Antibody Responses to Foot-and-Mouth Disease Virus VIA Antigen Monitored During a Field Vaccination Trial

Chanpen Chamnanpood*, L.J. Gleeson† and M.D. Robertson†

Abstract

Sera was collected from village livestock during the vaccination trial in 21 northern Thai villages. Animals from the project database were divided into two groups. Those with log_{10} serum neutralisation test (SNT) titres of < 1.2 to all three serotypes (A, O, and Asia 1) were classified as seronegative and those with a higher titre to at least one were classed as seropositive. At the start of the trial there were no reactors among the seronegative animals and there was an increase to about 10% one month after the first vaccination. Most reactions disappeared by six months after vaccination but returned after revaccination. Vaccination with the new production batch of the same vaccine provoked a substantial reactor prevalence. The seropositive group reactor rate rose from 30% to 70% after one vaccination, and many animals were still seropositive six months after vaccination.

The antibody response to the foot-and-mouth disease (FMD) virus non-structural protein called the virus infection-associated (VIA) antigen has been used to detect recent infections with FMD virus (McVicar and Sutmoller 1970). Although it was initially thought this antigen would prove to be a very useful diagnostic tool to discriminate immune responses induced by vaccination from those induced by infection, animals that have received multiple vaccinations respond serologically to VIA antigen present in inactivated vaccines (Dawe and Pinto 1978; Pinto and Garland 1979). The VIA agar gel diffusion test (AGDT) is still used to gather epidemiological information about virus activity in the field, although recently a specific and sensitive liquid phase blocking enzyme-linked immunosorbent assay (ELISA) has been described (Alonso et al. 1990). While VIA AGDT status is very useful in situations where vaccine is not used, the results must be interpreted with caution where vaccine is in use. Widespread application of a new trivalent vaccine produced by the Department of Livestock Development is a key strategy of a program to control and eradicate FMD in Thailand. This paper briefly describes the VIA AGDT reactor prevalence profile of a group of animals monitored during a longitudinal study of the responses of village livestock in Northern Thailand to the trivalent vaccine.

Materials and Methods

Experimental design

Animals in 21 villages (seven in each of three provinces) in Northern Thailand were ear tagged and vaccinated as previously described (see Gleeson et al., these proceedings). Sera collected at seven visits on the established vaccination response monitoring schedule were tested by AGDT and the results recorded on a computer spreadsheet database (PANACEA). Data was summarised with the aid of a statistical software package (STATISTIX). Histogram plots were used to depict the results of the analysis. Serum neutralisation test (SNT) titres to O, A, and Asia 1 at the commencement of the program were included in the database.

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VIA antibody assay

The VIA AGDT was carried out according to Cowan and Graves (1966) except that the agar was prepared in 0.02 M Tris, 0.15 M NaCl buffer, pH 7.6 (0.02 M Tris buffer). VIA antigen was prepared from infected cell culture supernatant fluids treated with polyethylene glycol (PEG) 6000 for production of purified 146S antigen (Doei and Baccarini 1981). DEAE cellulose (Whatman DE-52) washed and equilibrated with 0.02 M Tris buffer was added to the PEG-treated supernatant fluid (40 g per 2 litres) and gently mixed overnight at 4°C. The gel was collected in a sintered glass funnel and washed extensively with 0.02 M Tris buffer. Bound protein was then eluted in a semi-crude batch procedure by increasing the NaCl concentration in the buffer to 1 M. The eluate obtained was progressively concentrated on Amicon XM300 and YM30 membranes using a nitrogen pressurised stir cell (Morgan et al. 1978). The two concentrates were pooled, then precipitated with NH₄SO₄ to 60% saturation, and resuspended in phosphate buffered saline (PBS).

Preparations were screened for VIA antigen activity by AGDT using a reference VIA antigen preparation and a reference convalescent bovine serum obtained from the Research Section, FMD Center, Pak Chong. Supplementary field test antigen was also supplied by the FMD Center and the positive control serum for the field tests was a pool of field sera that gave a reaction (3+) equivalent to the bovine reference in the test. The test was read after 48 and 72 hours incubation in a humidity chamber and the results recorded on a spreadsheet database (PANACEA). Reactions were scored from 1+ to 3+ in comparison to the positive control reaction. However for the purpose of frequency analysis of reactor prevalence all positive reactions were equally weighted.

Vaccinations

Animals were vaccinated at round 1 (R1), 6 months later at round 2 (R2), and again after a further 6 (R3) and 12 months (R4). Serum samples were collected at each vaccination round on the day of vaccination (B1) or 4 weeks later (B2) and were designated by round number and bleed number (B1 or B2). AGDTs were carried out on samples from R1B1, R1B2, R2B1, R2B2, R3B2, and R4B2. An additional collection was made on a subset of villages 3 months after the second vaccination (R2B3). The same batch of trivalent vaccine was used for the first three rounds of vaccination, and a second production batch was used for the last vaccination. Three different batches of VIA antigen were used to complete the study: one batch was used for the R1 and R2 tests, a second batch for R3 tests and a third for R4 tests.

Results

There were no reports of clinical FMD from any of the participating villages during the course of the study. During the course of the study there was a decline in animal numbers enrolled in the monitoring program and in some villages replacement animals, matched as closely as possible to those not returning, were added. Only animals present at R1B1 were included in the data set for this analysis. The remaining 644 animals were first divided across all age groups into two exclusive groups:

- 273 animals seronegative (SNT titre < 1.2) to all 3 serotypes of FMD at R1B1 (R1B1 FMD negative); and
- 371 animals seropositive (SNT titre ≥ 1.2) to any one serotype of FMD at R1B1 (R1B1 FMD positive)

The changes in AGDT reactor prevalence for these two groups are shown in Figure 1. There were no VIA reactors in the FMD negative group at R1B1.

