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Chapter 1

Epidemiology and Investigation of Foot-and-Mouth Disease (FMD) in the Republic of Korea

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Additional information is available at the end of the chapter

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Abstract

This chapter describes about the experience of dealing with FMD outbreaks in the Republic of Korea. We explain what is FMD, the concept of epidemiological investigation on outbreak sites of FMD, including the episode of detecting the index case for seven epidemics occurred since 2000, and information obtained from investigation in Korea. In any case, farmers' attitude (recognize clinical signs and report suspected cases) played the essential role in determining size and duration of epidemics. A rapid and correct diagnosis including clinical examination and laboratory test for confirmation is also important.

Keywords: foot-and-mouth disease (FMD), investigation, control measures, surveillance, Republic of Korea

1. Introduction

Foot-and-mouth disease (FMD) caused by virus infection of a small non-enveloped ribonucleic acid (RNA) virus belongs to family Picornaviridae, genus Aphthovirus. FMD virus affects Cloven-hoofed domestic animals including cattle, pig, sheep, goat, deer, boar, and wild animals. Due to its high contagiousness, FMD has a great potential for causing severe economic loss. There are seven immunologically distinct serotypes of FMD virus: O (Oise Valley), A (Allemand), C, Asia1, SAT (southern African territories)-1, SAT-2, SAT-3. According to the homogeneity of gene sequence of VP1 protein (approximately 639 base pairs, bps), the virus' topotype (concerns to the location) and lineage (concerns to the ancestor) are further catego-

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rized. RNA viruses show frequent spontaneous mutation, which results in emergence of new lineages. Phylogenetic analysis allows tracking the evolution and the origin of strains [1].

Clinical signs of FMD are characterized by vesicles in foot, mouth, and teats. Virus starts excreting 2 days before the appearance of clinical signs (4 days in case of milk), and antibody can be detected from 3-5 days after the appearance of clinical signs. High levels of antibodies are reached 2–4 days later and remained for many months. The virus disappears upon the appearance of antibody in most parts of the body. However, it continues to be detected exceptionally in laryngo-pharyngeal fluid. Antibodies to FMD virus are directed against structural proteins (SP) in the viral capsid and non-structural proteins (NSP) in the process of virus replication. SP antibodies are relatively serotype specific and induced by both vaccination and infection. Meanwhile, NSP antibodies are not serotype specific and induced by infection but rarely by non-purified vaccine also. SP antibodies usually start to appear approximately 3–4 days after the appearance of clinical signs, while 6–7 days in case of NSP antibodies [2, 3].

FMD occurs throughout the world, mainly in countries of Asia, Africa and parts of South America. It is the first disease for which the OIE (World Organisation for Animal Health) established an official list of free countries upon the science-based standards, guidelines and recommendations [4]. The Republic of Korea had been free from FMD without vaccination for the past 66 years, before a the outbreak of FMD in March 2000. In this chapter, epidemics of FMD in Korea from 2000 to 2015 are described together with their epidemiological characteristics.

2. Epidemics of FMD in Korea

Since 2000, Korea has experienced seven epidemics of FMD: March–April 2000, May–June 2002, January 2010, April–May 2010, November 2010–April 2011, July–August 2014, and December 2014–April 2015 [**Table 1** and **Figure 1**].

Year	**2000**	**2002**	**2010**			**2014**	
Month (Index region)			**January (Pocheon)**	**April (Ganghwa)**	**November (Andong)**	**July (Euseong)**	**December (Jincheon)**
Epidemic period	3.24–4.15 (23 days)	5.2–6.23 (53 days)	1.2–1.29 (28 days)	4.8–5.6 (29 days)	'10.11.28 –'11.4.21 (145 days)	7.23–8.6 (15 days)	'14.12.3 –'15.4.28 (147 days)
Number of outbreaks	15	16	6	11	153	3	185
Regions affected	6 counties in 3 provinces	4 counties in 2 provinces	2 counties in 1 province	4 counties in 4 provinces	75 counties in 11 provinces	3 counties in 2 provinces	33 counties in 7 provinces

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Year	**2000**	**2002**	**2010**			**2014**	
Month (Index region)			**January (Pocheon)**	**April (Ganghwa)**	**November (Andong)**	**July (Euseong)**	**December (Jincheon)**
Serotype	O (Pan-Asia O_1)	O (Pan-Asia O_1)	A	O (SEA)	O (SEA)	O (SEA)	O (SEA)
Slaughter (No. of animals)	12,216 from 182 farms	160,155 from 162 farms	5,956 from 55 farms	49,874 from 395 farms	3,479,000 from 6,241 farms	2,009 from 3 farms	172,798 from 196 farms
Vaccination	Ring	None	None	None	Nationwide	Nationwide	Nationwide

Table 1. Epidemics of FMD in Korea from 2000 to 2015.

