondii* oocysts. Following primary infection of a cat, oocysts may be shed in the faeces for several days, with large
77 numbers contaminating the environment; up to one billion oocysts from domestic cats, and probably similar numbers from
78 wild felids (Shapiro *et al.*, 2019). The oocysts sporulate in the environment over the next 1–5 days (depending on aeration,
79 humidity, and temperature), at which time they become infective. The structure of *T. gondii* oocysts results in extreme
80 resistance to environmental conditions, with the polymeric structure of the walls ~~giving~~ providing strength against
81 mechanical forces and protection against chemical agents (Shapiro *et al.*, 2019). This results in prolonged survival, up to
82 18 months in water at 4°C and, once sporulated, can persist in damp soil for as long, at temperatures ranging from –20°C
83 to 35°C. Sporulated oocysts are 11 × 13 µm in diameter and each contains eight sporozoites, four in each of two sporocysts
84 (Dubey, 2022). When a susceptible animal ingests sporulated oocysts, the sporozoites are released to penetrate the
85 intestinal lining, become tachyzoites, and establish an infection.

86 1. Human health risks

87 *Toxoplasma gondii* is a zoonotic parasite and readily infects people. While human infection, as determined by seropositivity,
88 is moderately common globally (local prevalence ranges from under 10% to over 90% [Pappas *et al.*, 2009]), clinical illness
89 is relatively uncommon. The immunosuppressed are particularly at risk of developing clinical illness. In patients being

90 treated with immunosuppressive drugs, toxoplasmosis may occur due to new infection or activation of chronic infection. In
 91 addition, the parasite can pose a serious threat to an unborn child if the mother becomes infected for the first time while
 92 pregnant. The *T. gondii* genotype is also relevant, and outbreaks of clinical infection with some non-archetypal exotic
 93 strains have occurred in people with no apparent immune deficiency. Toxoplasmosis usually manifests as general malaise,
 94 fever, and lymphadenopathy. However, more severe symptoms may occur, including ocular problems, such as
 95 retinochoroiditis, potentially resulting in loss of vision, pneumonitis, and also toxoplasmic encephalitis. The main burden of
 96 human disease, based on disability-adjusted life years (DALYs), ranks as having a high contribution to disease burden
 97 globally (Torgerson *et al.*, 2015).

98 As with animal infections, people may be infected by ingestion of bradyzoites in raw or lightly cooked meat containing live
 99 *T. gondii* tissue cysts or by ingestion of sporulated oocysts. These may be as contaminants of water or of raw or lightly
 100 cooked fresh produce; less commonly, people can be infected by ingestion of tachyzoites in non-heat-treated milk. In
 101 addition, transmission via blood transfusion or organ transplantation is also possible. Outbreaks of both waterborne and
 102 foodborne toxoplasmosis have been described (EFSA, 2018; Shapiro *et al.*, 2019). The largest outbreak to date occurred
 103 in Santa Maria, Brazil in 2018, and is considered to be due to contamination of the water supply with oocysts of a virulent
 104 strain of *T. gondii*; at least 930 confirmed cases occurred, among which 8% required hospitalisation, with three fetal deaths,
 105 10 abortions, and 29 cases of congenital transmission, with 19 infants with ocular lesions (Dubey, 2021).

106 Clearly, *T. gondii* represents a human health risk and all laboratory manipulations with live organisms should be handled
 107 with appropriate measures determined by risk analysis as described in Chapter 1.1.4 *Biosafety and biosecurity: Standard*
 108 *for managing biological risk in the veterinary laboratory and animal facilities.*

109 B. DIAGNOSTIC TECHNIQUES

110 **Table 1.** Test methods available for the diagnosis of toxoplasmosis and their purpose

Method	Purpose					
	Population freedom from infection	Individual animal freedom from infection prior to movement	Contribute to eradication policies	Confirmation of clinical cases	Prevalence of infection – surveillance	Immune status in individual animals or populations post-vaccination
Detection and identification of the agent						
PCR (including nested and real-time PCR)	–	–	–	++	+	–
LAMP	–	–	–	++	+	–
Histopathology	–	–	–	+	–	–
Immunohistochemistry	–	–	–	+	–	–
Detection of immune response						
IFAT^(a)	+	+	+	++	++	+
ELISA^(a)	+	+	+	+++ ^(a)	+++	++
DAT/MAT	+	+	+	+	++	+

111 Key: +++ = recommended for this purpose; ++ recommended but has limitations;
 112 + = suitable in very limited circumstances; – = not appropriate for this purpose.

113 PCR = polymerase chain reaction; LAMP = loop mediated isothermal amplification; IFAT = indirect fluorescent antibody test;
 114 ELISA = enzyme-linked immunosorbent assay; DAT = direct agglutination test; MAT = modified agglutination test.

115 ^(a)In IFAT and ELISA, detection of *Toxoplasma*-specific IgG and IgM antibodies may permit some discrimination between acute and
 116 chronic cases of infection. In ELISA, assays assessing the avidity of an IgG response to *T. gondii* may provide information regarding
 117 how recently the tested animals have experienced a primary *T. gondii* infection.

118 1. Detection of the agent

119 1.1. Histopathology

120 In animals that die with acute toxoplasmosis, focal mononuclear inflammation, with or without focal necrosis, may be
121 seen in a number of tissues, including the liver, heart, and lungs. The latter may be oedematous. Lymph nodes may
122 have undergone expansion and there may or may not be focal necrosis with or without haemorrhage. Typically, *T.*
123 *gondii* tachyzoites may be demonstrable in association with necrosis and inflammation. In fatal cases, tachyzoites
124 may be demonstrated in ascitic fluid or in lung impression smears.

125 In cases of abortion and stillbirth in small ruminants, affected placental cotyledons typically contain large foci of
126 coagulative necrosis that may have become mineralised with time. Any associated inflammation is characteristically
127 slight and non-suppurative. Well-preserved samples of placental cotyledons may show moderate oedema of the
128 mesenchyme of the foetal villi, with a diffuse hypercellularity due to the presence of large mononuclear cells. Small
129 numbers of intracellular and extracellular stages are sometimes visible, usually on the periphery of a necrotic area or
130 in a villus that is in the early stages of infection. The *T. gondii* tachyzoites appear ovoid, 2–6 µm long, with nuclei that
131 are moderately basophilic and located centrally or towards the posterior end.

132 In the fetal brain, primary and secondary lesions may develop. Microglial foci, typically with a necrotic and sometimes
133 mineralised centre, and often associated with a mild focal lymphoid meningitis, represent a fetal immune response
134 following direct damage by local parasite multiplication. *Toxoplasma gondii* tissue cysts are only rarely found, usually
135 at the periphery of these lesions. Focal leukomalacia is also common and is considered to be due to fetal anoxia in
136 late gestation caused by advanced lesions in the placentome preventing sufficient oxygen transfer from mother to
137 fetus. Such foci most commonly occur in the cerebral white matter cores, but sometimes also in the cerebellar white
138 matter. Focal leukomalacia on its own suggests placental disease or acute insufficiency, but the two types of
139 neuropathological change seen together are characteristic of *T. gondii* infection.