![Figure 1. VIA responses during vaccination trial: prevalence (percent) of AGDT positive samples among R1B1 FMD seronegative (all SNT titres < 1.2) and seropositive (any SNT titre ≥ 1.2) animals.](image)

A further two independent divisions of the animals present at R1 was carried out. In order to assess the influence of previous vaccination with type O monovalent vaccine, a subset termed R1B1 O positive (R1B1 SNT titre O ≥ 1.2) was selected using the following criteria: (omit age < 2 years);
In order to assess the influence of recent infection on the AGDT reactor rate after vaccination, a subset termed RIB1 Asia1 positive (RIB1 SNT titre Asia1 > 1.35) was selected using the following criteria: (omit if RIB1 SNT titre Asia1 < 1.35); and (omit if RIB1 SNT titre A > Asia1). These criteria selected 95 animals.

AGDT reactor prevalence in these two subgroups over the four rounds of vaccination is shown in Figure 2.

Figure 2. VIA responses during vaccination trial: prevalence (percent) of AGDT positive samples among RIB1 O positive (RIB1 only SNT titre O ≥ 1.2) and RIB1 Asia1 positive (RIB1 SNT titre Asia1 ≥ 1.35; Asia1 > O; Asia1 > A).

Discussion

The results indicated two major points of interest. First, that there was a low prevalence of reactors induced by the first two vaccinations of animals regarded as probably not previously exposed to FMD VIA. Second, for animals with previous exposure to FMD antigens either by vaccination or infection at RIB1 (i.e., seropositive to any serotype), there was a considerable anamnestic antibody response to VIA antigen as indicated by the large increase in reactor prevalence four weeks after the first vaccination. However, after the third vaccination of the RIB1 FMD negative group, there was a substantial rise in the prevalence of AGDT reactors.

Although the type O positive group showed a substantial increase in reactor prevalence after the initial vaccination, the overall reactor prevalence for the type O positive group was lower than for the type Asia1 positive group, suggesting that the selection criteria used had selected for animals with different previous exposure to FMD VIA. Type Asia1 was the most prevalent cause of FMD outbreaks in Northern Thailand in the period immediately prior to the commencement of the study (unpublished project data). The reactor prevalence in the type O positive group at R4B2 increased disproportionately to the other groups suggesting that the fresh batch of vaccine provided an increased VIA stimulus to this group. It has been reported that variation in the reactor prevalence might be expected to occur from batch to batch of VIA antigen, if the VIA source in the vaccine is predominantly from the same serotype used to prepare the AGDT antigen (Ahl and Wittmann 1986).

The results show that, during the current FMD control program in Thailand, in which widespread use of the trivalent vaccine is planned, results of the VIA AGDT will have to be interpreted with extreme caution. The sharp increase in reactor prevalence in the RIB1 FMD positive group occurred in the absence of FMD outbreaks in 21 villages. If the first 11% of AGDT reactors at R4B2 in the RIB1 seronegative group were due to some previous sensitisation, it would also appear that there is potential to stimulate AGDT reactors in a significant proportion (up to 20%) of animals after three vaccinations. Clearly further longitudinal investigations are required to clarify if there is any effect of vaccine batch on the VIA reactor prevalence, and to determine the duration of reactions following routine vaccination. Knowledge of expected reactor rates and decay times may increase the usefulness of the test in monitoring the effectiveness of the vaccine program in preventing subclinical infections.

Acknowledgments

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References


A Modelling Approach to the Investigation of Vaccination Strategies for Foot-and-Mouth Disease

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Abstract

A state-transition model of the temporal development of herd immunity to foot-and-mouth disease (FMD) in response to vaccination was constructed based on the observed dynamics of populations of cattle and buffaloes in villages in northern Thailand. Model parameters were the birth rate, age-specific mortality and selling rates as well as the vaccination rate and a number of probabilities derived from field studies and estimating vaccine efficacy and titre decay for different classes of animals. An animal was regarded as immune to FMD if its serum neutralisation titre was 1 in 32 or greater \((\log_{10} \text{titre} \geq 1.5)\). Output from the model was graphed as the change over time in the percentage of animals in a village having an immunity to FMD. For the purposes of the study, a minimum acceptable level of 80% prevalence of immune animals was assumed to be necessary to prevent spread of FMD virus. The model indicated that a simple strategy of six-monthly vaccination with an approximate 70% coverage would never achieve the minimum acceptable level of herd immunity. Increasing the coverage to 90% resulted in periods of several months where more than 80% of animals were immune alternating with periods immediately prior to revaccination where the level of herd immunity dropped below an acceptable level. A strategy which included a primary course of two inoculations one month apart for newcomers to the program combined with six-monthly revaccination of 80% of all animals produced a similar long-term effect to the simple 90% coverage but with the advantage that herd immunity levels were achieved more quickly.

Foot-and-mouth disease (FMD) is endemic in Northern Thailand where the circulating viruses are serotypes O, A and Asia 1. The control program for the disease has been based on 6-monthly vaccination of at least 70% of all village cattle and buffaloes greater than six months of age with a trivalent vaccine, combined with movement controls, supporting zoosanitary measures and ring vaccination in response to outbreaks (Kongthon 1991). A two-year Thai–Australian research project to evaluate the serological responses of village cattle and buffaloes to the trivalent vaccine commenced in January 1991. In addition to the vaccination response studies, data were collected on the population dynamics of village cattle and buffaloes. The information from these field studies was used to construct a computer spreadsheet model to simulate the development of immunity in a ‘typical’ village herd in response to FMD vaccination. Of primary interest was the likely impact of present vaccination strategies in reducing FMD spread. In addition, the model was used to compare a number of alternative strategies with the view to identifying possible improvements in the way vaccine is used.

Methods

Assumptions and model parameters were derived from field observations on 60 northern Thai villages.

Definitions

Herd: The aggregate of all cattle and buffaloes in a village set at a size of 250 animals.
**Efficacy:** The proportion of animals becoming immune to FMD infection following vaccination. Individuals with a serum neutralisation test (SNT) titre of 1 in 32 or greater were regarded as immune (log_{10} SNT \geq 1.5).

**Herd immunity:** The resistance to infection of a group of animals due to the immunity of a high proportion of individuals in the group. The level of herd immunity is the proportion of immune animals in a group. When the level of herd immunity is high, there will be insufficient susceptible animals for FMD to spread and infection will die out.