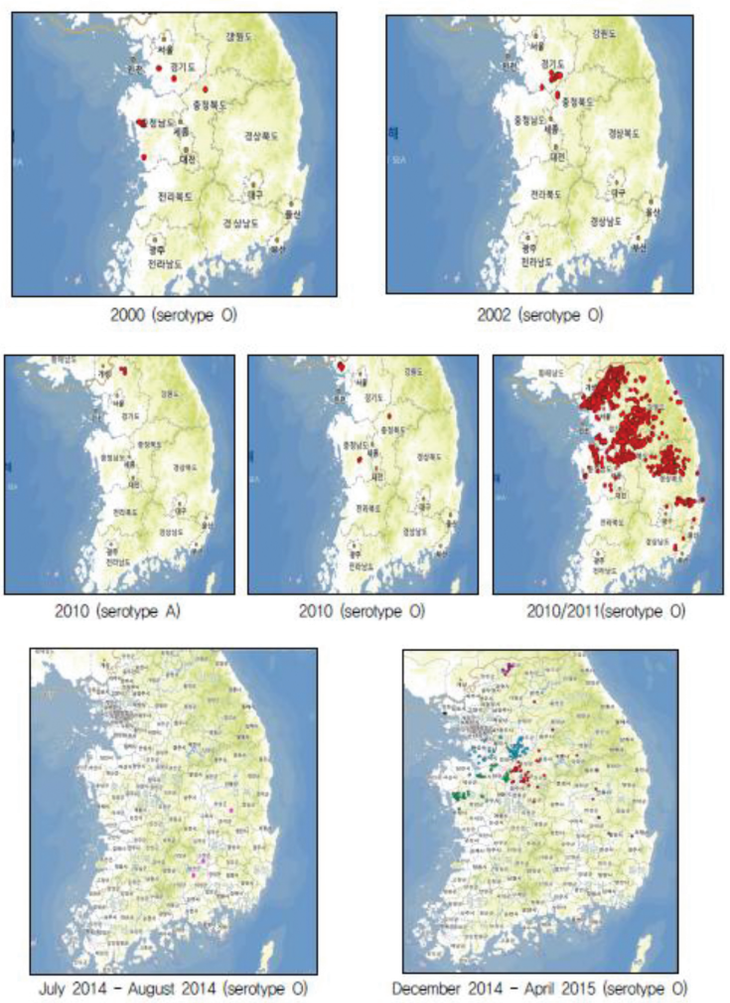


Figure 1. Distribution of outbreak farms of FMD in Korea from 2000 to 2015.

2.1. Epidemic in 2000

A suspected case was first reported from a dairy cattle farm in Paju, Gyeonggi-do, on 20 March 2000. Serotype O FMD virus was identified, which included in the Pan-Asian topotype. The route of virus introduction into Korea remains unclear. Fifteen outbreaks were reported until 15 April 2000. The outbreaks were concentrated in six counties of three provinces. There was one outbreak per county with the exception of one county, Hongseong, Chungcheongnam-do, from which 10 outbreaks were reported. All of the outbreaks in this epidemic involved cattle farm. A total of 2,216 cloven-hoofed animals of 182 farms were destroyed including all infected and neighbor farms within 500 m radius. Emergency vaccination (double-oil emulsion vaccines containing inactivated FMD virus strain O1 Manisa) of all susceptible animals within 3 km of radius of outbreak farms was performed. During the first round, 860,700 animals and 661,770 for the second booster round had been vaccinated by August 2000. All vaccinated animals except for soon to be slaughtered finishing pigs were indicated with ear marking either by punching holes (pigs) or by branding (cattle, goat, and deer). The animals have been registered and maintained by county offices to be directly transferred to designated slaughterhouses. Between first and second round of vaccinations, a total of 198,930 animals have been either slaughtered through a government buying out program or sent to the designated slaughterhouses. In the vaccinated zones, clinical inspections by field veterinarians as well as statistically designed serological surveillance were performed [5]. The country regained the previous status of FMD free country without vaccination from the OIE in September 2001.