140 1.2. Immunohistochemistry

141 Confirmation of the identity of *T. gondii*-like structures in tissue sections from such cases, as well as from instances
142 of acute toxoplasmosis, may be achieved by immunohistochemistry that labels intact *T. gondii* or antigenic debris
143 using polyclonal or monoclonal *T. gondii* specific antibodies (Dubey, 2022). The antigen-antibody reaction can be
144 visualized by avidin-biotin-complex (ABC) or indirect immune-peroxidase and the peroxidase–antiperoxidase (PAP)
145 technique. The method is both convenient and sensitive and is used with fixed tissues (including archived tissues)
146 that may also exhibit a degree of decomposition, where isolation would not be appropriate or possible. However,
147 cross-reactions with related parasites like *Neospora caninum* are possible.

148 1.3. Detection of oocysts

149 *Toxoplasma gondii* oocysts can be detected in stools of felids, as well as contaminating different environmental
150 matrices, such as soil and water, or food, such as molluscs and fresh produce. The low quantity or sparse distribution
151 of oocysts in the contaminated matrix, as for water and fresh produce, means that an initial procedure to concentrate
152 the oocysts from a large volume of sample is needed. Chemical flocculation (e.g. using ferric or aluminium sulphate
153 or calcium carbonate), filtration by cellulose acetate or polycarbonate membranes or cartridge filters and flotation with
154 sucrose or caesium chloride gradient have been widely used for water samples. Washing with appropriate buffer(s)
155 and pelleting by centrifugation is often used for fresh produce (Shapiro *et al.*, 2019; Slana *et al.*, 2021).

156 Although the autofluorescence of *T. gondii* oocysts, pale blue under UV light, facilitates detection by microscopy, this
157 property is shared with oocysts and sporocysts of other related coccidian parasites (e.g. *Hammondia hammondi*)
158 (Lindquist *et al.*, 2003). As a commercially available antibody specific for *T. gondii* oocysts for microscopy detection
159 is currently lacking, molecular assays are usually used to confirm *T. gondii* identification in field samples. Molecular
160 methods are needed to assess or confirm the identity of oocysts-observed.

161 1.4. Molecular methods – detection of nucleic acids

162 The presence of *T. gondii* (tachyzoites, tissue cysts, oocysts) can be assessed by detecting the parasite genomic
163 DNA using several molecular techniques, including conventional polymerase chain reaction (PCR), nested PCR and
164 loop-mediated isothermal amplification (LAMP) (Table 1). No standard methods are available and many of the
165 published protocols are not yet sufficiently validated (for details refer to Chapter 1.1.6. *Principles and methods of*
166 *validation of diagnostic assays for infectious disease* and Chapter 2.2.3. *Development and optimisation of nucleic*
167 *acid detection assays*).

168 Appropriate protocols may allow detection of *T. gondii* DNA from circulating tachyzoites (acute infection) or
169 bradyzoites in tissue cysts (latent infection) and in different biological samples, including animal and human
170 tissues (e.g. heart and skeletal muscle, placenta, brain) and body fluids (e.g. blood, urine, aqueous humour,
171 cerebrospinal fluid, amniotic fluid, milk). In addition, DNA from oocysts in stool (only felids), food and
172 environmental samples (fresh produce, water, soil) can be detected (Slana *et al.*, 2021). No standard method
173 for extracting *T. gondii* DNA exists, but suitable DNA extraction protocols, based on both in-house protocols and
174 commercial kits have been developed (Dzib Paredes *et al.*, 2016). Sample preparation and DNA extraction
175 procedures are likely to have a considerable impact on the sensitivity of the test. Sensitivity is generally higher
176 in DNA-poor matrices than DNA-rich ones (e.g. tap water vs meat samples). Moreover, inhibitors of DNA
177 amplification differ and are related to sample type. Inhibition of DNA amplification can be avoided by DNA
178 extraction optimised for sample type or by using appropriate additives (e.g. bovine serum albumin) during DNA
179 amplification. A specific concentration of the parasite stage (e.g. oocysts) or its DNA (e.g. by magnetic capture)
180 from the matrix might be required prior to DNA extraction as reported for oocysts from water, fresh produce, or
181 faeces (Slana *et al.*, 2021). A validated protocol for DNA extraction from meat and meat products using a
182 commercial kit is available at the website of the European Union Reference Laboratory for Parasites (EURLP)⁴⁸.
183 An example of in-house method for DNA extraction from pig tissue (Jauregui *et al.*, 2001) is reported below.

184 1.4.1. DNA extraction from animal tissue

185 Procedure

- 186 i) Homogenate sample (e.g. 50 g of brain or tongue, or 1 g of muscle) in a blender with 5 volumes
187 of sterile saline solution (phosphate-buffered saline [PBS]: 300 mM NaCl, 2.7 mM KCl, 10 mM
188 Na₂HPO₄, 1.7 mM NaH₂PO₄).
- 189 ii) Digest sample with an equal volume of warm (37°C) pepsin-HCl (1.4 mg of pepsin and 10 mg
190 of NaCl per ml in 0.1 N HCl) for 1 hour at 37°C in a shaking water bath.
- 191 iii) Neutralise mixture by two washes with 0.1 M Tris buffer (pH 8.0).
- 192 iv) Centrifuge mixture aliquots for 10 minutes at 1180 g.
- 193 v) For each aliquot, digest the post centrifugation pellet overnight at 55°C with DNA digestion
194 buffer (0.5% sodium dodecyl sulphate [SDS], 25 mM ethylene diamine tetra-acetic acid [EDTA],
195 100 mM NaCl, 20 mM Tris-HCl [pH 8.0], and proteinase K [0.1 mg/ml final concentration]).
- 196 vi) Extract with one volume of phenol-chloroform-isoamyl alcohol (25:24:1).
- 197 vii) Precipitate DNA in 0.3 M sodium acetate (final concentration) with 2.5 volumes of 100% ethanol.
- 198 viii) Resuspend DNA pellets in TE buffer (10 mM Tris-HCl, 1 mM EDTA). Store DNA at -20°C until
199 use.

200 PCR-based assays are commonly applied for the molecular detection of *T. gondii* genomic DNA (Dzib
201 Paredes *et al.*, 2016; Robert *et al.*, 2021; Slana *et al.*, 2021).

202 1.4.2. DNA extraction from oocysts

203 Although DNA detection is considered highly specific, cross reactivity has been observed between
204 *T. gondii* and *H. hammondi*, a non-zoonotic coccidian that also uses felids as definitive hosts and
205 cannot be differentiated based on oocyst morphology. A real-time PCR targeting a repetitive element
206 of *H. hammondi* (HhamREP-529) has been demonstrated to be highly sensitive and efficient in
207 distinguishing between the two parasites (Schaes *et al.*, 2021).

