Clinical and laboratory investigations of five outbreaks during the early stages of the 2001 Foot-and-Mouth disease epidemic in the United Kingdom

Soren Alexandersen¹*, R Paul Kitching¹, Leonard M Mansley² and Alex I Donaldson¹

¹ Institute for Animal Health, Pirbright, Woking, Surrey, GU24 0NF, UK
² Department for Environment, Food and Rural Affairs (DEFRA), Animal Health Divisional Office, Carlisle, UK

SUMMARY
Clinical and laboratory investigations by staff from the Institute for Animal Health (IAH), Pirbright of five foot-and-mouth disease (FMD) outbreaks during the early stages of the UK 2001 epidemic are described. The first outbreak, confirmed on 20 February 2001, was at an abattoir in Essex which specialised in the processing of culled sows and boars. On 23 February the disease was confirmed at a pig farm in Northumberland. This holding contained waste-food-fed cull sows and boars and was probably the origin of the epidemic. Other premises investigated were a waste-food-fed cull sow/boar pig unit in Essex, probably infected by contact with either the Essex abattoir or the Northumberland pig farm, two sheep and cattle farms, one of which was located close to the Northumberland pig unit, and probably infected by airborne virus plumes from it, and another in Devon which was probably infected by sheep originating from Northumberland. In addition, analyses of the risk of airborne spread from the premises to other holdings in the area and to the nearby continent were performed in collaboration with meteorologists in the UK and Denmark. These results will be reported in detail elsewhere.

INTRODUCTION
This paper describes the results of clinical and laboratory investigations conducted by staff from the Institute for Animal Health (IAH), Pirbright at the start of the UK 2001 epidemic and gives an initial assessment of potential airborne spread. The main objective was to estimate the time when infection was probably introduced onto the farms. This was done by determining the age of the oldest lesions in those animals left to examine, calculating the date when clinical disease commenced on the farm and then subtracting 4-14 days from this date, the assumed incubation period for airborne farm-to-farm spread (Sellers and Forman 1973). A 2-14 day within-farm incubation period was used for all other predictions for example, if transmission resulted from direct contact with an infected animal. These estimations were compared with an analysis of laboratory results of samples collected from the holdings. The procedures for the ageing of lesions and the collection of samples were the same throughout the study and were done according to criteria established at IAH, Pirbright.

First outbreak visited
FMD 1, near Brentwood, Essex
The first suspicion of FMD was at an abattoir near Brentwood, Essex that specialised in the processing of culled sows and boars. On Monday 19 February 2001 the official veterinary surgeon (OVS) observed 27 sows to be lame. The sows’ feet were found to have vesicular lesions in the inter-digital clefts and around the coronary bands. No mouth or snout vesicles were detected. The affected animals had arrived on Friday 16 February from two sources, one group was from a farm in Buckinghamshire and a second group was from a farm on the Isle of Wight.
Temperatures were recorded from 15 animals from the Buckinghamshire farm and they ranged between 38 and 40°C. Clinical examination of animals from both farms revealed ruptured vesicles on the coronary band and the inter-digital area. The animals from the Buckinghamshire farm were in the more serious condition and were reluctant to stand up. A group of boars that arrived at the abattoir on Sunday 18 February from Yorkshire contained an animal that was acutely lame and had a ruptured vesicle at the interdigital space of one foot. Samples were collected and sent to IAH, Pirbright for investigation. Pigs from FMD 4, Northumberland, (see later), delivered to the abattoir around midnight on 15/16 February and slaughtered on 16 February had not been recorded by the OVS to have any signs of FMD.

