Introduction

Risk assessment is an important tool in identifying and quantifying risks associated with imported animals and animal products. Once risks are identified, management strategies can be formulated to protect the health of livestock in importing countries. The World Trade Organization has designated the Office International des Epizooties (OIE) as the body to set standards and develop guidelines for the safe international movement of animals, animal products and germplasm from both disease-free and disease-affected countries or regions. Such standards are detailed in the OIE International Animal Health Code (10).
The OIE recommendations for importation of beef from countries or zones that are free of foot and mouth disease (FMD) and practise vaccination are as follows:

a) meat should come from cattle that have remained in the exporting country or zone for at least three months prior to slaughter

b) the slaughterhouse should be officially approved and the cattle should have passed ante-mortem and post-mortem inspection

c) meat should come from deboned carcasses from which the major lymphatic glands have been removed

d) prior to deboning, the carcasses should be submitted to maturation at a temperature over + 2°C, for a minimum period of 24 h following slaughter, during which the pH value of the meat is below 6.0 when tested in the middle of both the longissimus dorsi muscles (10).

In addition, when importing from countries or zones infected with FMD, the OIE recommends the following:

a) the meat originates from cattle that are regularly vaccinated and have been vaccinated at least twice, with the last vaccination not more than twelve months and not less than one month prior to slaughter

b) the cattle have been in the country for at least three months prior to slaughter

c) the cattle have been kept in a single location for the previous thirty days, and FMD has not occurred within 10 km of the establishment during that period.

These regulations are based on rules developed by the United Kingdom (UK) for the importation of meat from Argentina, following the extensive epidemic of FMD in Great Britain during the period 1967-1968. This combination of measures has apparently been effective, since deboned frozen beef was exported to Europe for many years without the introduction of disease, even during periods of extensive outbreaks of FMD in South America (2).

Risk assessment has facilitated trade in beef while safeguarding the animal health status of importing countries. These risk assessments have made use of pathway analysis (1, 21), which considers the disease incidence, the efficiency of Veterinary Services, veterinary inspections at slaughterhouses and carcass treatment (e.g. maturation and deboning). Examples of such risk assessments are as follows:

– the report of the Tuskegee University School of Veterinary Medicine in relation to the importation of beef from Argentina into the United States of America (USA) (20)
– the study by Yu et al. (22).

These studies used risk pathways of which Figure 1 is a rather simplified example. Figure 1 shows different events (E) that may lead to the contamination of meat with FMD virus. According to this scenario, the final product may be contaminated with FMD virus, given that an infected herd is selected for slaughter (E1), that the disease is not detected at any of the inspections (E2, E3, E4), that the carcass is contaminated (E5) and that the virus survives maturing of the carcass and is not removed by the deboning process (E6). To estimate the risk that the final product (beef for export) is contaminated, qualitative or quantitative estimates must be made for each adverse event in the scenario that allows the virus to remain in the chain of events.

\[
P_{\text{contam.}} = P_1 \times (1-P_2) \times (1-P_3) \times (1-P_4) \times P_5 \times P_6
\]

**Fig. 1**
Scenario pathway for the risk of contaminating meat with foot and mouth disease virus

The probability of selecting an infected herd as a source for export beef (P1) is a function of the epidemiological situation and the incidence of FMD in the zone in which the source farms are located. The probability of detecting FMD through the animal health system (P2), on the farm or during slaughterhouse inspections (P3, P4), depends on the efficiency of the animal health system and inspection services. The probability that the carcass is contaminated (P5) is a function of the number of viraemic cattle in the herd being slaughtered.
The outcome of the maturation and deboning process ($P_6$) depends on several factors. Cottral et al. noted that not all virus in the carcass was eliminated by the maturation process or deboning (4). The effectiveness of the maturation depends on FMD virus inactivation by lowering the pH of the meat. The pH change depends on the amount of glycogen in the muscle at the time of slaughter, which in turn is influenced by the general health and the required resting period of the animal. In addition, the desired pH is not usually reached within lymph glands, bone marrow or the contents of the large blood vessels (4). These parts are therefore removed during deboning, but the possibility of human error in pH measurements or in removing the required parts must be considered. For instance, blood clots, bone chips and pieces of large vessels or parts of lymphatic glands may not be completely removed. In addition, virus is likely to survive in blood enclosed in chunks of fat, which are not affected by the decline in pH, or in organs such as the liver or kidneys.

