FOOT AND MOUTH DISEASE (FMD) IN LIVESTOCK

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History

Foot and mouth disease is a viral disease that infects cloven-hoofed animals including cattle, pigs, sheep, and many wildlife species (Thomson, Vosloo, & Bastos, 2003). The history of FMD shows that foot and mouth disease started in the 16th century and was an epidemic disease that caused serious damage to cattle disease (Woods, 2013). Frosch and Loeffler, two well-known scientists in the late 19th century demonstrated that FMD was caused by filterable transmissible agents that were sub-microscopic and were smaller than any well-known bacteria(Bos, 1999). It was considered the first virus that could infect vertebrates(Mahy, 2005). Waldman and Pape studied the Foot and mouth disease virus on guinea pigs and later in vitro cell culture in 1920 (Mahy, 2005). The chemical and physical characteristics of foot and mouth disease viruses were studied and demonstrated in the late 20th century (Grubman & Baxt, 2004). In 1989 the three-dimensional structure of the virus was described(Prasad, Yamaguchi, & Roy, 1992).

Importance and Economic Impacts of FMD

Foot and Mouth Disease has a significant impact on livestock animals (Thomson et al., 2003). It has posed serious damages to livestock industries in such a way that it has decreased the livestock productivity rate in huge amount (T. J. Knight-Jones & Rushton, 2013). It has low mortality in general but often shows high mortality in young animals because they often have myocarditis (Jonathon Arzt et al., 2011). FMD is a WOAH (World Organization of Animal Health) listed disease and must be reported to the organization (Singh, 2023). Foot and Mouth disease is not a zoonotic disease (It, 2001).

The signs and symptoms of the Foot and Mouth Disease virus show blisters on the mouth region (tongue and Lips) as well as in between the hooves and on the teats that are followed by high-grade fever (Pikul, Ilchenko, & Prylutskiy, 2019). It is a serious disease but often animals do recover from this disease but it leaves the animal body systems weakened and debilitated (Stenfeldt, Diaz-San Segundo, De Los Santos, Rodriguez, & Arzt, 2016).

Visible loss includes loss of milk production, loss of draught power, lower weight gain, and death of animals (Admassu, Getnet, Shite, & Mohammed, 2015). The invisible losses include fertility problems, changes in herd structure, and delays in sales of animals and livestock products (Souley Kouato et al., 2018). The additional costs include vaccines, vaccine delivery, Movement control, Diagnostic Tests, and culled animals while revenue foregone includes use of suboptimal

breeds and denied access to markets both local and international (T. J. D. Knight-Jones, McLaws, & Rushton, 2017).

Another significant impact of Foot and Mouth Disease is its socioeconomic impact in the regions that depend on livestock production to meet their daily requirements and necessities. It creates a pessimistic effect on the farmers (Baluka, 2016).

Etiology

Causative agent

The causative agent of Foot and mouth disease is Foot and Mouth Disease virus(Grubman & Baxt, 2004). Foot and Mouth Disease Virus is a species that belongs to the genus Aphthovirus of the family Picornaviridae(Domingo, Baranowski, Escarmís, & Sobrino, 2002). This family belongs to the order Picornavirales (Zell, Knowles, & Simmonds, 2021). Foot and mouth disease virus species have 7 serotypes (Callens & De Clercq, 1997)..



Figure 1. Causative agents of FMDV

These serotypes are differentiated from each other according to the antigenic diversity (Tayo, 2011).

Characteristics

The molecular characteristics of the Foot and Mouth Disease virus denote that it is a non-enveloped virus with icosahedral symmetry(Carrillo, 2012). Foot and Mouth Disease virus consists of a positive sense single-stranded RNA molecule with 8.5kbp length(Sarangi et al., 2015). The 3' end of its RNA genome is polyadenylated while the 5' end is covalently linked to a small protein called VPg (Domingo et al., 2002). The replication occurs according to the same pattern as of other viruses of the family Picornaviruses i-e in the cytoplasm membrane-bound replication complex (Rowlands, 2003).

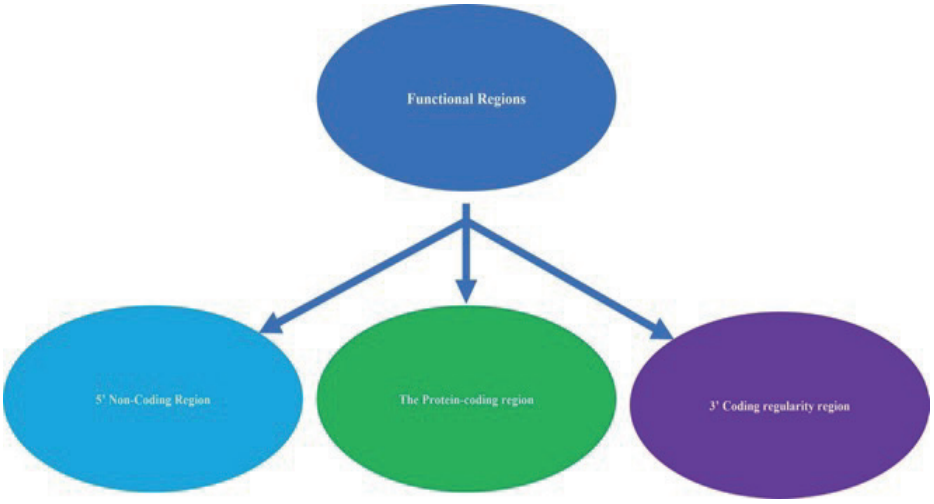


Figure 2. Functional regions of genome of FMDV

The structural characteristics of Foot and Mouth disease virus show that it has icosahedral

head with 60 copies of each of 4 capsids (structural proteins) Vp1-VP4 (Zhu, 2017). The diameter of the particle of Foot and Mouth Disease Virus is 30nm (Liu et al., 2019).

Host range

Cloven hoofed animals mostly of order Artiodactyla are greatly affected by FMDV(Vosloo & Thomson, 2019). The host range of Foot and Mouth Disease includes animals such as cattle, pigs, sheep and goats (Admassu et al., 2015). It also infects some wild animals of the same order. Such as buffalo, giraffe, camel and deer (Weaver, Domenech, Thiermann, & Karesh, 2013).

Epidemiolgy

Though Foot-and-Mouth disease is highly contagious disease and is endemic throughout the Asia (Jamal & Belsham, 2013).