208 Detection of DNA from *T. gondii* oocysts may present additional challenges because of inhibitors in
209 faecal matter, vegetable or water sediment, and difficulty of extracting DNA from the oocysts. Options
210 for an efficient breaking of oocysts walls include bead-beating, freeze-thaw cycles, heating or
211 chemical/enzymatic treatments (Slana *et al.*, 2021). An in-house method is detailed below for
212 preparation of oocysts and extraction of DNA. An example of a validated method using a commercial
213 kit and a bead-beating-based DNA extraction is available (Lalle *et al.*, 2018).

214 Procedure

- 215 i) Wash oocysts four times in 15 ml PBS (300 mM NaCl, 2.7 mM KCl, 10 mM Na₂HPO₄, 1.7 mM
216 NaH₂PO₄) in a 15 ml centrifugation tube, with centrifugation between washes (1100 g for
217 7 minutes without braking).

48 https://www.iss.it/documents/5430402/5722370/MI_12_rev_1.pdf/a82a4078-f511-affe-8f90-cabc397bc8ce?t=1620381672663

-
- 218 ii) Incubate pellet (up to 0.5 ml) in 2 ml 5.75 % sodium hypochlorite (sodium hypochlorite, aqueous
219 solution, $\geq 4\%$ as active chlorine) for 30 minutes at 37°C .
- 220 iii) Add double-distilled H_2O up to 15 ml.
- 221 iv) Centrifuge supernatant (1100 g for 7 minutes without use of brake) and mix the pellet with PBS.
222 Wash the pellet three times with PBS (1100 g for 7 minutes without brake).
- 223 v) After final centrifugation, re-suspend pellet in 1 ml PBS, transfer into a 1.5 ml reaction tube and
224 spin down (1100 g for 7 minutes without brake).
- 225 vi) Remove as much supernatant as possible and apply three freeze–thaw cycles (10 minutes at
226 -20°C followed by 2 minutes at room temperature) to the pellet.
- 227 vii) Re-suspend pellet in 100 μl OOC lysis buffer (600 mM EDTA, 1.3% [v/v] N-lauroylsarcosine, 2
228 mg/ml proteinase K, pH 9.5) for 45 minutes, at 65°C .
- 229 viii) Add 400 μl OOC-CTAB buffer (2% [v/v] cetyl-trimethyl ammonium bromide, 1.4 M NaCl, 0.2 %
230 [v/v] mercaptoethanol, 20 mM EDTA, 100 mM tris[hydroxymethyl]aminomethane) for 60
231 minutes at 60°C .
- 232 ix) Mix with 500 μl phenol/chloroform/isoamyl alcohol (25/24/1) by inverting 50 times. Centrifuge
233 for 7 minutes at 13,000 g.
- 234 x) Transfer supernatant to fresh tube and mix with 500 μl phenol/chloroform/isoamyl alcohol
235 (25/24/1) by inverting 50 times. Centrifuge for 7 minutes at 13,000 g.
- 236 xi) Transfer supernatant to a fresh tube and add 0.04 volumes of 4 M NaCl and 2–3 volumes of –
237 20°C cold 96% (v/v) ethanol to precipitate DNA (keep at least 20–30 minutes at -20°C).
- 238 xii) Centrifuge for 15 minutes at 13,000 g. Decant the supernatant.
- 239 xiii) Wash the pellet using 70% (v/v) ethanol and centrifuge for 15 minutes at 13,000 g.
- 240 xiv) Discard the ethanol solution and air dry the pellet.
- 241 xv) Solve DNA in double-distilled water for at least 12 hours at 4°C .
- 242 xvi) Use 2.5–10 μl aliquots for PCR (see Section B.1.2 above).

243 The same PCR-based and LAMP assays detailed in Section B.1.2 have been also used for oocyst
244 detection, with B1 gene and the 529RE being targets of choice (Slana *et al.*, 2021).

245 Another important issue is the possibility of combining detection with information on oocyst viability.
246 Bioassays, currently the only definitive way to detect viable oocysts, are expensive and relatively few
247 laboratories have the necessary facilities. Reverse transcription (RT) real-time PCR (real-time RT-
248 PCR) or propidium monoazide-based real-time PCR have shown some promise for assessing oocyst
249 viability in complex sample matrices (Kim *et al.*, 2021; Rousseau *et al.*, 2018).

250 1.4.3. Nucleic acid detection methods

251 Although single copy genes (e.g. SAG1, SAG2, SAG3, GRA6, and GRA7) have been used, multi-
252 copy genes or genetic elements (e.g. 18S rDNA, B1, ITS1, 529RE) are preferred as they provide a
253 higher sensitivity (Dzib Paredes *et al.*, 2016; Slana *et al.*, 2021). For instance, 35 copies of the B1
254 gene and 200–300 copies of the 529 bp repetitive element (529RE) are present in the *T. gondii*
255 genome, and 10 to 100-fold higher sensitivity is generally observed in amplification targeting the
256 529RE compared with B1, although this also reflects the type of assay and sample being analysed
257 (Belaz *et al.*, 2015). In addition, some strains may have partially lost, or have a mutated, 529RE, and
258 this could compromise diagnostic sensitivity (Wahab *et al.*, 2010).

259 Conventional PCR targeting B1 was the first to be used in clinical diagnostics in people (Burg *et al.*,
260 1989). To obtain details on *T. gondii* genotype (e.g. for outbreak investigation, infection source
261 tracing) the methods of choice are multi-locus PCR combined with restriction fragment length
262 polymorphism (PCR-RFLP) or sequencing and multi-locus microsatellite typing (Ajzenberg *et al.*,
263 2010; Su *et al.*, 2006).

264 To increase sensitivity, several nested PCR assays have been implemented (Dzib Paredes *et al.*,
265 2016). The reaction consists of two successive rounds of amplification. The product of the first
266 amplification serves as template for the second amplification, using one or two internal primers. The
267 risk of cross- and carry-over contamination and false positives is increased with nested PCR, and
268 precautions should be taken to mitigate the risk (Dzib Paredes *et al.*, 2016).

269 There are several real-time PCR protocols and real-time PCR in combination with a hydrolysis probe
270 is the most frequently applied (Slana *et al.*, 2021). This has largely improved both sensitivity and
271 specificity of detection of *T. gondii* DNA, with the advantage of avoiding post-amplification
272 manipulations and thus limiting the risk of carry-over contamination. Although sensitivity can be
273 satisfactory with both conventional and real-time PCR using pure genomic *T. gondii* DNA, assay
274 specificity might be affected when testing field samples. Conventional PCR can result in non-specific
275 amplification, whereas this is not detected by real-time PCR due to the probe detection, despite the
276 amplified target being the same. Furthermore, real-time PCR can be multiplexed and simultaneous
277 amplification of an internal amplification control (a heterologous DNA fragment) can be used to
278 monitor for the presence of inhibitors. In addition, amplifying two *T. gondii*-specific targets at once
279 may increase sensitivity. Another advantage of real-time PCR is the possibility of quantification of *T.*
280 *gondii* DNA.