**Model overview**

A state-transition model of a village herd, based on discrete monthly time-steps over two years was constructed incorporating age and immune states. A flow diagram is shown in Figure 1. In the model, animals occupied one of three states: susceptible, immune or removed through death or sale. The herd was divided into age classes of six-month intervals from birth to > 8 years old. The whole herd was assumed to be susceptible at the commencement of the vaccination program and immunity developed only in response to vaccination, there being no exposure to natural challenge. Herd size was held fairly constant with time. Output from the model was graphed as the change with time in the percentage of animals in a village having an immunity to FMD.

**Assumptions and parameter estimation**

Females comprised 75% of animals greater than three years old. Cows calved for the first time at three years of age and thereafter every second year. Calving was non-seasonal and the proportion of immune calves born in any one month was equal to the proportion of immune cows present in that month. Colostral immunity persisted for six months and calves were first vaccinated at six months of age. The probability of being vaccinated, dying or being sold was independent of FMD immune status.

Rate parameters were the vaccination rate, age specific death and selling rates, rates estimating the probability of a susceptible animal responding to vaccination and becoming immune one month later depending on the number of previous vaccinations it had received (vaccine efficacy) and rates estimating the probability of an immune animal maintaining its status from one vaccination round to the next.

Estimates of vaccine efficacy were obtained from a database of cattle and buffaloes selected from a purposive sample of 21 villages, whose serological responses to vaccination were monitored over four six-monthly vaccination rounds (R1-R4). Blood samples for serology were taken at each vaccination visit and at one month after vaccination. Antibody titres to FMD virus types O, A and Asia 1 were measured by the serum neutralisation test (SNT) using standard methods (Golding et al. 1976). A subset of animals which had log_{10} reciprocal SNT titres of less than 1.2 to all three serotypes at R1 (and therefore unlikely to have been previously vaccinated or infected with FMD virus) were selected as the base sample for estimating vaccination efficacy. These animals were subsequently classified as immune if the log_{10} reciprocal SNT titres to all serotypes were greater than or equal to 1.5. On the basis of this classification, the probabilities of individuals responding to vaccination and maintaining immunity from one vaccination round to the next were calculated. The resultant probabilities for maintaining immunity between vaccination rounds used in the models are probably overestimates if vaccination coverage is less than 100%, since these rates were derived from a database where all animals had been vaccinated at each round.

For each age class, the proportion of immune animals one month after R1 was:

\[
\text{(the number of animals present)} \times \text{(vaccination rate)} \times \text{(vaccine efficacy for the particular age class)}
\]

The number of animals maintaining immune status until R2 was then calculated as:
To simplify the arithmetic, those animals maintaining immunity to the start of R2 were assumed to retain their immunity for an additional month, irrespective of whether they received vaccine at this round or not. Losses of immune animals as deaths and sales were also ignored during this month. The model therefore slightly overestimated the number of immune animals present at this point in time.

The susceptibles present at the start of the second vaccination round were considered in two ways since they either received vaccine at R1 or they did not. The number of immune animals present one month after R2 was calculated as:

\[(A \times B) + (C \times D) + E\]

where:

- A is the number of susceptibles present at R2 which had been vaccinated in both rounds;
- B is the probability of a susceptible animal becoming immune if previously vaccinated twice;
- C is the number of susceptibles vaccinated at R2, but not R1;
- D is the probability of a susceptible animal responding to a single vaccination;
- E is the number of immune animals present at the start of R2.

The above calculation steps were then repeated to determine the number of immune animals present at the third vaccination round, one month later, and at the fourth vaccination round and one and six months later. The number of immune animals present in intermediate months was calculated by assuming that the number of animals reverting to susceptible status doubled in each successive month.

To allow for revaccination of newcomers one month after enrolment, expected responses were derived from a field trial comparing single with dual priming vaccinations carried out in Northern Thailand. Where dual vaccination was assumed, the rate used for maintenance of immunity for age classes between their second and third vaccination rounds is probably underestimated because the interval between these vaccinations is five and not six months.

For the purposes of the study, a minimum acceptable level of 80% prevalence of immune animals was assumed to be necessary for a vaccination strategy to prevent spread of FMD virus (based on Henderson 1970).

Results

Vaccine efficacy estimates

There were 272 animals at the start of the vaccination study which had \( \log_{10} \) reciprocal SNT titres of less than 1.2 to all serotypes. The same 272 animals were present one month later, when 37 were classified as immune. The probability estimate of a susceptible animal becoming immune one month after a single inoculation was therefore 37/272 or 13.6%. All of these 37 immune animals were present at the start of R2 when 11 were still classified as immune. Hence, the probability estimate of an animal maintaining immunity from the first to the second inoculation was 11/37 or 29.7%. There were 258 non-immune animals present at the start of R2. All were present one month later when 241 were classified as immune. Hence, the probability estimate of a susceptible animal becoming immune one month after a second inoculation was 241/258 or 93.4%. Of all the immune animals present one month after R2, 208 were still present at R3. A total 145 of these were classified as remaining immune, so the probability estimate of an animal maintaining immunity from the second to the third inoculation was 145/208 or 69.7%. A total of 51 non-immune animals at R3 were present one month later. Of these, 49 were classified as immune, so the probability estimate of a susceptible animal becoming immune one month after a third inoculation was 49/51 or 96%. 92 animals which had been classified as immune one month after the third vaccination round were present at R4. A total of 64 of these were still classified as immune, so the probability estimate of an animal maintaining immunity from the third to the fourth inoculation was 64/92 or 69.6%. There were only 13 non-immune animals at R4 still present one month later. All were classified as immune, so the probability estimate of a susceptible animal becoming immune one month after a fourth inoculation was 13/13 or 100%. There were no data on which to base an estimate of the probability of an animal maintaining immunity from the fourth to the fifth vaccination. We assumed that with additional exposure to the vaccine, an animal had a higher likelihood of maintaining immunity and used a probability of 0.8 in the model.