Distribution in Asian countries

FMDV has prevailed in different regions of Asia, these countries have a history of wide range of outbreaks of FMD (Rweyemamu, Roeder, Mackay, Sumption, Brownlie, Leforban, et al., 2008). FMD has a headache of livestock for decades (Aslam & Alkheraije, 2023). A total of 1,478 small ruminants were tested for seroprevalence and 22.8% were reported as FMD in Pakistan (Aslam & Alkheraije, 2023). In India, geographically the prevalence was reported to be 31.5%, 11.6%, 4.4%, 5%, and 4% in southern, North-eastern, western, Eastern, central and North regions (Aslam & Alkheraije, 2023). In Afghanistan, over the past few decades conflicts has been ongoing that have resulted in massive destruction of infrastructure of the country (Wajid, Chaudhry, Rashid, Gill, & Halim, 2020). Illegal transboundary movement of livestock between the Pakistan and Afghanistan border has boosted the spread of FMD (Aslam & Alkheraije, 2023). Between 1995 and 2008, the total number of outbreaks reported were 4,171 (Osmani, Robertson, Habib, & Aslami, 2019). In Bangladesh, the prevalence of FMD in Raj Shahi region was reported 25.7 million (Samad, 2019). In China, serotypes O and A were prevalent and effect 17 regions on China mainland (Guo et al., 2006). The Asia 1 serotype was eradicated in 2009, and since 2010, only serotypes O and A have been observed in northwestern and southeastern China (Aslam & Alkheraije, 2023). In Mongolia, 44 outbreaks of FMD were reported in goats, camels, sheep and cattle (Shiilegdamba, Carpenter, Perez, & Thurmond, 2008). In Kazakhstan, 76,851 cases were reported in which 8% tested positive. In Russia, high morbidity was seen in pigs and cattle (Aslam & Alkheraije, 2023).

Table 1. Prevalence and percentage of FMD in Asian countries

Countries	**prevalence**
Pakistan	22.8%
India	21%
Iran	1381 cases
Iraq	48.64%
Bangladesh	25.7%
Afghanistan	20%
Kazakhstan	8%
Russia	79%
Mongolia	Serotype O and A
Egypt	48-68%
China	Serotype O and A
Kuwait	2722 cases till 2016, still reporting
Oman	64 cases from 2011-2015

UAE	Serotype O, A and Asia1 reported
Turkey	Serotype O, A and Asia1 reported

Transmission

The transmission is facilitated when the virus sheds from ruptured vesicles into the bodily secretions and excretions (Feng, Hirai-Yuki, McKnight, & Lemon, 2014). The virus enters in the body via ingestion and also by inhalation (Pal, 2018). The transmission of FMDV occurs both directly and indirectly (Jonathan Arzt, Juleff, Zhang, & Rodriguez, 2011). The direct contact is done by animals, there secretions such as saliva, semen, milk, urine and feces while the indirect transmission occurs via air, wind, fomites and other mechanical conditions like vehicles and humans (mechanical vectors) (Sandip Chakraborty et al., 2014). Pigs are mostly resistant to the aerosol transmission of Foot and Mouth Disease virus (Alexandersen, Brotherhood, & Donaldson, 2002).

Table 2. Different routes of FMDV transmission

Transmission routes		**References**
Direct animal contact	*Most common transmission route*	*(Paton, Gubbins, & King, 2018)*
Animal products	*Through ingestion of animal products e.g. feeding of waste food or untreated milk to young animals*	*(Tomasula & Konstance, 2004)*
Mechanical transmission	*Transmission through virus particles and inanimate objects such as footwear, clothing, vehicles and instruments.*	
Wind	*It's not common, but it's possible, especially if pig farms are in the vicinity and under certain weather conditions, e.g., cool and high humidity temperatures.*	*(J. Arzt, White, Thomsen, & Brown, 2010)*

Pathıgenesis

After the transmission of the foot and mouth disease virus that is either transmitted by direct contact or indirect contact the virus enters the body and adheres to the mucosa of pharynx in the respiratory tract (J. Arzt, Pacheco, & Rodriguez, 2010). After its attachment to the mucosal cell membrane of pharynx in the respiratory tract it is spread to the secondary sites (Admassu et al., 2015). Macrophages play the role of transporting virus to the secondary sites such as epithelium, other mucosal cells and myocardium (Meidaninikjeh et al., 2021). In the secondary sites the virus replicates, it penetrates the host cells and uses its DNA to make copies of its RNA and proteins. After the assembly of the virus inside these secondary site cells the cell burst and the virus enters the blood, causes systemic infection called as viremia. After the viremia the virus infects epithelial at many other sites and within few days the vesicles develop (Fuller, Von Bonsdorff, & Simons, 1984). The process of pathogenesis takes 2 weeks and the clinical signs and symptoms appear after 2 weeks. The young animals get necrotizing myocarditis (a heart disease) and eventually dies (Błyszczuk, 2019).