281 A selective enrichment of target DNA combined with real-time PCR (i.e., magnetic capture PCR) has
282 been reported to increase *T. gondii* detectability in animal samples (Gisbert Algaba *et al.*, 2017). The
283 principle relies on separating and concentrating *T. gondii* DNA from sample DNA by specific DNA
284 probes, complementary to the targeted parasite 529RE genomic region, which are conjugated to
285 magnetic beads and followed by real-time PCR (Gisbert Algaba *et al.*, 2017). However, this method
286 is expensive, time consuming, and requires further expertise, so might be not suitable for routine
287 analysis or large surveys.

288 As an alternative to PCR, LAMP has been considered for *T. gondii* DNA detection, and diagnostic
289 purposes, in environmental, veterinary, and human samples. LAMP takes advantage of a DNA
290 polymerase (originally Bst) having both high strand displacement and replication activities. Nucleic
291 acid amplification is performed under isothermal conditions (60–65°C), without the need of a DNA
292 denaturation step. Both, B1 and 529RE have been widely used as targets in different LAMP assays,
293 and LAMP is reported as comparable to real-time PCR for the detection of *T. gondii* in blood and
294 animal tissues (Robert *et al.*, 2021). Although LAMP provides an opportunity for development of point-
295 of-care testing or implementation of molecular tests in settings with limited facilities, there are several
296 drawbacks including design of appropriate primers and the high risk of carry-over contamination.
297 Commercial assays for both real-time PCR and LAMP are available for clinical diagnosis of
298 toxoplasmosis.

299 Overall, the reported sensitivity of published molecular methods can be as low as one (or even less)
300 genome equivalent per reaction. However, this largely depends on sample type, DNA extraction,
301 copies of the targeted gene or sequence, amplification and detection reagents, procedures and
302 platforms. The lack of accepted standard methods prevents robust comparison of sensitivity and
303 specificity of the currently applied molecular tests.

304 2. Serological tests

305 There are several serological tests available for the detection of *T. gondii* antibodies (Table 1). All serological tests have
306 limitations in diagnostic sensitivity and specificity and need proper validation to ensure confidence in results (refer to
307 Chapter 1.1.6. *Principles and methods of validation of diagnostic assays for infectious disease* and Chapter 2.2.1.
308 *Development and optimisation of antibody detection assays*).

309 The Sabin-Feldman dye test (DT) is a reference serological test for *T. gondii* antibody in humans (Dubey, 2022). Although
310 the DT appears both specific and sensitive in humans, it is not extensively validated in other species. In addition, it is
311 potentially hazardous as live parasite is used, is expensive, and requires a high degree of technical expertise.

312 2.1. Preparation of antisera and antigens

313 Antisera to *T. gondii* and conjugated antisera for use in IFAT and ELISA, to allow screening of a variety of animal
314 species, may be obtained commercially. International standards for animal sera are not available.

315 Below are protocols for the preparation of tachyzoite antigen for use in the IFAT and ELISA. Tachyzoites may be
316 grown in tissue culture and retained as whole parasites for the IFAT, or prepared as soluble antigen for the ELISA.

317 **2.2. Preparation of frozen stabilates of *T. gondii* tachyzoites**

318 **2.2.1. Test procedure**

- 319 i) Produce tachyzoites in tissue cell culture as described. Suitable *T. gondii* strains, able to multiply
320 in cell culture, like the RH strain are available in a number of repositories; e.g. at the American
321 Tissue Cell Culture Collection (ATCC⁴⁹).
- 322 ii) Centrifuge three times at 500 **g** for 5 minutes and resuspend tachyzoites in Iscove's modified
323 Dulbecco's medium (IMDM) or any other cell culture medium suitable to cultivate *T. gondii*. Final
324 concentration of the tachyzoite suspension should be approximately 1.5×10^8 tachyzoites/ml.
- 325 iii) Combine dimethyl sulphoxide (DMSO), normal horse serum (free from antibody to *T. gondii*)
326 and the tachyzoite suspension to give these final concentrations: 10% DMSO, 20% normal
327 horse serum, 70% tachyzoite suspension; this gives a final concentration of approximately $1 \times$
328 10^8 tachyzoites/ml.
- 329 iv) Allow the preparation to stand on the bench for 1 hour (4-10°C; optimally on ice).
- 330 v) Dispense into 1-ml aliquots using screw-topped tubes appropriate for liquid nitrogen storage.
- 331 vi) Put the tubes into a small container, wrap in thick insulating material (e.g. paper towels) and
332 place in -70°C freezer to allow the tachyzoites to freeze gradually.
- 333 vii) The next day transfer to liquid nitrogen, keeping well insulated while transferring.
- 334 viii) These stabilates may then be used for tissue culture growth of the parasite. When removing
335 from storage, thaw the sample rapidly in a water bath (37°C).
- 336 ix) Centrifuge three times at 500 **g** for 5 minutes and resuspend tachyzoites in Iscove's modified
337 Dulbecco's medium (IMDM) or any other cell culture medium suitable to cultivate *T. gondii* and
338 add suspension to cell culture.

339 **2.3. Production of *Toxoplasma* tachyzoites in cell culture**

340 **2.3.1. Test procedure**

- 341 i) *Toxoplasma gondii* can be grown and maintained in tissue culture by twice-weekly passage in
342 African green monkey kidney (Vero) cells. Other cell lines (e.g. MARC145 cells) are also
343 suitable. Cell lines are available from repositories (e.g. ATCC).
- 344 ii) Cells and parasite are grown in IMDM supplemented with 50 IU/ml penicillin, 50 µg/ml
345 streptomycin, and 2% fetal bovine serum; there are other cell culture media suitable as well.
- 346 iii) Tachyzoites are harvested from tissue culture flasks by scraping the cell monolayer using a
347 sterile cell scraper.
- 348 iv) Using 25 cm² vented tissue culture flasks that have each been seeded with 1×10^5 Vero cells,
349 add tachyzoites at the rate of two tachyzoites per monolayer cell and incubate at 37°C in a 5%
350 CO₂ humidified chamber. Harvest, when 2/3 of the cell layer was destroyed by tachyzoite
351 multiplication, usually after 3-4 days.

352 **2.4. Preparation of whole tachyzoites for IFAT and agglutination**

353 **2.4.1. Test procedure**

- 354 i) Produce 4×10^7 /ml suspension of *T. gondii* tachyzoites in PBS.
- 355 ii) Add formaldehyde (40%) to give a final concentration of 0.2% (v/v).
- 356 iii) Incubate at 4°C overnight and divide into aliquots in suitable tubes and store frozen until
357 required (-20°C).

358

49 American Type Culture Collection, P.O. Box 1549, Manassas, Virginia 20108, United States of America.

359 **2.5. Production of soluble antigen for ELISA**

360 **2.5.1. Test procedure**

- 361 i) Produce a suspension of *T. gondii* tachyzoites in PBS.
- 362 ii) Centrifuge at 2000 **g** for 15 minutes, retain the pellet and resuspend it in nine times its volume
363 of distilled water.
- 364 iii) Lyse the tachyzoites by freezing and thawing three times.
- 365 iv) Sonicate the antigen preparation for 20 seconds at 4°C at an amplitude of 20 microns.
- 366 v) Remove any cellular debris by centrifugation at 10,000 **g** for 30 minutes at 4°C.
- 367 vi) Retain the supernatant and store at –20°C until required; protein estimation should be between
368 2 and 4 µg/ml.