2.2. Epidemic in 2002

On 2 May 2002, a suspect case with vesicles on the nose, tongue, hoof and teat, deletion of hooves, and high mortality in piglets was reported at a pig farm located in Anseong, Gyeonggi-do. The second case was reported the next day at a pig farm in Jincheon, Chungcheongbuk-do. Serotype O FMD was confirmed on a total of 16 farms (15 pig farms and one cattle farm). It was concluded that the use of vaccines was not advisable for this epidemic. The following facts explain the reasons: The outbreaks were in intensive pig farming areas and some surrounding farms would already likely be infected; period required for pigs to gain immunity is 2–3 weeks, during which they would still be vulnerable to infection; the use of vaccination would prolong the required period to regain FMD free status; there was a risk of spread by vaccination teams; and vaccination would hinder the effectiveness of surveillance, making it difficult to detect any new FMD cases. Most of all, the epidemic was not spreading out of control [6].

2.3. Epidemic in January 2010

A private veterinarian notified early symptoms indicative of FMD such as loss of appetite and hyper-salivation on a dairy cattle farm in Pocheon, Gyeonggi-do, on 2 January 2010. Local veterinary service visited the farm, but lack of FMD-specific lesions at that time interfered a proper sampling for laboratory test. The farm was placed under close observation. On 6 January, FMD-specific lesions including erosion and ulcer in oral cavity and nasal passage, as well as ulcer and crust on teats, were observed. FMD virus serotype A was confirmed. All of

six cases in cattle farm in this epidemic were detected within 3.8 km radius from the first outbreak farm [7].

2.4. Epidemic in April to May 2010

An outbreak of FMD serotype O was confirmed on April 9, following the previous day's notification of vesicles in the mouth and teats from a Hanwoo (Korean native beef cattle) farm in Ganghwa county of Incheon metropolis. As the second to fifth outbreaks, all occurred in the adjacent area, control measures including preemptive culling for all susceptible livestock in the protection zones within 3 km, were focused to prevent further spread of FMD. Extensive disinfection was carried out passing through two bridges connecting the Ganghwa Island to the mainland. Despite these collective efforts, on 21 April, a suspected case was reported at a pig farm located 135 km away from the previous outbreak area. Additional two outbreaks occurred in the latter area, Cheongyang, Chungcheongnam-do, by 6 May. Comparison of the VP1 region of FMD viruses isolated from the infected farms showed 99.68–100% homology, suggesting that all of 11 outbreaks were from a same origin [7].

2.5. Epidemic in November 2010 to April 2011

FMD occurred three times in 2010 (January, April, and November). The first case of the third epidemic was reported on 28 November 2010, from one of the five pig farms in a complex in Andong, Gyeongsangbuk-do. When officers of national veterinary services arrived in the farm, approximately 700 dead piglets were piled up in the farm yard. They found out that FMD was already widespread in all five piggeries. The oldest lesion was observed at the innermost farm. Until 21 April 2011, for 145 days, FMD outbreaks were confirmed in 153 farms raising cattle, pigs, goats, or deer in 75 counties of 11 provinces. Serotype O SEA topotype (Mya-98 lineage) was isolated. Phylogenetic analysis showed nucleotide differences more or less 1.0% among FMD virus of outbreak farms. In early December 2010, FMD broke out primarily on Hanwoo (Korean native beef cattle) farms around the index case in Andong. However, on 14 December, two pig farms in Yeoncheon and Yangju in northern Gyeonggi-do, belonged to the same owner, also reported FMD suspected animals. The nationwide spread of FMD was imminent. The epidemic continued until April of the next year [8]. The status of an FMD-free country with vaccination was recognized by the OIE on 27 May 2014, 3 years after the last cases of the epidemics in April 2011. The approval was obtained after the review of the report, submitted on October 2013, which verified the non-circulation of FMD virus for more than a year based on a test of non-structural protein (NSP) antibodies in vaccinated animals.