Model outputs

The simulated change in prevalence of immune animals over time is shown in Figure 2. The percentage of animals protected increased in a stepwise manner, peaking one month after a vaccination round and then declining between vaccinations. At
a vaccination coverage rate of 70%, herd immunity did not exceed the threshold level of 80% protection considered necessary for effective control. At a coverage rate of 90%, herd immunity first exceeded 80% one month after the third vaccination round (month 13) and remained above this threshold for 7 of the following 11 months.

![Figure 2](image)

**Figure 2.** Model predictions of the development of herd immunity (prevalence of immune animals) in a northern Thai village for 3 different FMD vaccination strategies. It is assumed that all animals are initially fully susceptible and there is no exposure to natural infection. 70% vaccination: 70% of animals over 6 months of age vaccinated every 6 months; 90% vaccination: 90% of animals over 6 months of age vaccinated every 6 months; 80% + revaccination: newcomers receive a primary course of 2 inoculations 1 month apart with 6-monthly revaccination of 80% of all animals. The horizontal line at 80% indicates the assumed minimum desirable level of herd immunity.

When 80% of animals were vaccinated and newcomers were revaccinated one month after the initial vaccination followed by regular six-monthly boosters an acceptable level of herd immunity of 80% protection was reached by month eight and then fluctuated around this level, exceeding 80% in eight of the following 16 months but dropping to as low as 56% in month 12.

**Discussion**

The results from this study indicate that vaccinating 70% of village cattle and buffaloes twice a year is unlikely to produce a level of herd immunity sufficient to prevent spread of FMD virus. Reasons for the relatively low level of herd immunity resulting from this strategy include poor responses to initial vaccination, decline in titres between vaccinations and natural increases in the number of susceptibles through births. The relatively short-lived immunity induced by the trivalent FMD vaccine under study highlighted the need for vaccination to include as near to 100% of the cattle and buffaloes population within the control zone as possible.

Using an alternative approach of giving newcomers two inoculations a month apart followed by six-monthly boosters improved the rate of development and overall level of herd immunity substantially. However, even with a dual inoculation priming vaccination, it appears that coverage rates in excess of 80% would be required to maintain continuous protection against outbreaks at the village level.

The findings from the present study of a requirement for high vaccination rates to maintain an effective herd immunity in a dynamic and open population are consistent with reports for other directly transmitted viral diseases. In humans, it has been estimated that 92–96% of children must be vaccinated to eliminate measles and pertussis, 84–88% to eliminate rubella and 88–92% to eliminate mumps in Western Europe and the United States (Anderson and May 1985). The situation is similar for Rinderpest in cattle where vaccination rates of between 80% and 100% are required, depending on the level of vaccine efficacy (Rossiter and James 1989).

The FMD herd immunity model did not take into account the problem of sustaining herd immunity when the field virus is heterologous to the vaccine virus. Serological differences are frequently observed between field viruses within the same subtype group in countries where the disease is endemic. When serological differences occur between the field and vaccine virus, the herd immunity resulting from vaccination is lowered because of lowered vaccine efficacy (Brown 1992; Rweyemamu et al. 1982).

A further limitation of the model is that the probability of being vaccinated may not be independent of FMD immune status. One of the main reasons for failure of villagers in Northern Thailand to present their animals for routine FMD vaccination is due to difficulties in mustering (Cleland, unpublished data). It is likely that animals missed at a vaccination round are at higher risk of being missed subsequently. Furthermore, there currently is substantial variation in vaccination coverage among villages in Northern Thailand. Both factors would favour the maintenance of high levels of infection in the field and increase the level of challenge in villages in which animals have been well
vaccinated. Effective control of FMD by vaccination therefore requires that not only must the proportion of the herd vaccinated be as high as possible, but that there is little variation in vaccination coverage between villages.

Despite the potential pitfalls implicit in the assumptions used, the modelling approach taken has provided useful insights into what vaccination strategies may be required to achieve effective control of FMD under Thai village conditions. Further field trials are required to validate model predictions. If these trials are combined with carefully planned serological monitoring, it should be possible to evaluate the ongoing effectiveness of the vaccination program and to assess the risk of FMD outbreaks in specific control zones.

Acknowledgment

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References

CONTROL OF FOOT-AND-MOUTH DISEASE IN SOUTHEAST ASIA

One of the key objectives of the veterinary authorities of the countries meeting at this workshop is the control and eventual eradication of FMD. In this session the keynote speaker, Dr Peter Ellis addressed the very important issue of the economic benefits and costs of disease control programs and emphasised the need to employ economic evaluation in planning and implementation phases. A partial budget analysis procedure was used by Dr Ellis to illustrate how financial effects of disease and control costs can be evaluated.

A regional success story — Indonesia — was the subject of the next presentation in which Dr Herawati Setyaningsih from the Veterinary Biologies Centre at Surabaya, Indonesia presented a paper describing the strategies used to eradicate FMD from Indonesia.

In considering the issues for the regional control of FMD in Southeast Asia it is of interest to compare the situations that have occurred elsewhere in the world. To this end Dr Alex Donaldson presented a discussion of the strategies used in Europe to control and eradicate FMD and the present European Community policies to prevent and control outbreaks in the future.

In respect of the strategies for regional control of FMD Dr Masao Sasaki from the Food and Agriculture Organisation Regional Office in Bangkok discussed the important patterns of livestock movements in Southeast Asia, especially across international boundaries and stressed the importance of these movements in any regional strategy to control FMD. A regional plan for the eradication of FMD was further discussed by Dr Y. Ozawa, of the Tokyo office of the Office International des Epizooties. The proposed plan includes the formation of a Sub-Commission for the Control of FMD in Southeast Asia. A proposed organisational structure for this sub-commission was presented by Dr Ozawa.
The Economics of Foot-and-Mouth Disease Control

P.R. Ellis*

**Abstract**

Foot-and-mouth disease can cause tremendous economic loss and remains a threat to the livestock industries of many countries. Economic analysis helps to justify investment in prevention, control and eradication programs but a wide variety of information must be gathered on the characteristics and productivity of animal populations involved as well as on incidence rates and losses in different production systems. The analysis must satisfy the farmer that the cost and inconvenience he has to bear are far exceeded by benefits that he can appreciate. A partial budget analysis procedure is used to illustrate how financial effects of disease and control costs can be evaluated. Benefit-cost analysis procedures and findings are used to explain how a foot-and-mouth disease control strategy can be evaluated from the nation's point of view taking into account the changing value of money over time. Strongly positive net present values and benefit-cost ratios of 6:1 are commonly obtained. However, adjustment may have to be made to take into account national livestock development goals, market requirements and trade policies.