369 **2.6. Indirect fluorescent antibody test**

370 The indirect fluorescent antibody test (IFAT) (Dubey, 2022) is a simple and widely used method. Whole, killed
371 *Toxoplasma* tachyzoites are incubated with diluted test serum, the appropriate fluorescent labelled secondary
372 antibody is added, and the result is then viewed with a fluorescence microscope. Fluorescent-labelled species-
373 specific secondary antibodies are available commercially, the method is relatively inexpensive, and kits are
374 commercially available. However, the results are read by eye, so subjective variation may occur. It may be difficult to
375 find some species-specific conjugates and there is a risk of possible cross-reactivity with rheumatoid factor and anti-
376 nuclear antibodies. The following is a protocol for carrying out an IFAT for anti-*Toxoplasma* IgG antibodies in sheep
377 serum. It only requires minor modifications for testing different species or for measuring IgM antibody.

378 **2.6.1. Test procedure**

- 379 i) Clean the required number of multi-well immunofluorescence assay slides (e.g. 10–21 well-
380 slides with wells of 4–6 mm in diameter are suitable) and allow to dry.
- 381 ii) Apply 5 µl of a whole tachyzoite preparation (Section B.2.4.1 above) on to each well and allow
382 to air dry.
- 383 iii) Fix in methanol for 10 minutes.
- 384 iv) Wash twice (10 minutes for each wash) in 0.3 M PBS, pH 7.4.
- 385 v) Prepare serial dilutions of the test sera in PBS (e.g. 1/16, 1/32, etc. up to 1/1024).
- 386 vi) Add 5 µl of the given test sheep serum (diluted in PBS) to each well. Ensure that positive and
387 negative control sera are included in each test as well as a 'PBS-only' sample. Incubate for
388 30 minutes at room temperature.
- 389 vii) Wash twice (10 minutes each time) in PBS.
- 390 viii) Add 5 µl of an appropriate dilution of rabbit-anti-sheep IgG conjugated to fluorescein
391 isothiocyanate, diluted in 0.2% filtered Evans blue dye in PBS (filtered through a 0.45 µm sterile
392 filter), to each well and incubate for 30 minutes at room temperature.
- 393 ix) Wash three times for 10 minutes each time in PBS.
- 394 x) Mount the slides under cover-slips with buffered glycerol (nine parts PBS, one part glycerol).
- 395 xi) Examine using a fluorescence microscope, fitted with ×20 and ×40 objective lenses.

396 With a negative test serum result, the whole parasites will appear red due to the autofluorescence of
397 the Evans blue dye. They may also present with a green fluorescent cap at the parasite pole
398 (nonspecific polar fluorescence). With a positive test serum, the parasites will fluoresce red and at
399 least 80% of them within a given well will be surrounded by an unbroken band of green fluorescence.
400 In an adult sheep/goat a positive titre could be defined as $\geq 1/64$ and a negative titre as $\leq 1/32$. For
401 lamb/kid and fetal sera, respective titres could be defined as $\geq 1/32$ and $\leq 1/16$. These cut off values
402 should be validated locally as results may vary between laboratories, depending on, e.g., the
403 fluorescence microscope and the operator. Optimally, each slide should include positive control and
404 negative controls.

405

2.7. Modified agglutination test

406 The modified agglutination test (MAT) (Dubey, 2022) is both sensitive and specific. Formalinised *Toxoplasma*
407 tachyzoites are added to U-shaped well microtiter plates and dilutions of test sera are then applied. Positive samples
408 will produce agglutination that can be graded, whereas negative samples will produce a 'button' of precipitated
409 tachyzoites at the bottom of the well. The test is simple and easy to perform although relatively large amounts of
410 antigen are required. Kits are commercially available. It is important to treat sera with 0.2 2-mercaptoethanol to avoid
411 false positives due to non-specific IgM. The MAT has been used extensively for detection of *T. gondii* antibodies in
412 sera of many animal species and the procedure is detailed below. A commercially available latex agglutination test
413 is also available, but this test is regarded relatively insensitive compared with MAT or IFAT.

414

2.7.1. Serum-diluting buffer

- 415 i) Dissolve 42.5 g NaCl, 1.54 g NaH₂PO₄, and 5.4 g Na₂HPO₄ in 900 ml deionised water.
- 416 ii) Adjust the pH to 7.2. Bring the volume to 1 litre with deionised water.
- 417 iii) Store in a refrigerator. This is the 5× stock solution.
- 418 iv) Dilute this stock solution 1/5 to give 0.01 M PBS (working serum-diluting buffer: 1 part stock and
419 4 parts deionised water). PBS should be filtered through a 0.22 µm filter immediately prior to
420 use.

421

2.7.2. Antigen-diluting buffer

- 422 i) Prepare a stock of borate buffer: dissolve 7.01 g sodium chloride, 3.09 g boric acid, 2.0 g sodium
423 azide in 900 ml deionised water.
- 424 ii) Add 24 ml 1 N NaOH and adjust the pH to 8.9.
- 425 iii) Bring the volume to 1 litre. This is the stock solution and can be stored at room temperature.
- 426 iv) For the working antigen-diluting buffer, dissolve 0.4 g bovine serum albumin in 100 ml borate
427 buffer. Store at 4°C.

428

2.7.3. Serum dilutions

- 429 i) Dilute serum samples with working serum-diluting buffer (Section B.2.7.1 above) in small test
430 tubes (1.2 ml in strips of 8 or 12) with a multichannel pipette, starting at 1/25.
431 Note: Microtiter plates may also be used for making serum dilutions.

432

2.7.4. Preparation of antigen mixture

- 433 i) For each plate, mix 2.5 ml working antigen-diluting buffer (see Sections B.2.4.1 and B.2.7.2
434 above), 35 µl 2-mercaptoethanol, 50 µl Evans blue dye solution (2 mg/ml water) and 0.15 ml
435 antigen (formalin-fixed whole parasites).

436

2.7.5. Agglutination procedure

- 437 Agglutination is done in U-bottom 96-well microtiter plates.
- 438 i) Pipette 25 µl antigen mixture to each well immediately after mixing.
- 439 ii) Pipette 25 µl serum dilutions into the wells and mix gently with the antigen by repeated pipetting
440 action.
- 441 iii) A positive control should be included in each plate. The control should have a titre of 1/200, and
442 two-fold dilutions from 1/25 to 1/3200 should be used.
- 443 iv) Cover the plates with sealing tape and incubate overnight at 37°C.
- 444 v) Read results using a magnifying mirror. A blue button at the bottom of the well means negative.
445 A clear bottom means positive.