Implementation of a vaccine containing inactivated O1 Manisa strain (monovalent) was urgently implemented. Injections were first administered on 25 December 2010, to cattle near the outbreak areas. Vaccination of pigs was first implemented on 6 January 2011. The program was gradually extended, and all cattle and pigs in Korea were subject to injection from 15 January 2011. The second set of injections was started on 23 January in cattle and 3 February in pigs, respectively, and completed by 26 February. In the case of pigs, the outbreak decreased remarkably 3 weeks after primary vaccination, while in the case of cattle, it decreased after 2 weeks. From 3 March, additional vaccination was implemented to animals born without

maternal antibodies because they were born before the beginning of vaccination, and pigs at 3–4 weeks before delivery. And deer and goats were also added to the vaccine object. Since September 2011, it was mandatory for all cloven-hoofed animals to be implemented with trivalent (O, A, Asia 1) vaccination by 6-month interval. Before nationwide vaccination, all animals in the outbreak farm were stamped out. However, after 27 January 2011, when the nationwide vaccination was successfully completed, only animals showing symptoms or a positive reaction were stamped out [8].

2.6. Epidemic in July to August 2014

On 23 July 2014, the suspected animals were reported from 1 pig farm with 1,500 animals in Euseong, Gyeongsangbuk-do. The presence of FMD virus was confirmed in the next morning. Clinical signs appeared in unvaccinated animals in that farm. Subsequently, FMD was diagnosed in two more farms by 6 August 2014 [9].

2.7. Epidemic in December 2014 to April 2015

After 4 months, on 3 December 2014, a veterinarian of a farm with 15,884 animals in Jincheon, Chungcheongbuk-do, observed vesicles and ataxia in 30 pigs and reported the same to the county office. FMD was confirmed on the next day. During the next 147 days, until 28 April 2015, 180 pig farms and 5 cattle farms were confirmed with FMD [9].

3. On farm investigation

3.1. Regulation associated to investigation

In the Republic of Korea, in case of FMD outbreak, control measures are implemented based on the investigation of outbreak epidemiology. Both investigation and control measures were stipulated by the Act on the Prevention of Contagious Animal Diseases, the FMD Control Guidelines, and the standard operation procedure for FMD. These regulations include notification of suspected cases, movement control, stamping-out, disinfection, regular and emergency vaccination, import quarantine, disposal, compensation, and penalties [8, 9].

3.2. Principle of investigation

A smart investigation on the epidemiology of outbreak is crucial in order to implement control measures in case of confirming FMD. In case of FMD outbreak, the veterinary epidemiology division of the Animal and Plant Quarantine Agency (QIA) took overall responsibility for the epidemiological investigation throughout Korea. Field investigation and contact tracing were performed for each outbreak farm and putative dangerous contacts. All movements in-and-out associated with animals, people, vehicles, and materials were investigated for each farm for at least 21-day period (14 days in case of vaccination) immediately before the outbreak date. Then, the forward-and-backward tracings, which list up all the places visited before and after

being at the outbreak farm, were performed for each visitor, resident, and worker related to the farm [10].

3.3. Example of field investigation in Korea

A template to guide epidemiological investigation on the outbreak site is is prepared. The investigation process includes three steps: confirming infection, estimating date of first infection and determining mode of introduction. Below is example of investigation on FMD outbreak in Korea.

3.3.1. Confirming infection

FMD suspected animals were reported from a pig farm with 1,552 pigs in two houses located adjacent to buildings of pork-processing plant, on 2 June 2002. FMD outbreak in this farm was confirmed on 3 June, based on serological and virological tests.

3.3.2. Estimating date of first infection

In the late evening of 1 June, one of the farm workers notified "something abnormal on the hooves of the growing pigs to the owner. O the next morning, upon reporting of the owner, staffs of QIA (it was named National Veterinary Research and Quarantine Service, NVRQS, at that time) visited the site and observed intact vesicles (nasal plane, oral cavity, and coronary band), ruptured vesicles (coronary band), lameness, anorexia, and fever on nine animals examined in detail. Based on the number of animals with clinical signs and the age of the oldest lesion, the first clinical sign was estimated to have been developed since 7 days. Considering the incubation time of 4 days (a range of 2–14 days), FMD virus infection in this herd was the most likely to start on on 22 May (12 May at the earliest to 24 May at the latest)s.