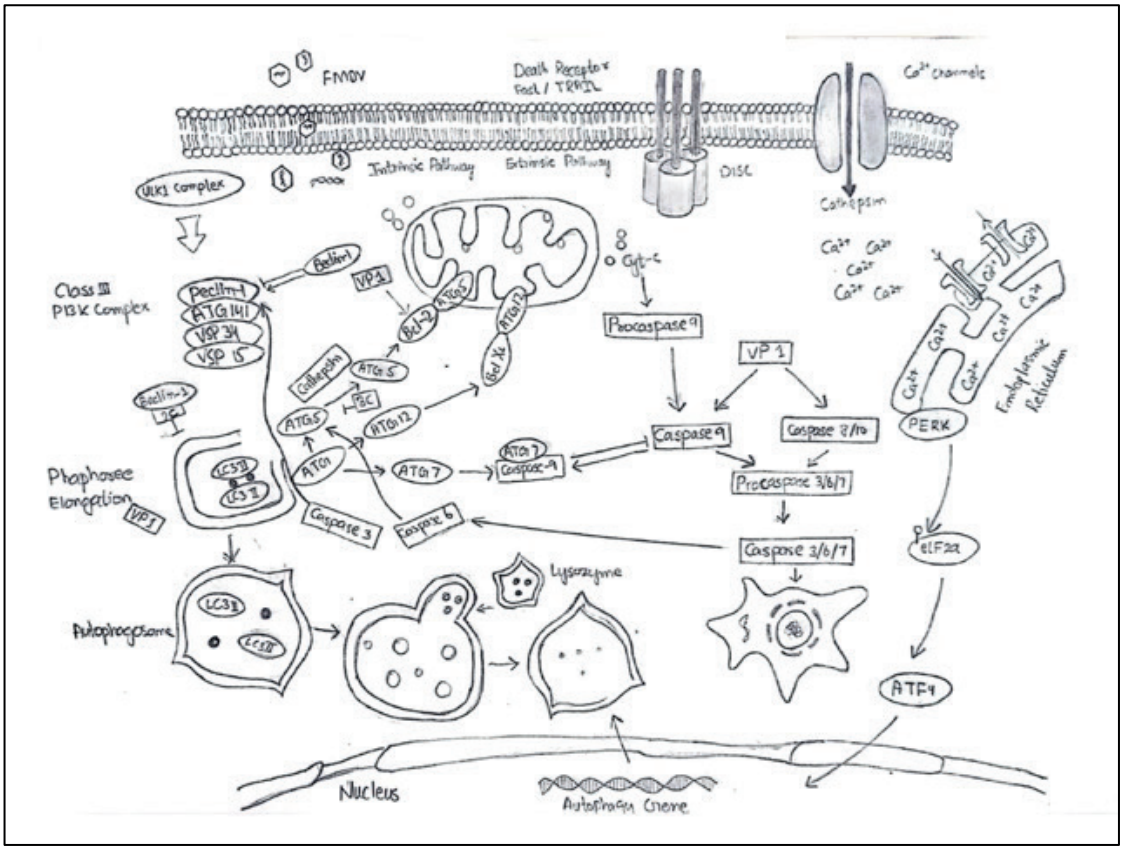


Figure 3. Immunity to Foot-and-Mouth disease virus

Clinical Signs and Diagnosis

This ssRNA virus show various signs after invading living body (Nelemans & Kikkert, 2019). The clinical signs include Lameness or ataxia, vesiculation, profuse salivation and ulceration are the common manifestation in cattle (Petrovski, 2015). Vesiculation on the nose including the snout and muzzle are the major lesions observed in infected beef cattle and pigs. The teat and feet were the second most frequently vesiculated body parts on infected pigs. Other symptoms observed are fever, loss of appetite, weight loss, hypersalivation, growth retardation, depression and severe decrease in milk production, which could persist after recovery (Attia).

Generally, FMD can be identified on the basis of clinical signs. Severity of symptoms may be due the several reasons, such as species and the age of animal, dosage of exposure, virus strains and host immunity to virus (Klein, 2009). So, diagnosis based on clinical signs are unreliable due to the other several disease share symptoms as FMD. However, confirmatory laboratory diagnosis of suspected FMD case is vital. Conventional techniques are routinely used like CFT (Complement-fixation test), VNT (Virus neutralizing test), virus isolation test and ELISA (enzyme-linked immunosorbent assay). VNT and CFT are well-established and now using to detect FMD (Binti Senawi, 2019).

Nucleic acid detection methods are used to detect the presence of viral nucleic acids (Haase, Brahic, Stowring, & Blum, 1984). As these methods involve amplification of viral nucleic acids, they have higher sensitivity compared to serological methods. Reverse Transcriptase-Loop-Mediated Isothermal Amplification capable of amplifying DNA at a single temperature at 60-65°C (Naveen & Bhat, 2020).

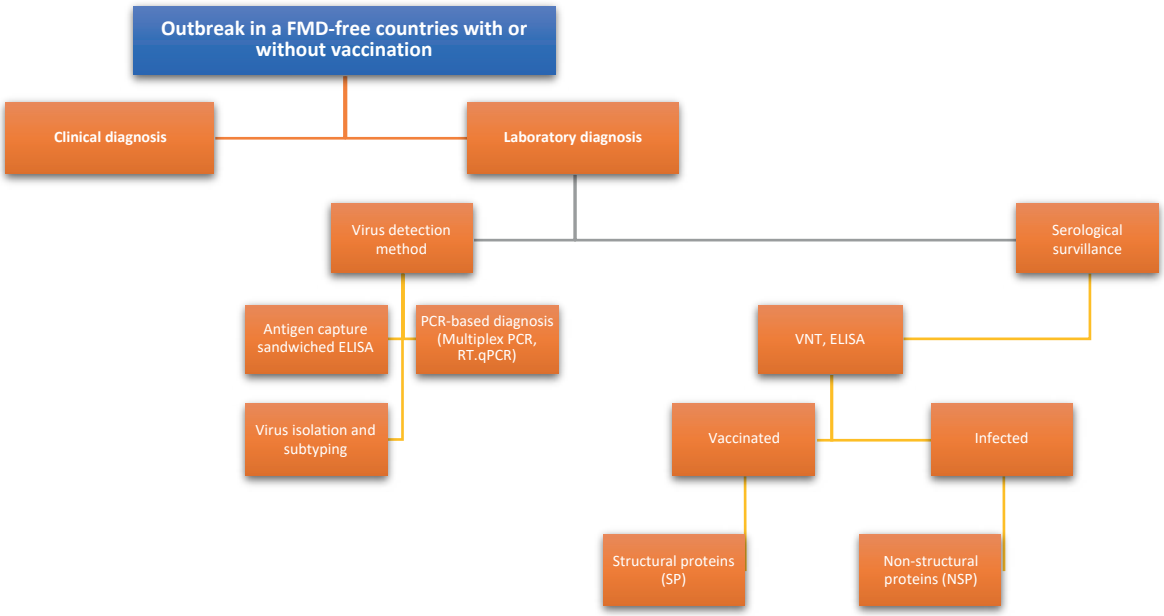


Figure 4. Laboratory tests for determining FMD

Impact on Livestock and Economy

FMD is a contagious viral disease that effect the cloven-hooved animals (deer, cattle, pigs, goats and sheep etc.) cause fever and vesicular eruption in nose, feet, muzzle and on mammary glands after which they became erosions (Sandip Chakraborty et al., 2014). It causes severe morbidity and mortality in livestock. It can reduce the productivity of animals and also effect the various ally in the entire livestock chain (Herrero et al., 2013). At micro level, it effects the primary producer due to the mortality and also causes reduction in milk yield (Lérias et al., 2014). The loss due to FMD are direct and indirect. Direct loss (80%) due to decreased production, and Indirect loss is due to the cost for FMD control and poor access to market can be indirect loss of economy. A big impact posed on world's poorest areas where people are dependent on livestock is also the major issue caused by the FMD (T. J. Knight-Jones & Rushton, 2013). FMD reduces the herd fertility leading to the less livestock production which effects the food security. FMD controls require large cost and its often difficult to discontinue control programs due to the risk of new FMD incursion (Kitching et al., 2007).