A specialist from IAH, Pirbright visited the abattoir during the afternoon/evening of Tuesday 20 February. A series of trotters, snouts and tongues, collected post mortem from 5 sows from the farm in Buckinghamshire and with the most advanced lesions were presented for examination. All the trotters had lesions, typical of a vesicular disease, around the coronary bands, extending to the heel bulbs on eight of 20 trotters. The majority of the lesions were deep erosions with loose epithelium at the edges. Three snouts and two tongues had vesicular lesions at different stages ranging from unruptured vesicles to shallow erosions. The ages of the lesions were first estimated to be mainly 3-4 days of age with a few of 4-5 days. In the lairage many pigs were seen to be lame and recumbent. Vesicular lesions were apparent on the feet, snouts and mammary glands. All of the 22 sows that had arrived on Friday 16 February from the Isle of Wight had vesicular lesions, aged 2 to 3 days. Two of eight pigs examined in this group had temperatures above 40°C. Lesions, aged 2-day and 1-day old respectively, were also seen in pigs delivered on 18 and 19 February. Three boars delivered on Sunday 18 February had vesicular lesions on all four feet and were recumbent. A group of 101 fattener pigs, delivered on 19 February, and being slaughtered during the visit, was inspected ante mortem. Two animals were found to have suspected very early vesicular lesions on the coronary bands of a single foot. The time from delivery to the abattoir until these lesions were found was estimated to be around 33 hours. The total number of pigs with lesions at the time of the visit was 47. Two steers, present in the lairage since Thursday 15 February, were inspected. Neither was febrile but one had a suspected early vesicular lesion (<1 day) at the bulb of a heel.

The clinical signs in the sows and boars were typical of early acute generalised FMD. The virus isolate was evidently highly contagious for pigs since two animals admitted to the lairage on 19 February had early vesicular lesions when examined 33 hours later. The presence of lesions estimated to be 4-5 days in pigs delivered on 16 February suggested the possibility of an even shorter incubation period and/or an over-estimation of the age of the lesions.

Second outbreak visited
FMD 4, Heddon-On-The-Wall, Northumberland
Suspected cases of FMD were seen on this farm, a licensed waste food-feeder, on 22 February when the farm was visited by an official veterinarian due to the tracing activities in relation to pigs delivered to the Essex abattoir at Brentwood. Twenty out of twenty blood samples from adult pigs taken on 22 February and submitted to IAH, Pirbright, were found strongly positive for antibodies (titre above 1:2048 in LPBE) to FMD virus (results available 23 February). The farm was visited on 24 February and around 500 of the total 527 pigs examined. The farm consisted of housed cull sows and boars, a few family groups as well as a number of growers and bacon pigs. A collection of 248 blood samples was taken at this visit, mainly from the adult sows and boars as well as representative pigs from each pen with piglets, growing pigs and bacon pigs. Vesicular lesions of varying age were found on the feet and snouts. Tongue lesions were not a major
feature. Approximately 450 out of the 500 pigs examined i.e. 90% had signs of FMD. The estimated age of the lesions ranged from 1 to 2 days in a few pigs up to 12 days (4% of affected pigs). The age distribution of the lesions indicated that most were 9 to 10 days old (45% of affected pigs) with a smaller group aged at 2 days (12%). These findings correlated well with the results of laboratory investigations that showed that 8.5% of the samples were virus positive and 88% antibody positive.

The finding of lesions 12 days of age indicated that disease (lesions) had been present at least since 12 February 2001. Subtracting from that a likely maximum incubation period of 14 days, the infection could have been introduced onto the farm on 29 January or perhaps a few days earlier given the potential variability of the estimate of age of lesions.

**Third outbreak visited**

**FMD 6, Ponteland, Northumberland**

On 25 February experts from IAH-Pirbright visited a farm at Ponteland (Prestwick), Northumberland, located 5 km north-north-east of premises FMD 4. This was a mixed farm consisting of around 100 housed pedigree beef cattle, 320 grazing sheep and 30 housed hogs. On 21 February a veterinarian was called to the farm and diagnosed acidosis among a group of 18 month old Limousin heifers. On the 22 February 25 animals were ill, sore mouths and tongue lesions were noted and suspected FMD was reported. At the visit on 25 February all of the cattle, consisting of 38 heifers (18-28 months) and 37 bull-beef (10-16 months) housed in four pens in one cattle shed and 22 young stock (6-12 months) housed separately were examined immediately after the animals had been slaughtered. The group of 38 medium sized heifers was located in the south-western part of the shed and was the group in which clinical signs had first been noticed; the 37 bull-beef animals were penned separately on the opposite side of this shed and some were beginning to show early clinical signs of disease. The group of 22 younger stock were housed separately and showed no clinical or post-mortem signs of FMD. No clinical signs had been reported in the sheep grazing away from the farm buildings but one small group of 11 Blue Face Leicesters, grazed and housed at nights close to the south western corner of the cattle shed, had been treated for “foot-scald” by foot bathing on 10 and 20 February according to information obtained at the visit. The majority of the sheep (237 animals) were bled in connection with the visit. The laboratory results (available on 26 February) showed, that the remaining 11 Blue Face Leicester sheep, located just outside the cattle shed, were all positive for antibodies while of the other 226 sheep (mainly cross-bred ewes located separately) only 4 sheep (2%) were positive for antibodies and another 8 sheep (3%) were virus positive. Some of these Blue Face Leicester sheep were kept together at night with a group of Texel sheep in the same pen (close to the other Leicesters and close to the cattle), before 16 of these sheep went to Hexham Market on 13 February.