The estimates for the probabilities of failure to detect infected cattle are highly dependent on the stage of the infection in the herd. In this regard, four disease stages can be distinguished that impact differently on a risk assessment. These are the incubation period, the period of clinical signs, the convalescent period and the carrier state.

**Incubation period**

Following natural exposure to the virus, the incubation period for FMD is usually from two to seven days, during which time the virus starts to replicate in the naso-pharyngeal area (9). Viraemia then can commence a few hours after infection, but usually not later than 24 h-36 h post infection. The lung can be an additional portal of entry of the virus, which then enters the bloodstream, followed by haematogenic infection of the pharynx and other replication sites simultaneously (e.g. the germinative layers of the skin and mucosa) (18). The viraemia results in FMD virus in the muscles, lymph glands, bone marrow, organs, etc. (12). If none of the cattle in the herd have developed macroscopic lesions, the herd is likely to pass all farm and slaughterhouse inspections. Table I presents the answers to the questions in the scenario pathway (Fig. 1) when cattle are slaughtered for export of meat during the incubation period.

**Period of clinical signs**

Shortly after the onset of viraemia, the cattle develop a high fever and within 12 h-24 h show the characteristic vesicles or blisters on the tongue, muzzle, nostrils, in the mouth and on the feet. Salivation is excessive and the animals show an unwillingness to stand up or walk. Clinical FMD is usually easy to recognise in a group of cattle because some obviously sick animals will have a high fever, excessive salivation (with or without visible mouth lesions) or lameness. Mortality usually does not exceed 5%, but may be very high in young animals. In areas in which the disease is enzootic or in regions in which systematic vaccination is practised, morbidity may be reduced and clinical signs less pronounced (16). However, these clinical signs are unlikely to escape notice while the cattle are on the premises of origin. If early signs of illness are missed at farm inspection, signs or lesions are likely to be detected during ante-mortem or post-mortem inspection at the slaughterhouse. A single animal with an FMD lesion will disqualify all cattle in the herd and all the contacts of these animals for meat export. The entire zone from which the cattle originate is likely to be compromised. Cattle showing clinical signs may be viraemic and consequently have FMD virus in the muscles, lymphatic glands, bone marrow, organs, etc. For herds with cattle showing clinical FMD, qualified answers to the questions posed in Figure 1 are presented in Table I.

**Convalescent period**

Most affected animals will recover in approximately two weeks. During the convalescent period, healing of tongue or foot lesions will be discernible for up to thirty days following

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Table I

Qualified answers to the questions posed for each of the events in the scenario pathway

<table>
<thead>
<tr>
<th>Event</th>
<th>Description</th>
<th>Incubation period</th>
<th>Period of clinical signs</th>
<th>Convalescence</th>
<th>Carrier stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_1$</td>
<td>Herd selected for export of meat</td>
<td>Yes</td>
<td>No, unlikely</td>
<td>No, unlikely</td>
<td>Yes</td>
</tr>
<tr>
<td>$E_2$</td>
<td>Infected herd detected before leaving the farm</td>
<td>No</td>
<td>Yes, likely</td>
<td>Yes, likely</td>
<td>No</td>
</tr>
<tr>
<td>$E_3$</td>
<td>Infected herd detected at ante-mortem inspection</td>
<td>No</td>
<td>Yes, likely</td>
<td>Yes, likely</td>
<td>No</td>
</tr>
<tr>
<td>$E_4$</td>
<td>Infected herd detected at post-mortem inspection</td>
<td>No</td>
<td>Yes, most likely</td>
<td>Yes, most likely</td>
<td>No</td>
</tr>
<tr>
<td>$E_5$</td>
<td>Carcasses contaminated</td>
<td>Yes</td>
<td>Yes, most likely</td>
<td>No, very unlikely</td>
<td>No, likelihood close to zero</td>
</tr>
<tr>
<td>$E_6$</td>
<td>Virus survival after treatment of contaminated carcasses</td>
<td>Yes, likely</td>
<td>Yes, likely</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>
infection and is usually clearly visible at port-mortem inspection. A single animal with FMD lesions will disqualify the entire group for meat export, in addition to the contacts of this group, and will probably affect the zone of origin of the animals.

Antibodies, which start to develop at five to fourteen days post infection, will clear FMD virus from the blood and tissues, including muscles, lymphatic glands, bone marrow and organs. Answers to the questions raised for each of the events in Figure 1 are listed in Table I. The principal difference in comparison with the previous group (clinical signs) is the development of antibodies and consequently, a lower probability of virus persisting in the carcass and organs.