Very few people concerned with livestock would disagree that foot-and-mouth disease (FMD) is still one of the most serious animal health problems. Enormous losses have been recorded, like those estimated at £250,000,000 in Britain in 1967 when a major FMD epidemic required the slaughter of thousands of highly productive animals to ensure eradication and the whole economy and trade of rural areas was disrupted. In Asia too, losses could be enormous. When preparations were being made in 1976 to launch a systematic FMD control program in India, a combined epidemiological and economic study revealed that an average of 15% of the country's livestock population was affected every year causing production losses in excess of 4000 million rupees or about £200,000,000. Fortunately improvements in the efficacy of vaccines and the efficiency of other control measures have helped countries to avoid such enormous disasters and are steadily reducing continuing losses in Latin America and Africa as well as in Asia. However, intensification of animal production systems results in increasing losses when FMD does occur and greater trade and movement of livestock and animal products are increasing the risks of spread of any infection that persists.

In order to improve the efficiency of prevention, control and eradication schemes and to justify rational and international support it has become essential to apply economic analysis techniques. At first sight these may appear incomprehensible to veterinarians and farmers but, in reality they involve simple and logical calculations.

The core requirement in FMD control is that benefits for the farmers should exceed all costs and inconveniences that they may have to bear. The owner of a valuable, high-producing, dairy herd does not hesitate to pay for regular vaccination or to conform to very strict sanitary regulations if the threat of FMD arises. In contrast owners of low-grade beef animals or small ruminants in extensive grazing systems, or pigs in smallholdings may be unwilling or unable to participate in an organised control scheme without subsidies and assistance.

Since FMD spreads so easily by contact, air and residues, control and eradication can only be achieved if the whole susceptible livestock population is involved in the program. Furthermore, the program must evolve systematically over a number of years as measures are extended and

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intensified. Governments are understandably reluctant to make necessary funding commitments unless they can be convinced that the benefits for the nation comfortably exceed the costs of government support and intervention. In addition the government needs to be confident that the total subsidy involved can be sustained over the years and that the expenditures on FMD do not rob other vital activities or plans of funds which would give the nation even greater net benefits.

For these complex reasons economic analysis has to be made from two different points of view, that of the producer and that of the nation or region concerned. Realistic results can only be obtained if realistic information has been gathered on the actual incidence and effects of FMD in the different areas and types of production system involved. Secondly, since the program is certain to extend for some years the probable changes in production systems must be evaluated. Only then can the new or more intensive control measures be specified, quantified and valued. Only then, too, can realistic projections be made about the reductions likely to occur in the number and severity of FMD outbreaks year by year which constitute the benefits that can be set against cost. To provide simple and practical illustrations of these steps which are applicable to Asia the author has drawn material from an excellent economic study made in northern Thailand by Bartholomew and Culpitt (1992) and from his own work in India (Ellis and James 1976).

Collection of Basic Information

Official records of FMD incidence vary widely in quality. The disease may be so mild where it is endemic that farmers may not recognise it and even if they do recognise it they may not bother to report cases. Effects are usually transient and insidious but often affect a large proportion of animals in the herd or flock.

Information from official records has, therefore, to be supplemented with data gathered from farms and opinions of field staff closely associated with them. Even very limited surveys can produce remarkably good results. It is important to concentrate on obtaining good quality of information from a few, well-selected farms or animal groups rather than a large volume of information of questionable reliability. Bartholomew and Culpitt (1992) were able to use epidemiological and production data from a total of 61 villages studied by Drs Baldock, Cleland and Chamnanpood and as part of the Thai-Australian FMD project (see papers included in these proceedings). In addition they conducted in-depth enquiries in four villages as to numbers of animals, ages, outputs and uses, feeding, management, frequency of FMD outbreaks and effects. Findings provided a sound basis for economic analyses in terms of the effects on two types of village in the area as described below:

... A Type 1 village was characterised by relatively highly productive animals while a Type 2 village was characterised by relatively low productive animals. Differences in animal productivity related to animal type (cross-bred vs native cattle), feeding practices (use of purchased food vs non use of purchased feed), natural soil fertility etc. Also the Type 2 village had an overall higher incidence rate of foot-and-mouth disease than the Type 1 village, based on epidemiological study (Bartholomew and Culpitt 1992, p. 7).

In India this author and a series of teams spent around six weeks in different sections of the country that had been selected on an ecological basis to represent different systems of production and different aspects of the FMD problem. Each team consulted key officials and farmers' organisations but also spent a large proportion of their time visiting villages and farms. While the information in villages was unrecorded they were able to build up, through discussions with farmers and veterinary assistants, a remarkably clear picture of the effects of FMD. They could then calculate losses on which estimates of potential gains from control measures could be based for seven representative categories of milk and draft animals.

Economics from the Farmer's Point of View

The partial budget

The key aid to the financial assessment of FMD loss and the valuation of gains from control is the partial farm budget which calculates:

(a) extra income resulting from the program;
(b) costs no longer incurred as a result of the program;
(c) costs of implementing the program;
(d) income lost as a result of the program; and

\[ Net \, gain = a + b - c - d. \]

Data and prices from the Bartholomew and Culpitt study have been used in Table 1 to construct hypothetical partial budgets for beef cattle in a fairly productive village with and without improved FMD control. Although benefits appear fairly close to those found in the study, they should not be regarded as representing the situation in any specific village situation in Thailand. The table provides a very simple illustration of the technique. It could be prepared with paper, pencil and calculator but is most useful if set up as a spreadsheet on a microcomputer. Animal numbers and production
parameters are listed for the situations with and without changes in the control scheme. Control measures for each situation are listed: proportion of all animals vaccinated twice yearly increased from 70% cover (0.7) to 90% (0.9) and revaccination of all calves is introduced. Treatments for the 20% of animals currently affected each year are assumed to be reduced to zero. Prices of animals are assumed to increase because of better values at sale but unit costs of vaccination and treatment remain unchanged.