3.3.3. Determining mode of introduction

Through field investigation and tracing, a total of 229 farms had contacts with this outbreak farm during 21-day period before the notification, either via people or vehicles visited to this farm or via slaughterhouse to which pigs were sent from this farm. No pigs had been introduced onto this farm. Preemptive slaughter was undertaken on three farms having epidemiological associations: One farm had dangerous contact such as sharing a common pig-transport truck, and the other two were located within 3-km distance from the outbreak farm.

A direct link was identified between this farm, reported on 2 June and the index farm, reported on 2 May. There was a person (man) worked at the neighboring pork-processing plant on a part-time basis, which was operated by the same owner with the outbreak farm. He has also participated in the culling operations on the index farm during three consecutive days from 3 May. He drove his car to the local animal health service then transported to the slaughter site, in wearing a T-shirt, a pair of blue jeans, and a pair of boots. At the slaughter site, disposable work-suit and boot covers were provided. After completing the operation, he cleaned himself at a public bath together with other work-

ers. Then, he put new underwear and shirts provided by the local government. But, he put again the same trouser that he wore in working because he had no spare one. While he took a bath, his jean was wrapped in a vinyl bag after being sprayed disinfectant. He returned back home by his own car in which no disinfection measures were implemented. He worked at the port-processing plant for three or four occasions, starting on 8 May. FMD virus was probably transmitted by this person considering that the index farm, on which 330 (4.0%) of 8,302 pigs showed clinical signs or died at the time of culling, was heavily contaminated at the time of culling. FMD virus must survive in environment such as interior of his car, and transmitted to the pork-processing plant and adjacent pig houses during 17 days of interval between the completion of culling (5 May) and the most likely date of first infection (22 April) [10].

4. Clinical signs

By carrying out epidemiological investigation, we can estimate how long has the disease been on the farm, where did the disease come from, and where the disease might have spread to. To establish a likely time period of infection dynamics took place in animals of the farm, aging clinical lesions is important. Looking for the oldest lesions allows identifying the time of first infection in the herd. Clinical examination starts by taking history about type and time of clinical signs and affected animals from the farmer. Then, the animals from a distance to see general demeanor, salivation, lameness, or ataxia were observed. When we examine the individual animal, check the mouth (especially in cattle) then the feet (in pigs) in order.

The clinical signs of FMD were the most clearly manifested in pigs followed by dairy cattle comparing to other species. In the epidemic of 2010/2011, only 2.6% of the dairy cattle farms and 1.9% of the pig farms were subclinically infected, while no clinical signs of FMD was observed in 10-20% of the outbreak farms with beef cattle, deer, or goats. For beef cattle, the number of farms with ulcers (n = 408, 28.6%) was higher than that showing vesicles (n = 316, 22.2%). For dairy cattle, on the contrary, vesicles (n = 166, 32.6%) were more frequent than ulcers (n = 107, 21.0%) in dairy cattle farms. In 58.9% of the pig farms, vesicle was the most dominant sign of FMD. In pigs, more severe signs, such as lameness or ataxia (14.6%) and shedding of claws (4.6%), were also distinctively shown. Another clinical characteristic observed in the 2010/2011 FMD epidemic was sudden death of suckling piglets, which was observed in 21.2% of pig farms. The average age of the oldest lesion in an outbreak farm was higher in the vaccinated than the non-vaccinated in cattle, while it was higher in non-vaccinated in pigs. Considering that vaccination was firstly performed on cattle then on pigs, and the outbreaks continued only in pig farms at the later phase of the epidemic, difference of lesions' age between cattle and pig at detecting seemed mainly associated with farmers' attention and recognition [11].

In the epidemic of 2014/2015, any clinical signs of FMD were observed in all of the 185 outbreak farms. Vesicles, which were observed 65.0% of the outbreak pig farms, were the most promi-

nent clinical signs, followed by lameness (43.9%), ataxia (38.9%), and hemorrhage in hooves (25.0%) [9].