**Carrier state**

During the first three months post infection, the proportion of FMD carriers with small amounts of FMD virus persisting in the throat may reach 50% of the recovered cattle. This number decreases with time, and the percentage of carriers remaining at two years post infection is usually low (17). Vaccinated cattle exposed to FMD virus can become carriers without showing clinical signs.

Carrier cattle are unlikely to have scars on the tongue or foot epithelium and will escape detection at the farm of origin and at ante-mortem or post-mortem inspection. The FMD virus is found only in small quantities in the pharyngeal area. Carriers have high levels of circulating FMD antibodies and no FMD virus is found in the blood, bone marrow, lymphatic glands or muscle tissue.

Circumstantial evidence strongly suggests that carrier cattle may initiate an outbreak of FMD among susceptible cattle, although experimental proof of this theory has been difficult to obtain (17, 19).

For herds containing FMD carrier cattle, the answers to the questions posed in Figure 1 are presented in Table I.

**Risk mitigation for foot and mouth disease in beef**

The qualified answers to the questions in Figure 1 for each of the disease stages are shown in Table I. These answers can also be stated in terms of risk levels, ranging from high to negligible, according to the likelihood that the adverse event will occur. Risk levels for each event for the four disease stages are listed in Table II.

During the periods of clinical disease and convalescence, the first four events in the scenario (selection, farm and two slaughterhouse inspections) show only a moderate to low risk. Efficient disease surveillance and animal health systems, combined with ante-mortem and post-mortem inspection of all cattle in the slaughterhouse effectively reduce the FMD risk for international trade in meat. Discovery of even a single infected animal at any of these events is likely to result in discontinuation of the meat export process from the zone of origin. Thus, in the case of cattle with acute or convalescent FMD, the accumulation of the low to moderate risks for failure of FMD detection means that FMD virus is very unlikely to remain in the chain of events. Clearly, this implies the existence of effective and reliable controls at the farm of origin and by meat inspection services.

The risk reduction measures are not effective for cattle in the incubation period of FMD. These cattle may be selected and may have large amounts of FMD virus circulating in the bloodstream, and consequently in muscles, lymph glands, bone marrow and organs. In the absence of clinical lesions, such animals are not detected at the farm or at ante-mortem and post-mortem inspections at the slaughterhouse. Since the risk for all events is high during the incubation period, the carcass is very likely to be contaminated with FMD virus. Maturation and deboning of the carcass will eliminate most of the virus, but beef from cattle slaughtered in the incubation period is likely to pose a considerable risk.

### Table II

<table>
<thead>
<tr>
<th>Event</th>
<th>Description</th>
<th>Incubation period</th>
<th>Period of clinical signs</th>
<th>Convalescence</th>
<th>Carrier stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td>Herd selected for export of meat</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>1–P₂</td>
<td>Failure to detect infected herd before leaving the farm</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>1–P₃</td>
<td>Failure to detect infected herd at ante-mortem inspection</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>1–P₄</td>
<td>Failure to detect infected herd at post-mortem inspection</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>P₅</td>
<td>Carcasses contaminated</td>
<td>High</td>
<td>High</td>
<td>Very low</td>
<td>Negligible</td>
</tr>
<tr>
<td>P₆</td>
<td>Virus survival after treatment of contaminated carcasses</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

**Table II**

**Risk level for each of the events in the scenario pathway**
The mitigations mentioned for cattle with clinical FMD or for those in the convalescent period do not apply to FMD carrier cattle. Such animals can very well be selected and pass all farm and slaughterhouse inspections. Therefore, the question asked repeatedly in discussions with stakeholders concerns the risk posed by healthy carriers.

Carrier cattle have high antibody levels and do not have virus in the bloodstream, muscles, lymph glands or other organs (17). However, superficial mechanical contamination of beef by virus present in the throat is a risk to be considered. At the slaughterhouse, the cattle are stunned, hoisted (head down) and exsanguinated. After the skin is removed, the head (including tongue and the pharyngeal area) is removed from the carcass. No further contact occurs between the head and the rest of the carcass. Tongues and adjacent tissues are removed from the rest of the head and processed separately. Pharyngeal tissue, including tonsillar tissue, is removed from the tongue and collected for rendering. Tongues are then rinsed with a strong jet of water and in the unlikely event that the minute amounts of pharyngeal virus contaminate the tongue surface, such virus will be rinsed off or at least diluted to a virtually insignificant quantity.