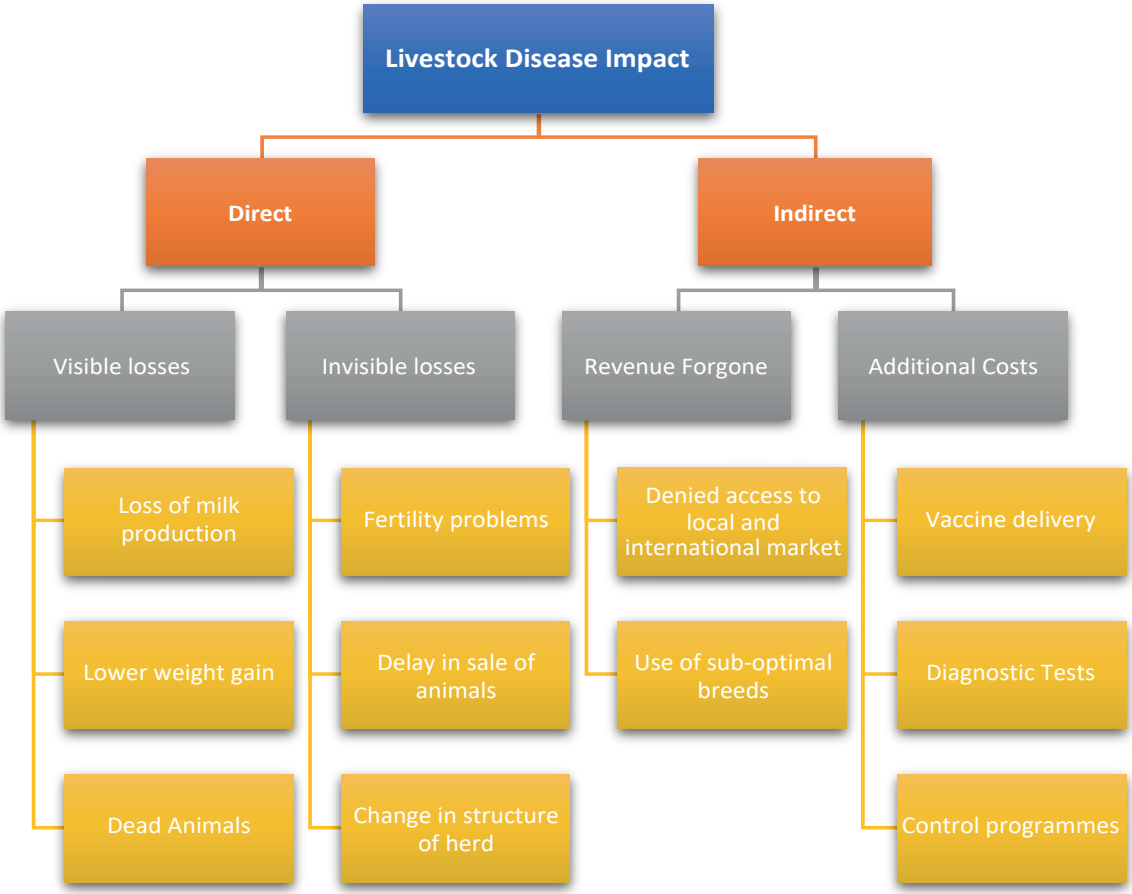


Figure 5. The impact of Foot-and-Mouth Disease.

FMD is present in the about 60% of countries in world and endemic in many countries (Rweyemamu, Roeder, MacKay, Sumption, Brownlie, & Leforban, 2008). It causes huge economic loss in livestock industry. In India 80% of the direct loss is due to the decreased milk production by the lactating animals. This disease has enormous economic consequences. In our country's production system, livestock serve multiple purpose like drought power for farming operations and milk to farm families (Herrero et al., 2013).

Thus, FMD permanently effects the productivity and health of animals and therefore can greatly affect the supply of milk, meat and dairy products (T. J. Knight-Jones & Rushton, 2013). Although many animals recover from this disease but this disease leaves them enfeeble and causes severe losses in milk and meat production (Law, 1906).

An FMD outbreak can affect the global economy by Billions of dollars by both direct and indirect losses (T. J. Knight-Jones & Rushton, 2013). To the government, direct cost would include for eradication and disease control such as maintenance of the animal movement control, disposal of infected animals, intensified border inspections, compensation to the products and costs of vaccine. FMD can also post negative impact on the food security and nutrition in developing countries (Kompas, Nguyen, & Ha, 2015). An FMD also has social impacts such as enormous physiological damage specially on families and localities directly affected by this disease.

Table 4. FMD affecting different species of animals, its symptoms, geographical distribution, percentage and impact on economy.

Species	Symptoms	Geographic Distribution	% impact on animals	Economic impact
Cattles	Shivering, slobbering and smacking lips, reduced milk yield, raised temperature, sores and blisters on feet, tender and sore feet, increased pulse and respiration	Worldwide, prevalent in Asia	Up to 90%	Loss in meat and milk production, trade restrictions affecting import and export
Pigs	Sudden lameness, blisters on snout and tongue	worldwide	100%	Loss in pork production, trade restrictions affecting export and import
Sheep	Sudden, severe lameness, lies down frequently, reluctant to move, blisters on hoof and dental pads	worldwide	90%	Reduced lamb and wool production
Deer	Mild symptoms, rarely severe	Limited cases reported	varies	Minimal economic impact due to the limited commercial importance
Goats	Fever, Blisters on tongue, mouth and feet	worldwide	90%	Lesions in meat and milk production
	varies	Africa, parts of Asia	varies	Economic impact due to the limited due to the commercial importance
Bisons	Similar to cattle	North America	varies	Economic impact varies by region affecting bison meat production

Prevention and Control

Prevention and Control have employed different means to eradicate the disease in a protective way (Almendras, 2001). The first step in any control program must be an absolute stand-still of livestock movement in the infected area. The biggest challenge is the destruction of infected animals without the spread of FMDV. Cleaning and disinfection of contaminated premises create additional hazards. So, it is difficult to control the disease because of their costly process (Carling & Huang, 2013).

If FMD enters your farm there are some steps to prevent this contagious disease. Strict biosecurity practices can help you to minimize the chances of getting exposure to disease. Use preventive measures to minimize the spread and introduction into your farm.

- Use strict biosecurity measures for animals and their products, people and equipment.
- Stop or restrict all animals to prevent spread or entry of disease.
- Observe, detect and report any clinical signs to your herd veterinarian as soon as possible

(Elbers et al., 2008).

- Limit access to your farm, keep the gate locked when not in use.
- Post signs to inform visitors to follow on your farm:
- Stay away from this farm until you get permission
- Hont before getting out of vehicle
- Check-in farm personnel upon arrival
- Follow farm biosecurity procedures
- Wear PPEs
- Avoid contact with animals specially those showing any kind of symptoms

- Educate yourself and train your employees about FMD and their ill signs (in previous mentioned chart) (Sieng et al., 2022).
- Discuss the threat of FMD with your neighbors.
- Eliminate the direct contact between animal across fence lines.
- Control normal moving animals in your farm like cats and dogs.
- Do not share equipment to other farms. (Ellickson, 1985).
- Change gloves and clothes properly and disinfect shoes when enter in to the farm. (Coronado et al., 2012).
- Wash hands after any contact with animals.
- Minimize the visitors to only those necessary for farm operations.
- Only one farm vehicle should be used.
- Record visitors on your log sheet.
- Provide the following items to visitors:
  - Clean head-covers and disposable or disinfected rubber foot wear
  - Facilities for disinfecting vehicles and all personnels
  - Pressure washers, brushes, water and EPA approved disinfectants for footwear and any equipment used
- Stop all the movements of animals on and off farm.
- Do not allow your animal to contact with neighbor's livestock.
- Fence off streams and rivers.
- Monitor animals closely
- Any animals that have recently been purchased should be quarantined for at least 30 days.
- Dispose of any bedding and manure from isolation areas. (Hutchison, Walters, Avery, Munro, & Moore, 2005).