5. Detection of outbreak farms

Detection of outbreak farm signifies the start of implementing control measures by animal health service. Large number of outbreak farms in the epidemics of 2010/2011 and 2014/2015 were attributed to the late detection of the infection, and FMD virus was already spread out at the time of confirming the index case [8, 9].

5.1. Delayed detection

In case of the 2010/2011 epidemic, implementation of control measures was delayed due to inappropriate diagnosis. When the first suspected case was reported on 23 November 2010, the NSP antibody test was conducted on the clinically suspected animals which had not yet developed NSP antibody, and negative results were drawn. Three days later, when the farmer notified the abnormalities for the second time, antibody test confirmed negative results again. Antibodies can be detected by enzyme-linked immunosorbent assay(ELISA) test from 3–5 days after appearing clinical signs of FMD. Finally, FMD was confirmed in isolating virus through reverse transcription-polymerase chain reaction (RT-PCR) by the QIA from the specimen taken on 28 November [12].

5.2. Early detection

On the contrary, prompt diagnosis contributed to the reduction of disease spread in the epidemic of 2002. From 9 May, 1 week after the confirmation of the first case, pen-side antigen test, which can detect FMD virus in vesicular fluids, was used for FMD suspect cases. This test enabled confirmation of infection to be made on the farm in about 20 min. Stamping out was implemented based on clinical examination (observing vesicles in most cases) and the pen-side antigen test results even before laboratory confirmation was made in some cases. During this epidemic, 13 of the 16 outbreak farms were culled within 24 h of diagnosis, which was an important factor in reducing the spread of the disease [6].

5.3. Probability of detection

The probability of early detection was the highest for pig farms, followed by dairy and beef cattle farms, and small ruminant farms in the case of the 2010/2011 epidemic. Almost 90% of the infected farms were detected by Day 11 of post-infection for pig farms, by Day 13 for both dairy and beef cattle farms, and by Day 21 for small ruminant farms. As far as concerned to the detection delay, that was time passed prior to the detection of FMD infection on a farm (average ± standard deviation), was 8.1 ± 3.1 days. The detection delays were shortest for pig farms (7.1 ± 2.5 days) and longest for deer farms where a large variation was also observed (14.4 ± 8.1 days) [13].

6. Epidemiological characteristics of FMD epidemics

Throughout the seven epidemics occurred since 2000, pig and cattle were the main species affected by FMD outbreak. The main factors of virus transmission were associated with the movement of vehicles, behaviors of people, and distribution of materials rather than movement of animals. Epidemics started in winter were usually long and large. The cold and dry winter climate in Korea made favorable condition for surviving FMD virus. In addition, low temperature during the winter might have preserved FMD virus for longer periods. Disinfecting farms, vehicles, and tools wasn't effective because the low temperature let disinfectants freeze. The hygiene status of livestock farms remained poor and animal disease could spread widely and rapidly. Epidemics of the 2010/2011 and 2014/2015 were the cases.

6.1. Characteristics of epidemic in 2002

The index case of the 2002 epidemic was notified on 2 May 2002. The next day, on 3 May, the second outbreak was notified at a pig farm in 25 km away from the index case. Based on the epidemiological investigation, FMD virus was probably spread from the index case to the second outbreak farm by a salesperson of a veterinary pharmaceutical company. Subsequently developed two spatial clusters centered of these farms and all known outbreak farms were encompassed except for one case. Genetic analysis of virus isolates from all of 15 outbreak farms, except for one from which no viral isolate was obtained, suggested that they had originated from a single common source. Herd serial interval of disease transmission at farm level was 8–9 (average ± standard deviation, 9.1 ± 2.0, median 8.5) days, and the transmission was extended into five generations. Eight farms were already infected before detecting the index case. A study on simulation modeling on various control strategy for the epidemic in 2002 suggested that the prompt implementation of control measures is the most effective in reducing both size and duration of future outbreaks [14].