In a simple series of calculation shown in the last two columns of Table 1, changes in values of income, costs saved, extra costs incurred and revenue foregone are all shown. The net benefit in this illustration is 41 300 baht and the ratio suggests that farmers should receive 7.35 baht for each additional baht spent on the FMD control measures.

Table 1. Partial budget for FMD control in an Asian village beef herd.

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<tr>
<td>Income</td>
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<td>treatments</td>
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<td>Total benefit</td>
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<tr>
<td>Change in value</td>
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<tr>
<td>steers sold</td>
<td>25 200 (a)</td>
<td></td>
</tr>
<tr>
<td>cows sold</td>
<td>18 600 (b)</td>
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<td>0</td>
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<tr>
<td>Revenue forgone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>none</td>
<td>14 000 (d)</td>
<td>20 500 (e)</td>
</tr>
<tr>
<td>Total cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NET BENEFIT</td>
<td>6 500 (y)</td>
<td>41 300 (x - y)</td>
</tr>
</tbody>
</table>

FINANCIAL BENEFIT:COST RATIO         | 7.35:1

Note: Values used in this table have been obtained from Bartholomew and Culpitt (1992).
The effects of further changes can easily be examined. For example, numbers of steers sold could be further increased by two and additional hygiene and disinfection costs of 5 baht per animal could be assumed. The spreadsheet program automatically calculates a revised net benefit as 47,000 baht, costs as 8,500 baht and the ratio as 6.53. Although the ratio is lower, the farmer gains an extra 5,700 baht for an extra cost of 2,000 baht.

Results of such analyses for FMD control among improved livestock are generally very good but for an unimproved animal the costs of regular vaccination often exceed the benefit. In the case of India in 1976 estimates were made of average losses for seven types of animals. The estimated cost of annual vaccinations with teams working to maximum efficiency was around 12 rupees. For an average native dairy animal the benefit was likely to be no more than 29.7 rupees. For the native cattle and buffaloes used for draft purposes returns at 81 and 73 rupees respectively were better but only the hire charge of 63 rupees would be obvious and still not a strong justification for a new FMD control initiative. Certainly, owners of such animals were unwilling to pay such a vaccination cost. Only for improved buffaloes and crossbred dairy cattle with potential gains at 136 rupees and 884 rupees respectively, and for crossbred draft cattle with a potential gain of 242 rupees, were results very attractive.

Other factors to be considered by the farmer

Analyses from the farmer’s point of view should not be limited to average financial benefits and costs. FMD rarely attacks all animals or all herds in a population and never to the same extent. For a farmer with one or two improved animals and little or no land, a single outbreak of FMD could lead to financial disaster whereas a farmer with a dozen or more unimproved cattle may hardly notice the effects of several cases of the disease. If many draft animals are affected in a village at a critical cultivation or crop marketing time, losses could be enormous, as was seen in India, because replacements could only be hired at enormously high prices. Fortunately tractors and trucks are becoming available as alternatives. Thus the perceived importance of FMD for the farmer in some situations may be much greater than the estimated financial loss. A case could be made for counting perceived benefits rather than average benefits and regarding vaccination as an insurance cost against the disease.

With respect to costs, other considerations also apply. For example, farmers might be expected to pay for vaccine, and perhaps the costs of vaccinating as nations as well, but can they be relied upon to have the money in hand when needed? If a year or two has elapsed since the last FMD outbreak in his area the farmer may decide to risk not vaccinating. In addition, if his animals can produce more milk or grow faster after FMD has been eliminated, is he able to grow or buy the extra feed needed to obtain these gains? If he decides to buy a crossbred dairy animal, could his wife or child carry the larger volume of milk to a collection point?

From the farmer’s point of view, these and many other considerations arise whenever a significant change is proposed so an economic evaluation must also extend to social and operational factors before a policy decision is made.

The National Economic View

Planning an appropriate program

A thorough and systematic appraisal of the extent and effects of FMD and of potential control measures in the farm or village is essential for realistic planning of an effective nationwide or area-wide control program. Appropriate packages of measures can be designed for the different areas, according to the production system characteristics, and special measures can be prepared for problem areas. Activities such as vaccination can be coordinated so as to minimise costs and plans can be made for the additional infrastructure needs such as vaccine production and storage, diagnostic facilities and movement control.

Economic analysis

As at the farm and village level this is a logical procedure which helps planners to sum the different kinds of costs that would be incurred year by year as a new FMD control scheme evolves. In parallel with this the total values of benefits arising year by year can be estimated.

A framework outlining the steps required is shown in Figure 1. In this case, gains from reduced treatment and disease effects are calculated by multiplying the gains calculated for farm or village ‘units’ and the numbers of such units in each area introducing the control scheme. In the same way costs can be calculated by totalling those for the units involved and adding in the common costs of new infrastructures such as vaccine storage, movement control posts and coordinating centres for the scheme.

To complete the economic analysis, the current (gross) values of benefits and costs for each year are assembled as in Table 2. However, these cannot
simply be totalled for all the years and used to calculate the net gain and benefit–cost ratio as was done at farm level for a single year. Adjustments have to be made for the changing value of money over time because major costs of a new program usually arise in the early years whereas benefits may take some time to build up. Table 2 lists a hypothetical series of benefits and costs from FMD control which follow these patterns. The ministry of finance of each country usually specifies a discount rate, between 5% and 12%, and commonly 10%, by which both benefits and costs accruing in future years have to be reduced. As can be seen in the table with a rate of 10%, 1000 baht spent or gained in year one is reduced in value to 909 baht. In year two the reduction factor is 0.826 and goes down to as little as 0.386 in year 10. Resulting figures are net present values (NPV). Justifications for this procedure are very complex and may be studied in books such as that of Gittinger (1984) but the basic principle is that money now in hand has a greater value than that obtained or to be spent in the future.