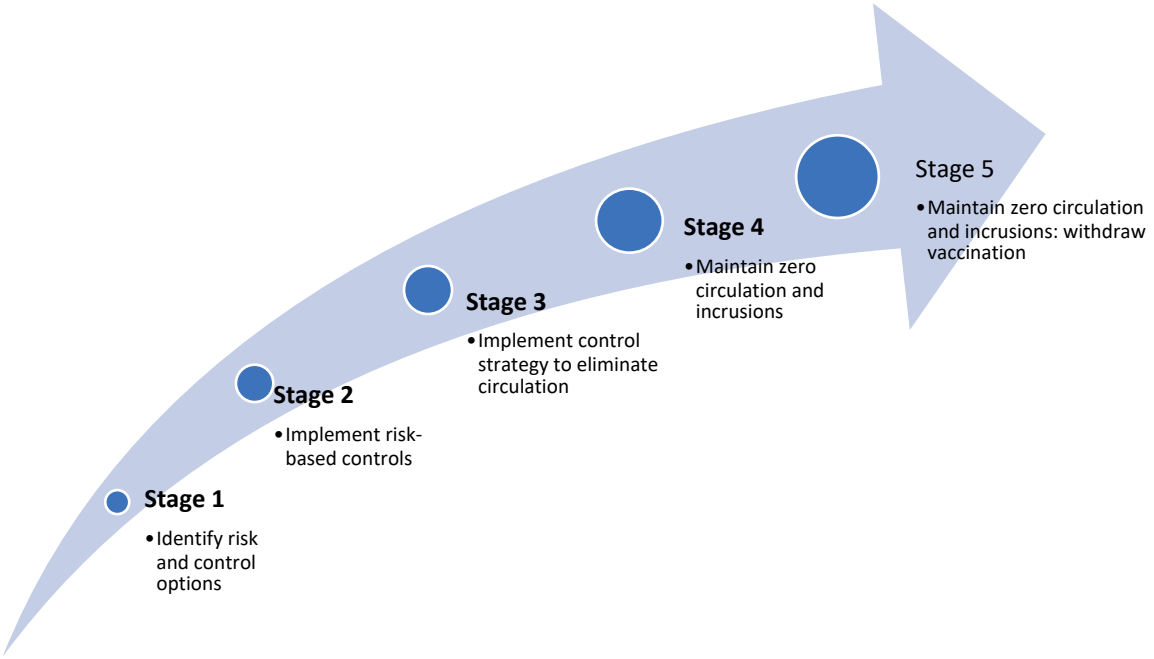


Figure 6. Stages in progressive control pathway for FMD.

Movement to a higher stage requires the completion of milestones indicated through arrows Stages 4 and 5 involve activities that lead to the submission of the application of official recognition of freedom (Donnelly, Mueller, & Gallahue, 2016).

FMD is controlled with quality vaccines containing appropriate FMD virus strains, also controlled by improving food security but it is difficult due to the existence of multiple serotypes of this virus, and multiple host species including wildlife. It is not currently possible to effectively control and eradicate FMD from the world because of a combination of technical constraints, an incomplete understanding of the epidemiology of the disease, and a lack of cost-effective disease control strategies (Kitching et al., 2007). Foot-and-mouth disease can be controlled by the cleanliness of animals and animal products. A slaughter policy was first applied in the UK in the late 19th century. Surveillance and early detection of FMD outbreaks are necessary. It involves clinical signs monitoring, conducting diagnostic tests, and reporting cases properly. During an outbreak, quarantine of animals becomes the major control of FMD from spreading. Spreading awareness to farmers, veterinarians, and community about the outbreak will help people to know the severity of disease so that it will help to cope-up with the disease rapidly (Pulla et al., 2021).

World has progressed a lot towards the control of Foot-and-Mouth disease through different eradication schemes.

Vaccination of FMD

Vaccination against Foot-and-Mouth disease is one of the control measures used during the FMD epidemic depending on the local epidemiological conditions (Rweyemamu, Roeder, MacKay, Sumption, Brownlie, & Leforban, 2008). A decision to make vaccination can be made only if there is enough knowledge on the effectiveness of the vaccination in eliminating the virus from the community. There are some points that need to be in mind are:

Immunity to FMD

Animals that are vaccinated or recovered from disease is mediated by the antibodies of which serum-neutralizing antibodies are more relevant in terms of protection (Plotkin, 2010). ELISA is quite extensively used in recent years, but this method measures the wide spectrum of antibodies.

Vaccine production environment

Production of vaccine and FMD antigens are carried out under the internationally recognized standard of GMP within the Quality assurance framework (De Clercq, Goris, Barnett, & MacKay, 2008).

Selection of Vaccine strains

After the confirmation of quality assured environment for vaccine production, selection of strain for vaccine preparation is the other major step. Although by vaccination control of FMD is complicated by the variability of antigen in virus, observers and vaccine producers are overplaying the issue (Doel, 2003).

Disease control strategy

This is difficult and controversial and there is no simple process to arrive at definite strategy for the control of FMD. The overall policy of any country and region affected by the disease will be based on the broad range of factors including cost.

Vaccine implication

The main issue in the safety of FMD vaccination is the target species. Foot-and-Mouth disease is contagious viral disease affecting livestock animals (Admassu et al., 2015). Commercial vaccines which are formulated with inactivated FMD virus, aluminum hydroxide/saponin or single or double emulsions for adjuvants are using worldwide for the control of disease in cattle. Animals immunized with high-load monovalent vaccine develop a high titer of antibodies at 7 days of postvaccination. However, it is difficult to remove all of the non-structural viral proteins that are produced during cell culture replication of FMDV and these can evoke antibodies that interfere with marker tests. Traditional vaccines remain the cornerstone for emergency and prophylactic uses.

Table 5. Importance of vaccine attributes in different situations (prophylactic and emergency vaccination).

Vaccine attributes	Prophylactic vaccination	Emergency vaccination
Rapid formulation	low	high
Rapid immunity onset	low	high
Thermostable formulation	high	medium
Antigenic broad spectrum	medium	medium
Efficacy	high	high
Negative marker	medium	high
Long lasting protection	high	low
Low production cost	high	medium
Low risk of virus release	high	high

Although current FMD vaccines can prevent clinical disease but the protection is short term (~6 months) requiring the booster doses for prophylactic control (Parida, 2009). Vaccination doesn't induce rapid protection against challenges or prevent the development of carrier state. So, it is clear that the length of protection depends on the expanse of immunization and duration of exposure methods.

World has progressed a lot towards the control of Foot-and-Mouth disease through different eradication schemes.

Table 6. Commercially available vaccines, their pros and cons.