446

2.8. Enzyme-linked immunosorbent assay

447 One of the first *T. gondii* enzyme-linked immunosorbent assay (ELISA) (Voller *et al.*, 1976) used a soluble antigen
448 preparation made from *T. gondii* RH strain tachyzoites (as described below) and layered into wells in an ELISA
449 microtiter plate. Test sera are added, followed by a species-specific secondary antibody conjugated with a reactive
450 enzyme, such as horseradish peroxidase. Protein A/G conjugates were used to replace species-specific antibody

451 conjugates, making ELISAs applicable to more than one animal species. Any conjugated enzyme causes a colour
452 change in the substrate that is directly related to the amount of bound antibody, and which can be read with a
453 spectrophotometer at the absorbance wavelength specific to the substrate used. The assay is simple, can readily test
454 a large number of samples, and is easy to perform with the chosen anti-species conjugate. Defined anti-species
455 conjugates, substrates, and whole kits are commercially available. The ELISA is well suited for analysing large
456 numbers of samples. A large number of species-specific or multi-species ELISAs are commercially available to detect
457 *T. gondii* antibodies.

458 To improve the specificity of the conventional ELISA, native purified *T. gondii*-specific antigens have been used
459 (Basso *et al.*, 2013). In addition, severam recombinant antigens have been established, and these seem suitable for
460 replacing native antigens for serological diagnostic tests. For many of these recombinant antigen ELISAs, thorough
461 validation is lacking.

462 Clinically, there is a need to distinguish between recent (acute) and long-standing (chronic) infections. With the
463 conventional ELISA, detection of *Toxoplasma*-specific IgG and IgM antibodies, along with IgA, may permit some
464 discrimination between acute and chronic *T. gondii* infection. Assays assessing the avidity of an IgG response to
465 *T. gondii* have been applied in sheep and pigs. However, such avidity tests were used for research purpose only.

466 C. REQUIREMENTS FOR VACCINES

467 Currently there is only one commercially available live vaccine, which is licensed for use in breeding sheep in some regions
468 (Europe and New Zealand) to reduce the effects of *T. gondii* infection (e.g. early embryonic death, abortion). It consists of
469 $\geq 10^5$ tachyzoites of the S48 strain of *T. gondii* that has been attenuated by multiple passages in mice. The vaccine
470 stimulates effective protective immunity for at least 18 months following a single intramuscular injection given at least 4
471 weeks prior to mating and only for use in healthy, non-pregnant female sheep. Despite the acknowledged importance of
472 human toxoplasmosis, human vaccines are currently unavailable, and the vaccine for sheep has disadvantages, such as
473 a short shelf-life (10 days), strict storage conditions, and, as a live vaccine, potential risk to operators. Information on the
474 production details of this vaccine and QC requirements are not available.

475 Although the importance of a killed or non-live vaccine is acknowledged – for vulnerable humans (e.g. women before they
476 are pregnant), for reducing abortions in sheep, for reducing tissue cysts in meat animals (pigs, cattle, chickens, etc.), and
477 for limiting oocyst shedding from kittens – to date this remains elusive (Innes *et al.*, 2019). However, with recent scientific
478 advances, including availability of genetic, transcriptomic, and metabolomic data, the potential for developing knockout
479 variants, and other new technologies suggest new possibilities for development of such a vaccine (Mevelec *et al.*, 2020;
480 Zhang *et al.*, 2022).

481 REFERENCES

482 AJZENBERG D., COLLINET F., MERCIER A., VIGNOLES P. & DARDE M.L. (2010). Genotyping of *Toxoplasma gondii* isolates with
483 15 microsatellite markers in a single multiplex PCR assay. *J. Clin. Microbiol.*, **48**, 4641–4645.

484 BASSO W., HARTNACK S., PARDINI L., MAKSIMOV P., KOUDELA B., VENTURINI M.C., SCHARLES G., SIDLER X., LEWIS F.I. & DEPLAZES
485 P. (2013). Assessment of diagnostic accuracy of a commercial ELISA for the detection of *Toxoplasma gondii* infection in
486 pigs compared with IFAT, TgSAG1-ELISA and Western blot, using a Bayesian latent class approach. *Int. J. Parasitol.*, **43**,
487 565–570.

488 BELAZ S., GANGNEUX J.P., DUPRETZ P., GUIGUEN C. & ROBERT-GANGNEUX F. (2015). A 10-year retrospective comparison of
489 two target sequences, REP-529 and B1, for *Toxoplasma gondii* detection by quantitative PCR. *J. Clin. Microbiol.*, **53**, 1294–
490 1300.

491 DUBEY J.P. (2021). Outbreaks of clinical toxoplasmosis in humans: five decades of personal experience, perspectives and
492 lessons learned. *Parasit. Vectors*, **14**, 263.

493 DUBEY J.P. (2022). *Toxoplasmosis of Animals and Humans*, Third Edition. CRC Press, Boca Raton, USA.

494 DZIB PAREDES G.F., ORTEGA-PACHECO A., ROSADO-AGUILAR J.A., ACOSTA-VIANA K.Y., GUZMÁN-MARÍN E. & JIMÉNEZ-COELLO M.
495 (2016). *Toxoplasma gondii* in meat for human consumption – A brief review of the most described strategies for its detection
496 and quantification, significance, prevention and control of food related diseases. IntechOpen, London, UK.