Having made the necessary adjustments to values, benefits can then be added together for all years, costs can be added in the same way as shown in Table 2 to provide:

\[
NPV = NPV \text{ of benefits} - NPV \text{ of costs}
\]

and

\[
\text{Economic benefit–cost ratio (BCR)} = \frac{\text{NPV of benefits}}{\text{NPV of costs}}
\]

Other measures of profitability such as internal rate of return (IRR) and breakeven point, are less commonly used and the reader should refer to Gittinger (1984) for details.

For the situation in northern Thailand, Bartholomew and Culpitt (1992) calculated an NPV of 179 million baht and a BCR of 11.75:1 at a 10% discount rate. They quote a ratio of 5:1 from an earlier study of FMD eradication in Thailand and a ratio of 3.15:1 estimated for FMD eradication in the Philippines. Governments consider favourably any project that gives a BCR greater than 2:1.

Sensitivity analysis

Anyone who knows the changing risks and variable effects of FMD should, at this stage, be wondering how errors in assumptions about the efficacy of control measures or in the rate of improvement in animal productivity would affect the result. To provide reassurance for policy makers, economists have developed a procedure called sensitivity analysis. If, for example, cost reduction in Table 2 were delayed by one year, the BCR would fall from 4.13:1 to 3.87:1. Again this is an easy task with a spreadsheet model.
Table 2. A hypothetical economic benefit-cost analysis (values in pounds (£) sterling)

<table>
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<th>Gross</th>
<th>Discount factor (10%)</th>
<th>Discounted value</th>
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</thead>
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<td>0</td>
<td>.909</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>100 000</td>
<td>.826</td>
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<td>.564</td>
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<td>Totals</td>
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<td></td>
<td>1 199 250</td>
</tr>
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<table>
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</tr>
<tr>
<td>Totals</td>
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<td>310 020</td>
</tr>
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</table>

Gross benefit - gross cost = 1 800 000
NPV benefit - NPV cost = 889 230
BC ratio (NPV benefit/NPV cost) = 3.87

Economists may also test the possible effect of a better than expected success rate. If the market cannot absorb all the additional products, prices might fall thus offsetting increased output and further changing the NPV and BCR. Thus sensitivity analyses usually lead the analyst to present a range of BCRs and other economic measurements. In the case of South India the Ellis and James evaluation (1976) produced basic BCRs ranging from 5.2:1 to 8:1 with a high discount rate of 12%. However, India needed much more milk to substitute imports and was promoting cattle and buffalo improvement very strongly. When the effects of these changes were also taken into account the increased BCRs ranged from 7.1:1 to 11.4:1. The program was adopted and is steadily achieving the desired improvement in FMD control and productivity.

This paper is intended only to introduce the main procedures used in economic analysis of FMD control so that veterinarians, animal production specialists and economists can share a common approach. The procedures outlined can be studied in greater depth in such texts as Gittinger (1984) and Putt et al. (1987).

Experience to date indicates that well-planned FMD programs give very high economic returns. The key points to remember in making economic evaluations are that:

- data about FMD incidence and effects and about the populations to be protected or freed from the disease must be carefully selected, collected and checked for reliability;
- the attitudes of farmers must be taken into account in designing control programs, and benefits and costs for the different types of production systems must be evaluated individually by partial budgets; and,
- economic analysis of national or area schemes must be based on a realistic representation of how the complexes of different production systems in each area will respond; sensitivity analysis must be used to assess the potential impact on any proposed program of variations in FMD epidemiology, in control costs and in animal production policies.

Conclusions

Over the past 20 years increasing numbers of veterinarians have come to use economic analysis in a widening range of activities. Government services use it to decide not only whether a national program is justified but also to determine which cost farmers can be expected to pay. Meanwhile, practising veterinarians have adopted partial budgeting as a means of determining the value of controlling such problems as infertility, mastitis and parasitism.
References


The Experience of Indonesia in the Control and Eradication of Foot-and-Mouth Disease

Soehadji,* Marthen Malole† and Herawati Setyaningsih§

Abstract

In 1974 the Indonesian livestock authorities divided the country into three zones with respect to foot-and-mouth disease (FMD); a disease-free zone; a suspected zone; and an infected zone. Strict animal movement and quarantine measures were introduced to protect the disease-free zone and routine surveillance was carried out in the suspected zone. In the infected zone a mass vaccination program was carried out using both 'crash' and 'low speed' programs. After three years of the mass vaccination programs many regions were declared free of FMD. However, in July 1983, just before the country was going to be declared free of the disease, an outbreak occurred on Java and spread over much of the island infecting 13,976 animals. Stringent control methods were brought into force including high-speed mass vaccination, movement control, stamping out and a range of other measures. The last cases of the disease occurred in December 1983 and the last vaccinations were carried out in Java in 1985. Indonesia was declared free of FMD in 1986 and vaccination and production of FMD vaccine are now prohibited.

The first outbreak of FMD in Indonesia was reported in East Java in September 1887, and 19 years later Madura Island was infected in 1906 and 1913. Since then the disease was endemic in East Java, and spread throughout the whole Java and some islands of the country such as Sumatra (1892), Kalimantan (1906), Sulawesi (1902), Bali (1962) and West Nusa Tenggara (1911).

The distribution of the disease to other parts of Java and outside of the island was influenced by the movements of animals which related to a distribution program of breeding stock during the Dutch occupation.

Only the FMD virus type O was found in Indonesia, as identified by the World Reference Laboratory (WRL), Pirbright, United Kingdom in 1973. Many efforts to control the disease were implemented which finally culminated in the eradication of the disease and in 1986 Indonesia was declared free from FMD.

Eradication Campaigns

The eradication of FMD in Indonesia can be divided into five stages as described below.