Type	Name	Pros	Cons
Inactivated	Aftovaxpur DOE	Safe, no risk of disease	Booster dose required
Live attenuated	SAT2, No use due to safety concerns	Long lasting immunity	Reverse-attenuation
DNA based	Ad5-FMD	Stable and easy to produce	Need of adjuvants, less immunogenic
Peptide vaccines	VP1 synthetic peptides vaccine	Safe, no risk of disease, chemically stable	Requires adjuvants, less effective

Advances in FMD

There are more advances in the diagnosis of Foot-and-Mouth disease including the Nucleic acid detection method, ELISA, and chromatographic strip tests (Parida, 2009). Molecular-based techniques are used to detect the presence of viral nucleic acid. Up to date, improved versions of RT-PCR have been employed for the detection of Foot-and-Mouth disease virus. Multiplex RT-PCR with more advancement, automated electronic micro assay for the simultaneous detection and differentiation of different swine viruses including FMDV is used. Real-time quantitative PCR-based analysis with fluorescent emitting compounds has been used to measure the number of amplicons during amplification in real-time. RT-LAMP is needed for the detection of FMDV genomic sequence targeting the FMDV 3D RNA polymerase gene (Ranjan et al., 2014).

Serological methods including ELISA detect the presence of viral antigens or antibodies in serum or body fluids. Current ELISA is the modified version of the radioimmune assay. In this technique, the antigen is immobilized in the solid phase by either direct or indirect labeled antibody. To improve the performance of ELISA in FMD diagnosis many modifications have been made focusing on developing on the development of new coating antigens and monoclonal antibodies. Also, double sandwich ELISA further improved the sensitivity of FMDV detection to 125 times higher than the CFT. More effective and safer vaccines are created by genetic engineering using CRISPR and other gene-editing technologies (Teng, Yao, Nair, & Luo, 2021).

There are also advances in the eradication of Foot-and-Mouth disease. The Action Plan for the regional Hemispheric program for the eradication of FMD without vaccination resulted in the FMD-free status of the bovine population of South America. There have been some limited attempts to develop antiviral drug therapy that affects specific viral protein targets. The technology is used to specifically inhibit FMDV replication in cell culture. However, this technology has not been extended to be susceptible animals (McEwen & Fedorka-Cray, 2002).

Future Recommendations

Countries having FMD are facing trade barriers posed by FMD-free countries and they're having high economic losses to the livestock industry (T. J. Knight-Jones & Rushton, 2013). In the era of eradication of rinderpest, progressive worldwide control of Foot-and-Mouth disease must be regarded as a major contribution. The strategy for the control of Foot-and-Mouth disease in the endemic era should be based on seven stages.

1. Assessing and defining the FMS status
2. Vaccination and movement control
3. Virus transmission should be suppressed to overcome the disease
4. Need to achieve freedom from FMD with vaccination according to OIE standards
5. Achieve freedom from FMD without vaccination according to OIE standards

6. Extend the FMD free zones

7. Maintain the FMD freedom

These issues should be addressed to eradicate foot-and-mouth disease (Rodriguez & Gay, 2011). To effectively monitor the control program in a country, we need to place a national commission to coordinate all organizations associated with the FMD control program including the assurance of quality of vaccines. Another major aspect of the future regarding better ways to eradicate FMD is the timing of vaccination. Quality of vaccine should be the other important for the success of control programs. Make sure the use of monovalent vaccines where a particular serotype is prevalent for a long time, will reduce the cost of the operation. Maintenance of the cold chain is important as immunogenicity of antigen is lost by exposure to high temperature and repeated freezing. Susceptible livestock populations primarily cattle and buffalo, should be covered under the vaccination campaign. Centers for the Control of FMD need to enhance their surveillance strategy with target-based surveys that contribute to increasing the degree of sensitivity in the search for viral circulation in the context of the absence of clinical occurrence of FMD. These all measures will be helpful in the future for the successful eradication of Foot-and-Mouth disease (Pattnaik et al., 2012).

References

Admassu, B., Getnet, K., Shite, A., & Mohammed, S. (2015). Review on foot and mouth disease Distribution and economic significance. Academic Journal of Animal Diseases, 4(3), 160-169.

Alexandersen, S., Brotherhood, I., & Donaldson, A. I. (2002). Natural aerosol transmission of foot-and-mouth disease virus to pigs minimal infectious dose for strain O1 Lausanne. Epidemiology & Infection, 128(2), 301-312.

Almendras, J. M. E. (2001). Immunity and biological methods of disease prevention and control Health management in aquaculture (pp. 111-136) Aquaculture Department, Southeast Asian Fisheries Development Center.

Arzt, J., Baxt, B., Grubman, M., Jackson, T., Juleff, N., Rhyan, J., . . . Rodriguez, L. (2011). The pathogenesis of foot-and-mouth disease II viral pathways in swine, small ruminants, and wildlife; myotropism, chronic syndromes, and molecular virus–host interactions. Transboundary and emerging diseases, 58(4), 305-326.

Arzt, J., Juleff, N., Zhang, Z., & Rodriguez, L. (2011). The pathogenesis of foot-and-mouth disease I viral pathways in cattle. Transboundary and emerging diseases, 58(4), 291-304.

Arzt, J., Pacheco, J. M., & Rodriguez, L. L. (2010). The Early Pathogenesis of Foot-and-Mouth Disease in Cattle After Aerosol Inoculation Identification of the Nasopharynx as the Primary Site of Infection. Veterinary Pathology, 47(6), 1048-1063. doi 10.1177/0300985810372509

Arzt, J., White, W. R., Thomsen, B. V., & Brown, C. C. (2010). Agricultural Diseases on the Move Early in the Third Millennium. Veterinary Pathology, 47(1), 15-27. doi 10.1177/0300985809354350

Aslam, M., & Alkheraije, K. A. (2023). The prevalence of foot-and-mouth disease in Asia. Frontiers in veterinary science, 10, 1201578.

Attia, H. of Infections Diseases in Farm Animals.

Baluka, S. A. (2016). Economic effects of foot and mouth disease outbreaks along the cattle marketing chain in Uganda. Vet World, 9(6), 544-553. doi 10.14202/vetworld.2016.544-553

Binti Senawi, J. (2019). Antigenic epidemiology of foot-and-mouth disease understanding the limitations of in-vitro vaccine matching for Malaysian strains. University of Glasgow.

Błyszczuk, P. (2019). Myocarditis in humans and in experimental animal models. Frontiers in cardiovascular medicine, 6, 64.

Bos, L. (1999). Beijerinck's work on tobacco mosaic virus historical context and legacy. Philosophical Transactions of the Royal Society of London. Series B Biological Sciences, 354(1383), 675-685.

Callens, M., & De Clercq, K. (1997). Differentiation of the seven serotypes of foot-and-mouth disease virus by reverse transcriptase polymerase chain reaction. Journal of virological methods, 67(1), 35-44.

Carling, P. C., & Huang, S. S. (2013). Improving healthcare environmental cleaning and disinfection current and evolving issues. Infection Control & Hospital Epidemiology, 34(5), 507-513.

Carrillo, C. (2012). Foot and mouth disease virus genome Viral genomes-molecular structure, diversity, gene expression mechanisms and host-virus interactions Citeseer.