Lesions found in the cattle consisted of vesicles and deep erosions on the tongue, the dental pad, gingiva and lips. The lesions were estimated to be from 1 to 9 days old, i.e. twelve bulls and a single heifer had lesions of 1-3 days whilst one bull and the rest of the heifers had lesions of 3 days and up to 9 days in a single heifer. Foot lesions were not a major finding although some heifers had obvious lesions (estimated age of 3-4 days). This reflected the general lack of lameness observed, possibly associated with the soft bedding on which they were kept. All of the heifers examined in the south-western part of the shed had clinical signs of FMD, while of the bulls at the other side of the shed only 13 of the 37 bulls (35%) examined showed lesions.

Assuming that the heifer with the 9-day old lesion was the index case, the most likely period for
the first clinical signs of FMD would have been around 16 February, and the introduction of the infection may have been as early as 2 February. Alternatively, if the group of Blue Face Leicester sheep were infected before the cattle and had 2 day old lesions when treated for "foot-scald" on 10 February then the introduction of the infection could have been between 25 January and 4 February. However, if the underlying condition on 10 February was not FMD but was foot-rot, whereas on 20 February it was FMD, then the period during which FMD virus was introduced would have been between 4 and 14 February.

**Fourth outbreak visited**  
**FMD 7, Highampton, Devon**

Movement of sheep from the Ponteland farm mentioned above occurred on 13 February through Hexham market in Northumberland, before stopping off at Longtown market near Carlisle on 15 February en route to Devon (Vet Record 3 March 2001). Therefore, FMD 7, Highampton, Devon, which had received sheep from Ponteland was investigated on 26 February by experts from IAH-Pirbright. The farm had a total of 730 sheep and 200 cattle. Of approximately 500 sheep examined, 23 (5%) had clinical signs of FMD. Lesions were between 1 and 6 days old. Ninety-eight of approximately 100 cattle had clinical signs and the lesions were between 1 and 6 days of age. A total of 148 sheep sera were collected, representing all groups. Of these, 12 (8%) were antibody positive (by virus neutralisation) and 36 (25%) were virus positive. Out of 22 rams tested from the pen where the sheep bought in from Northumberland had been placed, 10 were viraemic (45%), however of the total of 60 rams examined in this pen, only 7 (12%) had clinical signs.

The cattle on this premises had clinical disease from at least 20 February 2001 which, for a 4 to 14 between-farm incubation period would indicate that virus was introduced between 6 and 16 February. The results indicate that (1) 88% of the virus positive rams were not showing clinical signs, and (2) transmission of FMD between the sheep had been relatively slow, compared to the cattle.

**Fifth outbreak visited**  
**FMD 5, Canewdon, Essex**

This holding, a licensed swill feeding premises near Canewdon, Essex situated approximately 30 km from the FMD 1 in Brentwood, was visited on Monday 26 February. The holding contained 522 pigs, mainly cull sows and boars. Around 50 sows were examined out of the total 522 pigs (approximately 200 sows and 322 slaughter pigs). The rest of the pigs had already been moved to the incineration site. Around 160 sows had been in groups in twelve pens within one shed. Pigs in two of these pens had old lesions and in one pen early lesions. Some pens were unaffected. Few signs were observed in the slaughter pigs located separately. The pigs were killed on 23 February and left in their pen until on 26 February. They consisted of: 1) a pen with 17 sows where lesions were first observed, 2) another pen (19 sows) where the pigs had shown fewer clinical signs and finally 3) a pen (14 pigs) containing “fat sows”. Lesions at various stages of development were found on the feet and snout. The majority of pigs in the first pen (1) had FMD lesions with an estimated age of 7-8 days. In pen (2) only a very few animals had lesions (of less than 7-8 days) while the “fat sows” in pen (3) had more acute lesions with an estimated age of 4 days.