6.2. Characteristics of epidemic in January 2010

The index case farm for the epidemic of January 2010 employed a foreigner, entered Korea on October 2009, as a farm hand. Disinfection or other biosecurity measures had not been taken before starting work on that farm. Furthermore, a parcel was delivered to the person abovementioned from his country on November 2009. In 2009, countries in northeast Asia had numerous outbreaks reported of FMD serotype A. Considering these findings, employment of a foreign worker in the first outbreak farm was identified as a possible route of virus introduction into Korea. FMD virus was subsequently transmitted to other farms through local veterinarian's examination, farmers' meeting, and farm owner's visit to the infected area [15]. The honest report of the local veterinarian his visiting places allowed to detect potential infections in early stage then promptly implement control measures. Unlikely to other epidemics during winter, heavy snow of early January 2010 in the outbreak area helped to restrict moving vehicles. So the spread of virus could be minimized.

6.3. Characteristics of epidemic in April to May 2010

Investigation for the epidemic from April to May 2010 identified possible routes of between-farm transmission were mostly associated with livestock related vehicles including contaminated feed-delivery vehicles, artificial inseminators, and delivery of veterinary pharmaceutics, total mixed ration (TMR) feed. Meetings of livestock-related people, visits to contaminated regions, vehicle movements, sales agents of animal feed companies, and participants of livestock culling seemed also contributed [15].

6.4. Characteristics of epidemic in November 2010 to April 2011

In the epidemic from November 2010 to April 2011, the routes of FMD virus introduction and their estimated frequencies for the 152 subsequent outbreaks except for the index case pig-farming complex were visitors (105, 69.1%), farmers (23, 15.1%), local spread (18, 11.8%), and delivered materials (6, 3.9%). Six outbreak farms, for which virus pathway was attributed to visitors, were associated with treatment or manipulation of artificial insemination, and 14 outbreaks were due to vehicles transporting live animals. The initial contributing factor of the 2010/2011 nationwide FMD epidemic was the regional feature of Andong, Gyeongsangbuk-do, where the residents were closely related to each other. During the epidemic, the frequent contacts might help the virus spread rapidly out to adjacent areas. The main cause of the long-distance virus' spread to the northern Gyeonggi-do was presumed to be related to the transport of pig manure to be used to installation test of a manure treatment machine. On 17 November 2010, pig manure from the pig complex in Andong was sent to the developer of the manure drying machine in Paju, Gyeonggi-do. The FMD virus already had been spread to nearby farms in the northern Gyeonggi-do area before any preventive measure was taken. The first outbreak in northern Gyeonggi-do was occurred on the same day of 14 December 2010 in two farming sites with a large number of pigs, operated by a same owner. Many farms raising cattle or pigs existed nearby, and shared road. Through traffic in front of the farms, the virus spread quickly to nearby areas. The FMD outbreak in the densely located big farms led to difficulties in taking emergency control measures due to the lack of burial sites and slaughter personnel. These caused FMD spread widely [8].

6.5. Characteristics of epidemic in December 2014 to April 2015

During the outbreak of December 2014 to April 2015, FMD virus was introduced into 185 outbreak farms mostly by vehicles (143 cases, 78.9%), people (23 cases, 10.8%), local spread (16 cases, 8.6%), and movement of animals (3 cases, 1.6%) in the descending order. The pathways for spreading the virus to farms in other counties included (1) visits by vehicles (or drivers) contaminated at abattoirs, (2) vehicles (or drivers) visiting numerous farms, (3) distribution of infected animals to other farms, (4) distribution of feed from a factory affiliated to a large company to farms in various provinces, and (5) operation of two or more farms located in different provinces by one person (or members of the same family or an affiliated company). Meanwhile, delivery of veterinary pharmaceuticals, delivery of semen for artificial insemination, and transport of manure were associated with

transmission within the same county or province. Vehicles and people, responsible for the introduction of FMD virus into farms, were contaminated at abattoirs (75 cases, 40.5%); livestock facilities (93 cases, 50.3%), including feed factories (17 cases, 9.7%); previous outbreak farms (67 cases, 36.2%); and infected areas (24 cases, 13.0%). FMD outbreaks continued for a long time since December 2014 because of the following reasons: (1) The virus continued to replicate among farms where animals were partially slaughtered; (2) the number of subsequent outbreak farms was inversely related to the proportion of FMD vaccine antibodies at county level; (3) control measures were not implemented at proper times Because farmers were reluctant to report suspected cases; and (4) outbreaks began in December, at the beginning of winter, during which the conditions were favorable for virus survival [9].