Coronado, G. D., Holte, S. E., Vigoren, E. M., Griffith, W. C., Barr, D. B., Faustman, E. M., & Thompson, B. (2012). Do workplace and home protective practices protect farm workers? Findings from the "For Healthy Kids" study. Journal of occupational and environmental medicine, 54(9), 1163-1169.

De Clercq, K., Goris, N., Barnett, P., & MacKay, D. (2008). FMD vaccines reflections on quality aspects for applicability in European disease control policy. Transboundary and emerging diseases, 55(1), 46-56.

Doel, T. (2003). FMD vaccines. Virus research, 91(1), 81-99.

Domingo, E., Baranowski, E., Escarmís, C., & Sobrino, F. (2002). Foot-and-mouth disease virus. Comparative immunology, microbiology and infectious diseases, 25(5-6), 297-308.

Donnelly, F. C., Mueller, S. S., & Gallahue, D. L. (2016). Developmental physical education for all children theory into practice Human Kinetics.

Elbers, A. R., Backx, A., Meroc, E., Gerbier, G., Staubach, C., Hendrickx, G., . . . Mintiens, K. (2008). Field observations during the bluetongue serotype 8 epidemic in 2006 I. Detection of first outbreaks and clinical signs in sheep and cattle in Belgium, France and the Netherlands. Preventive veterinary medicine, 87(1-2), 21-30.

Ellickson, R. C. (1985). Of Coase and cattle Dispute resolution among neighbors in Shasta County. Stan. L. Rev., 38, 623.

Feng, Z., Hirai-Yuki, A., McKnight, K. L., & Lemon, S. M. (2014). Naked viruses that aren't always naked quasi-enveloped agents of acute hepatitis. Annual review of virology, 1(1), 539-560.

Fuller, S., Von Bonsdorff, C.-H., & Simons, K. (1984). Vesicular stomatitis virus infects and matures only through the basolateral surface of the polarized epithelial cell line, MDCK. Cell, 38(1), 65-77.

Grubman, M. J., & Baxt, B. (2004). Foot-and-mouth disease. Clinical Microbiology Reviews, 17(2), 465-493.

Gullberg, M., Muszynski, B., Organtini, L., Ashley, R., Hafenstein, S., Belsham, G., & Polacek, C. (2013). Assembly and characterization of foot-and-mouth disease virus empty capsid particles expressed within mammalian cells. The Journal of general virology, 94. doi 10.1099/vir.0.054122-0

Guo, H.-c., Liu, X.-t., Liu, Z., Yin, H., Ma, J., Wang, Y., . . . Guo, J. (2006). Recent outbreaks of foot-and-mouth disease type Asia 1 in China. Journal of Veterinary Medicine, Series B, 53, 29-33.

Haase, A., Brahic, M., Stowring, L., & Blum, H. (1984). Detection of viral nucleic acids by in situ hybridization Methods in virology (Vol. 7, pp. 189-226) Elsevier.

Han, S.-C., Guo, H.-C., & Sun, S.-Q. (2015). Three-dimensional structure of foot-and-mouth disease virus and its biological functions. Archives of virology, 160, 1-16.

Herrero, M., Grace, D., Njuki, J., Johnson, N., Enahoro, D., Silvestri, S., & Rufino, M. C. (2013). The roles of livestock in developing countries. animal, 7(s1), 3-18.

Hutchison, M., Walters, L., Avery, S. M., Munro, F., & Moore, A. (2005). Analyses of livestock production, waste storage, and pathogen levels and prevalences in farm manures. Applied and environmental microbiology, 71(3), 1231-1236.

It, W. C. (2001). Foot and mouth disease.

Jamal, S. M., & Belsham, G. J. (2013). Foot-and-mouth disease past, present and future. Veterinary research, 44, 1-14.

Kitching, P., Hammond, J., Jeggo, M., Charleston, B., Paton, D., Rodriguez, L., & Heckert, R. (2007). Global FMD control—Is it an option? Vaccine, 25(30), 5660-5664.

Klein, J. (2009). Understanding the molecular epidemiology of foot-and-mouth-disease virus. Infection, genetics and evolution, 9(2), 153-161.

Knight-Jones, T. J., & Rushton, J. (2013). The economic impacts of foot and mouth disease–What are they, how big are they and where do they occur? Preventive veterinary medicine, 112(3-4), 161-173.

Knight-Jones, T. J. D., McLaws, M., & Rushton, J. (2017). Foot-and-Mouth Disease Impact on Smallholders - What Do We Know, What Don't We Know and How Can We Find Out More? Transbound Emerg Dis, 64(4), 1079-1094. doi 10.1111/tbed.12507

Kompas, T., Nguyen, H. T. M., & Ha, P. V. (2015). Food and biosecurity livestock production and towards a world free of foot-and-mouth disease. Food Security, 7, 291-302.

Law, J. (1906). Text book of veterinary medicine (Vol. 4) The author.

Lérias, J. R., Hernández-Castellano, L. E., Suárez-Trujillo, A., Castro, N., Pourlis, A., & Almeida, A. M. (2014). The mammary gland in small ruminants major morphological and functional events underlying milk production–a review. Journal of Dairy Research, 81(3), 304-318.

Liu, Z., Ru, J., Sun, S., Teng, Z., Dong, H., Song, P., . . . Guo, H. (2019). Uniform dendrimer-like mesoporous silica nanoparticles as a nano-adjuvant for foot-and-mouth disease virus-like particle vaccine. Journal of Materials Chemistry B, 7(21), 3446-3454.

Mahy, B. W. (2005). Introduction and history of foot-and-mouth disease virus. Foot-and-Mouth Disease Virus, 1-8.

McEwen, S. A., & Fedorka-Cray, P. J. (2002). Antimicrobial use and resistance in animals. Clinical infectious diseases, 34(Supplement_3), S93-S106.

Meidaninikjeh, S., Sabouni, N., Marzouni, H. Z., Bengar, S., Khalili, A., & Jafari, R. (2021). Monocytes and macrophages in COVID-19 Friends and foes. Life sciences, 269, 119010.

Naveen, K., & Bhat, A. (2020). Reverse transcriptase loop-mediated isothermal amplification and reverse transcriptase recombinase amplification assays for rapid and sensitive detection of cardamom vein clearing virus. 3 Biotech, 10(6), 250.

Nelemans, T., & Kikkert, M. (2019). Viral innate immune evasion and the pathogenesis of

emerging RNA virus infections. Viruses, 11(10), 961.

Osmani, A., Robertson, I. D., Habib, I., & Aslami, A. A. (2019). History and epidemiology of foot-and-mouth disease in Afghanistan a retrospective study. BMC veterinary research, 15, 1-12.

Pal, M. (2018). Foot and mouth disease a highly infectious viral zoonosis of global importance. J Appl Microbiol Biochem, 2(3), 12.

Parida, S. (2009). Vaccination against foot-and-mouth disease virus strategies and effectiveness. Expert review of vaccines, 8(3), 347-365.