This farm had animals with FMD for 7-8 days at the time of slaughter on 23 February, which indicates that there were animals with clinical disease on this farm from 15 or 16 February.
ADDITIONAL LABORATORY RESULTS

FMD 1, the abattoir near Brentwood, Essex was diagnosed by tests on pig epithelial tissue samples as positive for FMD type O by initial and repeat ELISA tests on 20 February 2001. Subsequent isolates of FMD virus serotype O were obtained from each of the five premises. Serum samples were tested for antibodies against FMD virus in the liquid-phase-blocking-ELISA. Sera giving suspected positive or inconclusive results were tested by virus neutralisation. All the diagnostic techniques were carried out in accordance with the methods described in the Manual of Standards for Diagnostic Techniques and Vaccines, l’Office International des Epizooties (OIE; 2000). Nucleotide sequencing of the VP1 coding region of an isolate from the Essex abattoir (FMD1) showed that the virus belonged to the type O PanAsian strain (Knowles et al. 2001).

ANALYSIS AND PREDICTION OF AIRBORNE SPREAD

Three of the five premises investigated (FMD 1, 4, 5) contained pigs and that raised concerns about the risk of airborne spread both in the local area and more distantly, including the nearby continent. The risk of airborne disease spread from these three premises was analysed, both in real time based on a “worst case scenario” (Donaldson et al. 1982a and 1982b) and later based on more detailed virus emission data of the UK 2001 virus (Alexandersen and Donaldson 2002, Alexandersen et al. 2002, Donaldson and Alexandersen 2001, Donaldson et al 2001), using atmospheric dispersion models - the Gaussian and NAME-models (Gloster et al. 1981, Gloster et al. 1982, Ryall and Maryon 1998) operated by the Met Office, UK, and the RIMPUFF/LINCOM (Mikkelsen et al. 1984, Mikkelsen et al. 1997)) and DERMA models (Sorensen 1998) developed and operated by the Riso National Laboratory, Roskilde, and the Danish Meteorological Institute, Copenhagen, respectively. Both the local-scale RIMPUFF and the long range DERMA model have previously been used for the retrospective estimation of the dispersion of FMD virus (Sorensen et al. 2000, Sorensen et al. 2001), and the calculations performed corresponding to the current epidemic show that DERMA gave similar results to the long range NAME model. The methods used and the results obtained are being submitted for publication elsewhere (Gloster et al. 2002, “The 2001 epidemic of foot-and-mouth disease in the United Kingdom – airborne transmission of virus from Burnside Farm, Heddon-on-the-Wall, Northumberland”).

DISCUSSION

Both laboratory and field observations showed that the UK virus was highly virulent for pigs. Infected pigs developed severe clinical signs and in some pigs the incubation period was as short as 33 hours. Lesions seen in the mouth of cattle at FMD 6, Ponteland and FMD 7, Highampton Devon were severe and extensive. Clinical disease was seen in only a few sheep examined by us in the field, however, after careful examination of a group of animals it was possible to find sufficient vesicular epithelial tissue for laboratory diagnosis. In experiments performed later in which sheep were infected with the UK virus by inoculation or by contact all the animals developed foot lesions, however, no mouth lesions were observed. This points to the importance of making a complete examination of sheep, including the feet.

The data presented suggest that the first outbreak of FMD in the UK 2001 epidemic occurred at premises FMD 4, a pig farm near Heddon, Northumberland. The farm was a waste food-feeding premises and it can be speculated that if the virus was in the waste food then that could have been the mechanism by which the pigs became infected. Investigations at FMD 4, Heddon, indicate that FMD lesions had been present at least since 12 February and that virus could have been introduced as early as late January or the beginning of February 2001. Based on the history that
the farm had sent cull pigs to the abattoir near Brentwood, Essex on 8 and 15 February there is a very high probability that the pigs which were delivered on 15 February (arrived around midnight 15/16 February) were the source of the outbreak there.