Thus, the risk of mechanical contamination of the carcass or organs with ‘carrier virus’ from the pharyngeal area during slaughter and processing is negligible.

Discussion and conclusions

Efficient disease surveillance systems and properly functioning Veterinary Services and slaughterhouse inspections are the most important risk reduction factors in preventing the selection of infected herds for the production of beef for export. If an infected herd were selected, FMD would probably be detected at least in some cattle, and the whole herd and contacts would be disqualified for the export of meat.

However, inspections would fail in the unlikely event that none of the cattle in an infected herd showed FMD lesions. Some of those cattle probably could be viraemic with heavy virus loads of the muscles, lymphatic tissues and organs. According to a collaborative study by laboratories in Europe (7), the bleeding of viraemic cattle at slaughter removes most virus from skeletal muscles, and the maturation of the carcass further lowers the infectivity of the meat. However, the collaborative study fails to speculate on the enormous quantity of infectious virus (10^8-10^9) that may leave the slaughtered animal with the blood. Some of that infectious blood undoubtedly splashes on the floor, boots and protective clothing of workers and inspectors.

Excretions such as faeces and urine are also likely to be highly contaminated with FMD virus (12), and the breath exhaled by viraemic animals is extremely infectious (15, 19). Thus, highly infectious aerosols will also be produced during the processing of viraemic cattle by driving the animals up the chutes, killing and bleeding, removal of the skin and viscera, and splitting the carcass in half.

Under favourable conditions of temperature and a high relative humidity, airborne virus was shown to have a low inactivation rate (5). Low decay rates were also obtained with FMD viral aerosols from nasal fluid, milk or faecal slurry (6). Researchers at the Animal Virus Research Institute, Pirbright, UK, obtained infectious aerosols from stables housing FMD-infected pigs. Removal of the infected pigs led to an immediate reduction in virus recovered (of twenty-five-fold or more), but infectious virus persisted in the air of the stables for at least 24 h (13). Hosing down the boxes with water after removal of the infected pigs reduced the concentration of FMD virus in the air, a heavy spray causing a greater fall in titre than a light spray. The heavy spray brought about the greatest reduction in titre of the infectivity associated with larger aerosol particles but the infectivity associated with the smaller particles remained almost unchanged (14).

Official approval of a slaughter plant for beef export is based on general hygiene and good management practices, including the existence of reliable meat inspection services. However, abattoirs are not built to contain FMD virus and the virus will easily escape from the slaughterhouse in the event of processing of viraemic animals. Although tables and equipment are cleaned with hot water, detergents and steam at the end of the working day, the use of water from high pressure hoses to clean the contaminated premises may even cause virus to become aerosolised. The temperature of this water generally will not be sufficiently high to kill the virus. The cleaning of chutes and ramps soiled with contaminated faeces and urine is also likely to produce infectious aerosols. Thus, normal routine cleaning procedures probably do not remove all FMD virus from the premises of a slaughterhouse that becomes grossly contaminated with FMD by the processing of cattle during the incubation period. If the carcasses are removed from cold storage after 24 h, the environment in which the matured carcasses are further processed cannot be guaranteed to be virus-free.

Regulatory veterinary authorities and professionals involved in slaughterhouse inspection and management may not fully recognise this risk because the maturation of the carcass is generally believed to destroy FMD virus in beef. For instance, the scientists conducting the European study (7) noted that most of the FMD virus was eliminated from the musculature of the carcasses immediately after slaughter, but failed to indicate that the virus would instead remain on the abattoir floor and other surfaces. In addition, the OIE Code does not address this problem specifically.

Cottral reviewed the persistence of FMD virus in the environment at ambient temperatures (3). The survival time of virus for various contaminated materials such as blood, barn dirt, hay, feed sacks, clothing and footwear can be measured in terms of weeks. Other researchers at the Plum Island Animal Disease Laboratory, Greenport, USA, showed that FMD virus
remained infectious for a month to over a year on meat packaging materials, such as meat wrappers, experimentally contaminated with infected bovine tissues, when stored at + 4°C (8).

Therefore, it seems reasonable to assume that contamination of personnel and products leaving the premises, including packaging material and vehicles, cannot be excluded.