Paton, D. J., Gubbins, S., & King, D. P. (2018). Understanding the transmission of foot-and-mouth disease virus at different scales. Current opinion in virology, 28, 85-91.

Pattnaik, B., Subramaniam, S., Sanyal, A., Mohapatra, J. K., Dash, B. B., Ranjan, R., & Rout, M. (2012). Foot-and-mouth disease global status and future road map for control and prevention in India. Agricultural Research, 1, 132-147.

Petrovski, K. (2015). Vade mecum of cattle conditions. Bovine Medicine. 3rd ed.. Oxford, UK Wiley Blackwell, 560-637.

Pikul, K., Ilchenko, V., & Prylutskiy, K. Y. (2019). Pediatric infectious diseases in family doctor's practic.

Plotkin, S. A. (2010). Correlates of protection induced by vaccination. Clinical and vaccine immunology, 17(7), 1055-1065.

Prasad, B., Yamaguchi, S., & Roy, P. (1992). Three-dimensional structure of single-shelled bluetongue virus. Journal of Virology, 66(4), 2135-2142.

Pulla, S., Nisha, P., Subramonian, S., Prabhu, M., Thilakar, P., & Kumar, N. (2021). Comparison of vulnerability faced by farmers in different livestock farming and coping mechanisms. Indian Journal of Extension Education, 57(4), 35-40.

Ranjan, R., Kangayan, M., Subramaniam, S., Mohapatra, J. K., Biswal, J. K., Sharma, G. K., . . . Pattnaik, B. (2014). Development and evaluation of a one step reverse transcription-loop mediated isothermal amplification assay (RT-LAMP) for rapid detection of foot and mouth disease virus in India. Virusdisease, 25, 358-364.

Rodriguez, L. L., & Gay, C. G. (2011). Development of vaccines toward the global control and eradication of foot-and-mouth disease. Expert review of vaccines, 10(3), 377-387.

Rowlands, D. J. (2003). Foot and mouth disease (Vol. 91) Gulf Professional Publishing.

Rweyemamu, M., Roeder, P., MacKay, D., Sumption, K., Brownlie, J., & Leforban, Y. (2008). Planning for the progressive control of foot-and-mouth disease worldwide. Transboundary and emerging diseases, 55(1), 73-87.

Rweyemamu, M., Roeder, P., Mackay, D., Sumption, K., Brownlie, J., Leforban, Y., . . . Saraiva, V. (2008). Epidemiological patterns of foot-and-mouth disease worldwide. Transboundary and emerging diseases, 55(1), 57-72.

Samad, M. (2019). A 50-year review on the prevalence of clinical diseases and disorders of cattle in Bangladesh. Journal of Veterinary Medical and One Health Research, 1, 1-16.

Sandip Chakraborty, S. C., Naveen Kumar, N. K., Kuldeep Dhama, K. D., Verma, A. K., Ruchi Tiwari, R. T., Amit Kumar, A. K., . . . Singh, S. V. (2014). Foot-and-mouth disease, an economically important disease of animals.

Sanyal, A., Subramaniam, S., Mohapatra, J. K., Tamilselvan, R. P., Singh, N. K., Hemadri, D., & Pattnaik, B. (2010). Phylogenetic analysis of Indian serotype Asia1 foot-and-mouth-disease virus isolates revealed emergence and reemergence of different genetic lineages. Veterinary Microbiology, 144(1-2), 198-202.

Sarangi, L., Mohapatra, J., Subramaniam, S., Pandey, L., Das, B., Sanyal, A., . . . Pattnaik, B. (2015). Spectrum of VP1 region genetic variants in the foot-and-mouth disease virus serotype O populations derived from infected cattle tongue epithelium. Acta Virol [Internet], 59(3), 305-310.

Shiilegdamba, E., Carpenter, T. E., Perez, A. M., & Thurmond, M. C. (2008). Temporal-spatial epidemiology of foot-and-mouth disease outbreaks in Mongolia, 2000–2002. Veterinary Research Communications, 32, 201-207.

Sieng, S., Patrick, I. W., Windsor, P. A., Walkden-Brown, S. W., Sar, C., Smith, R. G. B., & Kong, R. (2022). Knowledge, attitudes and practices of smallholder farmers on foot and mouth disease control in two Cambodian provinces. Transboundary and emerging diseases, 69(4), 1983-1998.

Singh, S. (2023). Transboundary, Emerging, and Exotic Diseases of Goats. Principles of Goat Disease and Prevention, 137-154.

Souley Kouato, B., Thys, E., Renault, V., Abatih, E., Marichatou, H., Issa, S., & Saegerman, C. (2018). Spatio-temporal patterns of foot-and-mouth disease transmission in cattle between 2007 and 2015 and quantitative assessment of the economic impact of the disease in Niger. Transboundary and emerging diseases, 65(4), 1049-1066.

Stenfeldt, C., Diaz-San Segundo, F., De Los Santos, T., Rodriguez, L. L., & Arzt, J. (2016). The pathogenesis of foot-and-mouth disease in pigs. Frontiers in veterinary science, 3, 41.

Tayo, T. (2011). Antigenic variation of Foot and Mouth Disease Virus-An Overview. Vet World, 4(10).

Teng, M., Yao, Y., Nair, V., & Luo, J. (2021). Latest advances of virology research using CRISPR/Cas9-based gene-editing technology and its application to vaccine development. Viruses, 13(5), 779.

Thomson, G., Vosloo, W., & Bastos, A. (2003). Foot and mouth disease in wildlife. Virus research, 91(1), 145-161.

Tomasula, P., & Konstance, R. (2004). The survival of foot-and-mouth disease virus in raw and pasteurized milk and milk products. Journal of dairy science, 87(4), 1115-1121.

Vosloo, W., & Thomson, G. R. (2019). Natural habitats in which foot-and-mouth disease virus is maintained Foot and Mouth Disease (pp. 383-410) CRC Press.

Wajid, A., Chaudhry, M., Rashid, H. B., Gill, S. S., & Halim, S. R. (2020). Outbreak investigation of foot and mouth disease in Nangarhar province of war-torn Afghanistan, 2014. Scientific Reports, 10(1), 13800.

Weaver, G. V., Domenech, J., Thiermann, A. R., & Karesh, W. B. (2013). Foot and mouth disease a look from the wild side. Journal of Wildlife Diseases, 49(4), 759-785.

Woods, A. (2013). A manufactured plague the history of foot-and-mouth disease in Britain Routledge.

Zell, R., Knowles, N. J., & Simmonds, P. (2021). A proposed division of the family Picornaviridae into subfamilies based on phylogenetic relationships and functional genomic organization. Archives of virology, 166(10), 2927-2935.

Zhu, L. (2017). Structural and functional study of picornaviruses. University of Oxford.

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To Cite This Chapter

Rehman, A, et al. (2024). FOOT AND MOUTH DISEASE (FMD) IN LIVESTOCK. In Animal Production and Health (pp.240-257). ISRES Publishing.