-
- 497 EUROPEAN FOOD SAFETY AUTHORITY (EFSA) PANEL ON BIOLOGICAL HAZARDS (BIOHAZ), KOUTSOUMANIS K., ALLENDE A.,
498 ALVAREZ-ORDÓÑEZ A., BOLTON D., BOVER-CID S., CHEMALY M., DAVIES R., DE CESARE A., HERMAN L., HILBERT F., LINDQVIST R.,
499 NAUTA M., PEIXE L., RU G., SIMMONS M., SKANDAMIS P., SUFFREDINI E., CACCIÒ S., CHALMERS R., DEPLAZES P.,
500 DEVLEESSCHAUWER B., INNES E., ROMIG T., VAN DER GIESSEN J., HEMPEN M., VAN DER STEDE Y. & ROBERTSON L. (2018). Public
501 health risks associated with food-borne parasites. *EFSA Journal*, **16**, e05495.
- 502 GISBERT ALGABA I., GEERTS M., JENNES M., COUCKE W., OPSTEEGH M., COX E., DORNY P., DIERICK K. & DE CRAEYE S. (2017).
503 A more sensitive, efficient and ISO 17025 validated Magnetic Capture real time PCR method for the detection of archetypal
504 *Toxoplasma gondii* strains in meat. *Int. J. Parasitol.*, **47**, 875–884.
- 505 HATAM-NAHAVANDI K., CALERO-BERNAL R., RAHIMI M.T., PAGHEH A.S., ZAREAN M., DEZHAKAM A. & AHMADPOUR E. (2021).
506 *Toxoplasma gondii* infection in domestic and wild felids as public health concerns: a systematic review and meta-analysis.
507 *Sci. Rep.*, **11**, 9509.
- 508 INNES E.A., HAMILTON C., GARCIA J.L., CHRYSSEAFIDIS A. & SMITH D. (2019). A One Health approach to vaccines against
509 *Toxoplasma gondii*. *Food Waterborne Parasitol.*, **15**, e00053.
- 510 JAUREGUI L.H., HIGGINS J., ZARLENGA D., DUBEY J.P. & LUNNEY J.K. (2001). Development of a real-time PCR assay for
511 detection of *Toxoplasma gondii* in pig and mouse tissues. *J. Clin. Microbiol.*, **39**, 2065–2071.
- 512 KIM M., SHAPIRO K., RAJAL V.B., PACKHAM A., AGUILAR B., RUEDA L. & WUERTZ S. (2021). Quantification of viable protozoan
513 parasites on leafy greens using molecular methods. *Food Microbiol.*, **99**, 103816.
- 514 LALLE M., POSSENTI A., DUBEY J.P. & POZIO E. (2018). Loop-Mediated Isothermal Amplification-Lateral-Flow Dipstick (LAMP-
515 LFD) to detect *Toxoplasma gondii* oocyst in ready-to-eat salad. *Food Microbiol.*, **70**, 137-142.
- 516 LINDQUIST H.D., BENNETT J.W., HESTER J.D., WARE M.W., DUBEY J.P. & EVERSON W.V. (2003). Autofluorescence of
517 *Toxoplasma gondii* and related coccidian oocysts. *J. Parasitol.*, **89**, 865–867.
- 518 LORENZI H., KHAN A., BEHNKE M.S., NAMASIVAYAM S., SWAPNA L.S., HADJITHOMAS M., KARAMYCHEVA S., PINNEY D., BRUNK B.P.,
519 AJIOKA J.W., AJZENBERG D., BOOTHROYD J.C., BOYLE J.P., DARDE M.L., DIAZ-MIRANDA M.A., DUBEY J.P., FRITZ H.M., GENNARI
520 S.M., GREGORY B.D., KIM K., SAEIJ J.P., SU C., WHITE M.W., ZHU X.Q., HOWE D.K., ROSENTHAL B.M., GRIGG M.E., PARKINSON
521 J., LIU L., KISSINGER J.C., ROOS D.S. & SIBLEY L.D. (2016). Local admixture of amplified and diversified secreted
522 pathogenesis determinants shapes mosaic *Toxoplasma gondii* genomes. *Nat. Commun.*, **7**, 10147.
- 523 MEVELEC M.-N., LAKHRIF Z. & DIMIER-POISSON I. (2020). Key Limitations and New Insights Into the *Toxoplasma gondii*
524 Parasite Stage Switching for Future Vaccine Development in Human, Livestock, and Cats. *Front. Cell. Infect. Microbiol.*,
525 **10** (697) doi: 10.3389/fcimb.2020.607198.
- 526 PAPPAS G., ROUSSOS N. & FALAGAS M.E. (2009). Toxoplasmosis snapshots: global status of *Toxoplasma gondii*
527 seroprevalence and implications for pregnancy and congenital toxoplasmosis. *Int. J. Parasitol.*, **39**, 1385–1394.
- 528 ROBERT M.G., BRENIER-PINCHART M.-P., GARNAUD C., FRICKER-HIDALGO H. & PELLOUX H. (2021). Molecular diagnosis of
529 toxoplasmosis: recent advances and a look to the future. *Expert Rev. Anti-Infe.*, **19**, 1529–1542.
- 530 ROUSSEAU A., LA CARBONA S., DUMETRE A., ROBERTSON L.J., GARGALA G., ESCOTTE-BINET S., FAVENNEC L., VILLENA I., GERARD
531 C. & AUBERT D. (2018). Assessing viability and infectivity of foodborne and waterborne stages (cysts/oocysts) of *Giardia*
532 *duodenalis*, *Cryptosporidium* spp., and *Toxoplasma gondii*: a review of methods. *Parasite*, **25**, 14.
- 533 SCHARÉS G., GLOBOKAR VRHOVEC M., TUSCHY M., JOERES M., BARWALD A., KOUDELA B., DUBEY J.P., MAKSIMOV P. & CONRATHS
534 F.J. (2021). A real-time quantitative polymerase chain reaction for the specific detection of *Hammondia hammondi* and its
535 differentiation from *Toxoplasma gondii*. *Parasit. Vectors*, **14**, 78.
- 536 SHAPIRO K., BAHIA-OLIVEIRA L., DIXON B., DUMÈTRE A., DE WIT L.A., VANWORMER E. & VILLENA I. (2019). Environmental
537 transmission of *Toxoplasma gondii*: Oocysts in water, soil and food. *Food Waterborne Parasitol.*, **15**, e00049-e00049.
- 538 SHWAB E.K., SARAF P., ZHU X.Q., ZHOU D.H., MCFERRIN B.M., AJZENBERG D., SCHARÉS G., HAMMOND-ARYEE K., VAN HELDEN
539 P., HIGGINS S.A., GERHOLD R.W., ROSENTHAL B.M., ZHAO X., DUBEY J.P. & SU C. (2018). Human impact on the diversity and
540 virulence of the ubiquitous zoonotic parasite *Toxoplasma gondii*. *Proc. Natl Acad. Sci. USA*, **115**, E6956-E6963.
- 541 SLANA I., BIER N., BARTOSOVA B., MARUCCI G., POSSENTI A., MAYER-SCHOLL A., JOKELAINEN P. & LALLE M. (2021). Molecular
542 methods for the detection of *Toxoplasma gondii* oocysts in fresh produce: An extensive review. *Microorganisms*, **9** doi:
543 10.3390/microorganisms9010167.
-

544 SU C., ZHANG X. & DUBEY J.P. (2006). Genotyping of *Toxoplasma gondii* by multilocus PCR-RFLP markers: a high resolution
545 and simple method for identification of parasites. *Int. J. Parasitol.*, **36**, 841–848.

546 TORGERSON P.R., DEVLEESSCHAUWER B., PRAET N., SPEYBROECK N., WILLINGHAM A.L., KASUGA F., ROKNI M.B., ZHOU X.N.,
547 FEVRE E.M., SRIPA B., GARGOURI N., FURST T., BUDKE C.M., CARABIN H., KIRK M.D., ANGULO F.J., HAVELAAR A. & DE SILVA N.
548 (2015). World Health Organization Estimates of the Global and Regional Disease Burden of 11 Foodborne Parasitic
549 Diseases, 2010: A Data Synthesis. *PLoS Med*, **12** (12), e1001920.

550 VOLLER A., BARTLETT A. & BIDWELL D.E. (1976). Enzyme immunoassays for parasitic diseases. *Trans. Royal Soc. Trop.*
551 *Med. Hyg.*, **70**, 98–106.

552 WAHAB T., EDVINSSON B., PALM D. & LINDH J. (2010). Comparison of the AF146527 and B1 repeated elements, two real-time
553 PCR targets used for detection of *Toxoplasma gondii*. *J. Clin. Microbiol.*, **48**, 591–592.

554 ZHANG Y., LI D., LU S. & ZHENG B. (2022). Toxoplasmosis vaccines: what we have and where to go? *NPJ Vaccines*, **7**, 131.