Over-reliance on maturation and deboning of carcasses may create a false sense of security, but these measures fulfil important social and economic functions. The low pH of the meat prevents the replication of some human pathogens and thereby improves the safety of the meat. The deboning and the preparation of special cuts create work opportunities and require a considerable labour force in the area of the slaughterhouse, thereby stimulating development of the local economy. In addition, products can be selectively sold to those markets which pay the highest prices, and overall transportation costs of the final product may be lower.

The scenarios described, other than the slaughter of animals in the incubation period, show that the set of mitigation measures applied are effective in reducing the risk. Unfortunately, mitigation of the risk is difficult when animals incubating the disease have been selected for slaughter and processing. Maturation is not fully effective in eliminating FMD virus in beef and meat products originating from viraemic cattle. Therefore, emphasis must be on disease surveillance within the zone and on the farms of origin to prevent the selection of herds incubating FMD at time of slaughter. The degree of confidence of the importing country in the disease surveillance of the exporting country should be the most important factor in considering the importation of meat from a certain region.

Aperçu des mesures d’atténuation des risques liés à l’importation de viande bovine en provenance de pays infectés de fièvre aphteuse

P. Sutmoller

Résumé
Les mesures destinées à atténuer les risques associés à l’importation de viande bovine en provenance de pays infectés de fièvre aphteuse sont les suivantes : surveillance des élevages d’origine, inspection des abattoirs, maturation et désossage des carcasses. L’auteur évalue l’efficacité de ces mesures d’atténuation du risque sur la viande provenant de bovins atteints de fièvre aphteuse aux quatre stades de la maladie, à savoir : la période d’incubation, la phase de symptomatologie clinique, la convalescence et enfin le portage. Lorsque les animaux sont abattus pendant les phases de symptomatologie clinique ou de convalescence, l’application de mesures zoosanitaires efficaces, la surveillance de la maladie ainsi que l’inspection ante et post-mortem de tous les bovins permettent une réduction effective du risque de transmission de la fièvre aphteuse. Lorsque les bovins sont abattus pendant la phase d’incubation, c’est-à-dire avant l’apparition des signes cliniques, ces mesures s’avèrent insuffisantes. En effet, les bovins à ce stade peuvent présenter une virémie, le virus pouvant être présent dans les muscles. La maturation des carcasses provenant de bovins viraémiques réduit le risque de présence de virus dans la viande bovine. En outre, le désossage et l’élimination des principaux ganglions lymphatiques et des gros vaisseaux sanguins suppriment une source de
L’abattage de bovins porteurs présente un risque négligeable pour le commerce international de la viande bovine.

**Mots-clés**

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**Repaso de las medidas de reducción de los riesgos ligados a la importación de carne vacuna desde países infectados de fiebre aftosa**

P. Sutmoller

**Resumen**
Las medidas para reducir los riesgos asociados a la importación de carne vacuna desde países donde haya fiebre aftosa consisten básicamente en: vigilancia en la explotación de origen; inspección de mataderos; y maduración y deshuesado de las canales. El autor evalúa la eficacia de esas medidas para reducir los riesgos de transmisión de fiebre aftosa por carne vacuna en cada una de las cuatro fases de la enfermedad, esto es: el periodo de incubación, el de sintomatología clínica, el de convalecencia y el del estado de portador. Un sistema zoosanitario y una vigilancia de la enfermedad eficaces, juntos con la práctica de inspecciones de todos los ejemplares antes y después del sacrificio sirven para rebajar eficazmente el riesgo de transmisión de fiebre aftosa cuando los animales son sacrificados durante el periodo clínico o el de convalecencia. Si el sacrificio tiene lugar durante la fase de incubación, antes por lo tanto de que aparezcan signos clínicos, estas medidas resultan ineficaces. En esta fase, existe el riesgo de viremia, con presencia de virus en los músculos. La maduración y el deshuesado reducen el riesgo de presencia vírica en esos bovinos. El deshuesado y el descarte de los principales nodos linfáticos y vasos eliminan una fuente adicional de contaminación en la carne. Con todo, el sacrificio de bovinos virémicos aumenta gravemente el riesgo de contaminación del medio ambiente del matadero por el virus. Por lo tanto, el proceso de maduración puede dar lugar a una sensación ilusoria de seguridad. Más vale poner un énfasis en la vigilancia de la enfermedad dentro de la zona afectada y en las granjas de origen, de manera a impedir que ganado en fase de incubación del virus de fiebre aftosa llegue a los mataderos.
El sacrificio de ejemplares portadores conlleva un riesgo insignificante para el comercio internacional de carne vacuna.

**Palabras clave**
References