Pigs with FMD are potent emitters of airborne virus (Sellers and Parker 1969, Donaldson et al. 1970) and considering the number of pigs affected on the pig farm at Heddon, the quantity of airborne virus released would have been high. The number of pigs found to be affected at the Canewdon pig farm was 40 out of the 50 animals examined, however, as more pigs on that farm were at risk it is possible that others were also infected and so the amount of airborne virus excreted may have been high. Since fewer animals were affected at the abattoir in Essex, the amount of virus excretion would have been lower. Maximum excretion from the Heddon pig unit would likely have occurred at an estimated peak around 15 to 19 February with a continuing significant release throughout the period from 12 February or earlier until 24 February when the pigs were killed. Predictions were made based on estimations that a small number of pigs were already excreting virus from around 3 February. Simulation modelling of airborne spread from the Heddon farm using excretion values for the UK 2001 showed that the risk of long distance airborne spread was limited. However, short range models suggested a considerable risk of airborne transmission to cattle and perhaps sheep located within 5-10 km of the Heddon pig unit (to be described in Gloster et al. 2002, “The 2001 epidemic of foot-and-mouth disease in the United Kingdom – airborne transmission of virus from Burnside Farm, Heddon-on-the-Wall, Northumberland”). Thus cattle and/or sheep on the farm in Ponteland were most probably infected by windborne virus from the Heddon farm as the Ponteland farm fell under the plume of virus and despite exhaustive enquiries by MAFF/DEFRA no other links could be established (J. M. Scudamore, personal communication).

The movement of sheep from Ponteland on 13 February through Hexham market in Northumberland, before stopping off at Longtown market near Carlisle on 15 February en route to Devon (FMD 7, Highampton, Devon), was the probable mechanism by which the virus was spread to Devon (Vet Record 3 March 2001). It has been proposed that before the first case was confirmed at the abattoir in Essex on 20 February 2001, that infection had already spread further and was present on farms in Essex, Northumberland, Cumbria, Devon, Dumfries & Galloway, and Ireland. At least 57 premises may have been infected at that time (J. M. Scudamore, personal communication). The spread of infection by sheep moved off the Ponteland farm on 13 February, means that virus gained entry before 13 February 01. Simulated airborne excretion from the Heddon pig unit in the period from 3 to 12 February indicated that the meteorological conditions were favourable for local spread on several days although the predicted levels of airborne virus emission were low (to be described in Gloster et al. 2002, “The 2001 epidemic of foot-and-mouth disease in the United Kingdom – airborne transmission of virus from Burnside Farm, Heddon-on-the-Wall, Northumberland”).

If virus was transmitted to the Ponteland farm by the wind then either cattle or sheep could have been infected. Since clinical disease was more advanced in the medium-sized heifers then it is probable that either this group of animals or the sheep located outside were infected first. It may be relevant that a group of 17 Blue Face Leicester sheep were treated on 10 February for “foot-scald". Some of the 11 sheep remaining in this group after the departure of 6 cohorts on 13 February became acutely lame on 20 February and were foot-bathed. At the time of slaughter they were all FMD antibody positive. If the underlying condition was not FMD on 10 February but was on 20 February then the period during which virus was introduced would likely have been between 6 and 16 February. If the origin of infection on the Ponteland farm was airborne
virus it is more likely that the cattle were infected first since they are more susceptible to infection by airborne virus and disease was widespread in cattle at the time of the visit. Nevertheless, it seems most likely, independently of whether the infection was initially introduced to cattle or sheep, that the Blue Face Leicester sheep mixed with the Texel sheep and sold from the Ponteland farm on 13 February distributed the infection to many parts of the UK and subsequently abroad.

In conclusion, the primary outbreak, most likely the Heddon pig farm, probably resulted from the feeding to pigs of waste food containing or contaminated with FMD virus. Pigs taken from this premises to the abattoir in Essex on Thursday 15 February (arriving around midnight) spread infection to other pigs held in the lairage during the week-end. The presence of disease was seen on Monday 19 February when the pigs were being slaughtered. Airborne transmission is considered to be the most likely mechanism for spread from the Heddon pig farm to the mixed (sheep and cattle) farm at Ponteland. Sheep from this farm moving through a local market first and then through other markets probably spread the virus to a large sheep and cattle herd at Highampton in Devon. The mechanism of introduction of virus to the pig unit in Canewdon, Essex, located about 30 km away from the Brentwood abattoir is still under investigation by DEFRA.

Our analysis is based on data collected at the time of the visits early in the epidemic. It is likely that a more detailed picture of the sequence of events and the mechanisms involved will be constructed as more data and additional information become available.

ACKNOWLEDGEMENTS
We thank Eleni Michalopoulou, Craig Kirby and David Harris from the DEFRA Regional Office, Essex for their help on infected premises during the field visits. The work was supported by the UK Department for the Environment, Food and Rural Affairs (DEFRA), Meteorological Office, UK and the Danish Ministry of Transport.

REFERENCES