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557 **NB:** At the time of publication (2024) there were no WOA Reference Laboratories
558 for toxoplasmosis (please consult the WOA Web site:
559 <https://www.woah.org/en/what-we-offer/expertise-network/reference-laboratories/#ui-id-3>).

560 **NB:** FIRST ADOPTED IN 2004. MOST RECENT UPDATES ADOPTED IN 2017.

Annex 19. Analysis of the questionnaire for Reference Laboratories

MEETING OF THE BIOLOGICAL STANDARDS COMMISSION

Paris, 4–8 September 2023



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Annex 20. List of Main Focus Areas and Specialties for WOAAH Collaborating Centres

The role of WOAAH Collaborating Centres is anchored to the WOAAH's founding mandate and to the Seventh Strategic Plan (2021–2025)⁵⁰.

1. Animal health management

WOAH has the responsibility to collect, analyse and disseminate relevant scientific information, especially on disease control methods, and to provide expertise in the control of animal diseases including zoonotic diseases, as well as health threats at the animal–human–ecosystems interface, ~~while taking into account~~ under the “One Health” approach concept whenever possible. This topic covers issues primarily, but not exclusively, related to Sections 2 and 4 of the *Terrestrial and Aquatic Codes* and to Parts 3 of the *Terrestrial Manual* and Part 2 of both the *Terrestrial and Aquatic Manuals*, respectively. The topic is expected to assist WOAAH and its Members to fulfil the core missions of the organisation.

- Disease ~~control~~ prevention, risk assessment, early warning and preparedness
- Species related (e.g. molluscs, bees, camelids)
- ~~Preventing animal disease~~ Biosecurity and disease prevention along the value-chain ~~biosecurity~~
- Emerging animal diseases (early detection, warning and response)
- Animal health emergencies
- Zoonotic diseases
- Epidemiology, modelling, surveillance
- Social and economic implications of animal diseases control
- Biothreat reduction
- Impact of climate change on animal health

2. Animal production

WOAH's founding mandate has evolved and has been adapted to Members' needs, it now includes improving the safety of food of animal origin from hazards originating in animal production, and establishing standards and guidelines for animal welfare through a science-based approach and promote their application. This topic corresponds to this mandate and more specifically to Section 7 of the *Terrestrial and Aquatic Codes* on animal welfare, and the relevant provisions on food and feed safety in ~~the chapters in~~ Section 6 on Veterinary Public Health of the *Terrestrial Code* (Chapters 6.1, 6.2, 6.3, 6.5, 6.12, 6.13) and Chapter 4.8 ~~4.9~~ of the *Aquatic Code*.

- Animal welfare
- Animal production food safety
- Sustainable animal production (including integrated health management)
- Safety of animal feed
- Climate change and impacts

3. Laboratory expertise

This topic covers issues related to management and operation of veterinary diagnostic laboratories. It corresponds essentially to provisions of Chapters 1.1.1 to 1.1.7 of the *Terrestrial Manual*, as well as Chapter 2.1.2, and to Chapters 1.1.1 and 1.1.2 of the *Aquatic Manual*. Beyond WOAAH standards, the topic is expected to assist WOAAH and its Members to follow the recommendations of the first two International Conferences on Biological Threat Reduction, as well as to contribute to the Seventh WOAAH Strategic Plan and commitment to modern technology.

- Biorisk management
- Quality management systems
- Biobanking and reference collections
- Genomics and bioinformatics
- Laboratory information systems technology
- Validation procedures for diagnostic tests of laboratory methods
- Development and application of innovative technologies

⁵⁰ <https://www.woah.org/en/document/seventh-strategic-plan/>

48 4. Training and education

49 It is part of the WOA's founding mandate to improve the legal framework, competency and resources of national
50 Veterinary Services, and particularly their global public good components. This topic covers the scientific and
51 technical veterinary knowledge and skills needed for veterinarians, animal health professionals and veterinary para-
52 professionals to implement WOA Standards. The topic primarily, but not exclusively, corresponds to provisions of
53 the Section 3 of the *Terrestrial* and *Aquatic Codes*. The topic is also expected to assist the WOA and its Members
54 to follow-up on the recommendations of the first two International Conferences of Veterinary Education.

- 55 • ~~Veterinary education (under- and post-graduate) education~~
- 56 • ~~Veterinary Post-graduate training and education (scientific and technical) and capacity building~~
- 57 • ~~Veterinary specialisation and Laboratory or epidemiological expertise in infectious diseases~~
- 58 • ~~Capacities Capacity building of Veterinary Services or Aquatic Animal Health Services~~

59 5. Veterinary products

60 This topic corresponds to Chapters 1.1.8 to 1.1.10, and most of the specific recommendations included in the Part 2
61 of the *Terrestrial Manual*. Progress made on vaccines, diagnostics and the development of new drugs is believed to
62 contribute to the global efforts against antimicrobial resistance. As for antimicrobial resistance, the topic also
63 corresponds to Chapters 6.1 to 6.4 of the *Aquatic Code*, Chapters 6.6 to 6.10 of the *Terrestrial Code*, and Chapter
64 2.1.1 of the *Terrestrial Manual*.

- 65 • ~~Vaccines, diagnostics (kits), and drugs~~
- 66 • ~~Managing antimicrobial agents resistance~~
- 67 • ~~Alternatives to antimicrobials~~
- 68 • ~~New technologies~~

69 6. Wildlife health and biodiversity ~~Environment and climate change~~

70 ~~WOAH provides expertise to Members in understanding and managing the effects of environmental and climate~~
71 ~~changes on animal health and welfare. Climate change is likely to increase pressure on animal production, and~~
72 ~~provide newly suitable conditions for invasive pests and pathogens. The risk of emergence of new pathogens has~~
73 ~~increased as a consequence of global changes in the way food is produced, moved and consumed. This topic is~~
74 ~~expected to address animal health issues, including aquatic animals, connected to wildlife, biodiversity, climate~~
75 ~~change, and emerging risks. Wildlife plays a vital role in maintaining healthy and functioning ecosystems, thus~~
76 ~~contributing to the preservation of biodiversity. Wildlife is an asset, supporting livelihoods through the provision of~~
77 ~~income, whether it be through tourism or as a source of food. Importantly, wildlife has a positive effect on human well-~~
78 ~~being, contributing to education, physical and mental health, social values, culture and spirituality. This topic is~~
79 ~~expected to address animal health issues, including terrestrial and aquatic animals, connected to wildlife, biodiversity,~~
80 ~~and emerging risks.~~

- 81 • ~~Threats to livestock or wildlife health and welfare and biodiversity~~
- 82 • ~~Impact of climate change and biodiversity on wildlife~~
- 83 • ~~Disease related (including vector-borne)~~
- 84 • ~~Wildlife disease epidemiology, modelling, and surveillance~~
- 85 • ~~Transboundary diseases at the ecosystem/human/domestic animal health interface~~
- 86 • ~~Drivers for emerging risks~~
- 87 • ~~Wildlife's role in the epidemiology of diseases affecting livestock and humans, and in disease emergence at the~~
88 ~~human-animal interface~~

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