7. Economic Impacts of FMD outbreaks

The cost of each epidemic varied from 26 billion Korean won (KRW, approximately US$ 23.6 million) at the lowest to 2044 billion KRW (US$ 1.9 billion) at the highest. The cost was the highest for the 2000 epidemic, to which vaccination to slaughter policy was implemented to control outbreaks of 15 cattle farms. Mean cost attributed to one outbreak cattle farm was 18.2 billion KRW. In 2002, January 2010 and April to May 2010 epidemics with slaughter without vaccination costed 6.6 billion KRW, 4.4 billion KRW, and 9.2 billion KRW, respectively. Then, vaccination-to-live policy dragged the lowest costs of 0.5 billion for the 2010/2011 and 0.3 billion for the 2014/2015 epidemic [16].

The highest cost of an outbreak of FMD reached in cattle farms. Average costs per infected premises were 7.0 billion KRW for cattle farms (95% confidence interval, CI = 4.72–9.28), 1.38 billion KRW for pig farms (95% CI = 0.88–1.87), 0.11 billion KRW for deer [16].

8. Surveillance

The surveillance system consists of passive epidemiological surveillance for investigating reported disease and active epidemiological surveillance that involves serological surveillance. The latter can be further divided into statistically designed surveillance and purposive surveillance focusing on targeted samples within host populations. On the other hand, clinical surveillance included clinical inspection And telephone calls. Emergency vaccination was launched in end of December, the middle of the 2010/2011 epidemic. And Only animals with positive reaction or showing clinical signs of FMD were slaughtered. The NSP antibody test on the outbreak farm was conducted together with clinical inspection at 3 weeks after the partial slaughter. The NSP antibody tests were conducted on all cattle, deer, and goats. In pig farms, all sows and three fattening pigs per pen were subjected to be tested. This test was aiming at getting rid of movement restriction on the outbreak farm. After 26 March 2011, the effective preventive measures at the site: clinical, serological (16 animals per farm), and

environmental antigen tests were conducted on cattle, deer, and goats, and clinical examination and environmental antigen test were conducted on pigs.

Post-vaccination seroprevalence must be examined on vaccinated animals. This can be performed using commercial diagnostic kits. Sera are collected from farms and slaughterhouses. Purpose of this serological surveillance is to assure the OIE Code for FMD states that all vaccinated animals should develop at least 80% protective immunity to be recognized as a FMD-free country with vaccination [12].

9. Data management

Korea Animal Health Integrated System (KAHIS) is in operation since January 2013. This system contains all data concerning livestock and animal health in Korea. Data on farm (owner, geolocation, farm type, animals), livestock-related facilities (slaughter house, feed factory or feed distribution center, manured disposal plant, livestock market, veterinary clinics, veterinary pharmaceutical agencies, semen for artificial insemination distribution center, etc.) and vehicles transporting (animals, raw milk, eggs, veterinary pharmaceutics, feed, feces, manure, rice husks) and for the use of personnel (veterinarian, artificial inseminator, consultant, specimen taking and control, machine mender) are available. When a vehicle visits farm or livestock-related facility, the receiver installed on the site recognized the signal from the geographical positioning system (GPS) tracking device attached to the vehicle. A real time inquiry can be made on data of visit record both on the aspects of farm and vehicles. In addition, all the pathway of a vehicle can be traced. This web-based system is available at http://www.kahis.go.kr [17].

10. Conclusion

During the epidemic of 2010/2011, FMD virus had already widely spread before detecting the index case and it induced unprecedentedly large number of outbreak. The animal health service of Korea failed to respond timey and adequately due to lack of experience of controlling a massive epidemic of FMD with emergency vaccination to live. In the same manner, another big epidemic was occurred in 2014/2015 under routine vaccination.

As mentioned in the example of the 2002 epidemic, prompt implementation of control measures (e.g. removal of virus reservoirs), immediately after an early detection is the most effective to control FMD. The key determinant of the early detection is the report. In reality, an immediate report subsequent to recognizing abnormality is the collaboration with local veterinarians, related industries and animal health services. And this collaboration can be achieved upon proper education.

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