1. 1887–1912

No regulation concerning FMD control was published during this time. However, the Dutch Government made many efforts to control the disease using conventional and traditional treatment of all infected animals.

2. 1912–1945

The Dutch Government promulgated the first regulation concerning animal disease control in 1912 (State Gazette 1912 No. 432 and 435) after which controlling and reporting of infectious disease became compulsory in Indonesia. The first vaccine for FMD was introduced in 1930 using the Waldmann method. Vaccination of animals in areas surrounding infected areas and stamping out of positive cases were conducted to prevent the spread of the disease.

3. 1945–1974

Indonesia became independent in 1945. During the independence war and governmental transition...
period, animal disease control in Indonesia was discontinued and it was suspected that in some areas FMD became endemic. From 1962 FMD control was undertaken locally and was financed from provincial government resources.

In Java and Madura FMD control was based on routine vaccination of dairy cattle and livestock at the centre of infected areas. A stamping out policy was not undertaken in the island due to socio-economic considerations.

An FMD outbreak occurred in Bali in 1963. The outbreak was controlled by restraining livestock movements in and out of the area, stamping out of infected animals and vaccination. The disease was under control in 1965 and no cases were reported thereafter. However, an outbreak occurred in 1973 because of buffaloes smuggled in from an infected area in Java.

FMD control in other islands outside Java and Bali such as Sumatra, Sulawesi and Kalimantan, were carried out by intensive vaccination surrounding infected areas, control of livestock movements and intensive surveillance activities.

4. 1974-1981

Prior to 1974 FMD control activities were conducted by local governments. The disease status was sporadic at low incidence. However, in 1974 a national program was launched by the Directorate General of Livestock Services (DGLS) to eradicate the disease. During this period the National FMD Eradication Program was assisted by the Australian Government.

To ensure the success of the eradication program, provincial governors, members of the police, the armed forces, the civil defence, women and youth organisations all fully supported the campaign.

Recognising the fact that prior to 1974, FMD cases occurred almost annually and the disease spread sporadically at low incidence in certain areas, the Government of Indonesia formulated methods and approaches for the control and eradication of FMD based on technical and economic rationales.

Based on the incidence and distribution of FMD in Indonesia in 1974, the country was categorised into three zones (see Map 1):

- a **disease-free zone** which includes East and West Nusa Tenggara, Irian Jaya, Moluccas and East Timor;
- a **suspected zone** areas without any reported case for the last few years. This zone includes Kalimantan, Sumatra and Sulawesi (except South Sulawesi); and
- an **infected zone** which included Java, Bali and South Sulawesi.

According to the above categories the program consisted of three different measures.

(i) Free zone: strict animal movement/quarantine measures. Transport of livestock from infected/suspected zone to this area was not allowed.

(ii) Suspected zone: surveillance in these areas was carried out routinely.

(iii) Infected zone: a mass vaccination campaign was conducted in two stages:
- crash program — mass vaccination was implemented in order to prevent reappearance of the disease in the infected areas; and
- low speed program — undertaken gradually but in an intensive manner and covering the areas where the disease had the potential to spread to the non-infected areas.

Basically the vaccination procedure was similar for both systems:
- vaccination was carried out annually (three times in three years) for all livestock more than three months old. Pig were vaccinated only in infected herds. In 1976, it was decided to vaccinate goats and sheep voluntarily because they had been shown experimentally to be possible disease carriers;
- vaccination coverage was at least 80% of the livestock population;
- vaccinated animals were identified by ear marking (earcut);
- there was a strict control of livestock, vehicle and feed movement to the vaccination areas; and
- intensive epidemiological surveillance was carried out continuously during the program to monitor the possible reappearance of cases.

After three years of vaccination, an epidemiological evaluation team carried out surveillance of the animal population in order to prepare the disease-free declaration.

Java

In Java, the eradication campaign was started in 1975 in the eastern part of East Java moving westward, while in West Java it was started in 1976 moving eastward. The coverage of animals vaccinated during that first campaign was 93% for cattle/buffaloes and 69% for sheep/goats.

The second and third vaccination campaign were combined into one and were successfully undertaken from 1976 to 1980. In early 1978, Madura was declared a FMD-free area while in 1981 the rest of East Java was also declared FMD free.

In Central Java the vaccination campaign started from 1976 and from 1976–81 over 2.5 million of cattle and buffaloes were vaccinated. Vaccination coverage of 80% was achieved in 1980–81. No further cases of FMD were recorded in Central Java until an outbreak in Blora erupted in 1983.

In West Java and the municipality of Yogyakarta the vaccination campaign was initiated in 1975 and extended to 1982. The coverage of animals vaccinated during the vaccination campaign in West Java and Yogyakarta was 90–98% of the livestock population.

Bali

The first year a mass vaccination campaign was undertaken was 1974 and vaccination continued until 1975. Total number of animals vaccinated were 333,397 cattle, 11,073 buffaloes and 11,051 sheep and goats. About 97% of the cattle and buffaloes in Bali were vaccinated during the first campaign.

The second campaign started in August 1975 and was completed at the end of the year. The total number of vaccinated animals in the campaign was 296,729 cattle, 10,427 buffaloes, 8,801 sheep/goats. To follow up the mass campaign in order to ensure that young and other unvaccinated animals were covered, vaccination was continued in 1976.

The third year of vaccination and associated mini-campaigns were staged from October 1976 to April 1977 representing a vaccination coverage of 94% animals. No cases of FMD were reported during 1976 at the end of the third vaccination campaign, as active surveillance was undertaken by the DGLS and the Provincial Livestock Services in selected villages. Based on the accumulated evidence, Bali was declared free from FMD early in 1978 and the island has remained free ever since. The situation was reported to the Office International des Épizooties (OIE) in Paris by the DGLS.

South Sulawesi

South Sulawesi has breeding and commercial stock resources and distributes cattle to other provinces in Indonesia. FMD was recorded in South Sulawesi in 1962 and the last case was reported in 1973. During 1973–74 about 125,000 heads of animals or 92% were vaccinated in the province.

At the end of the vaccination campaigns, an active surveillance was undertaken by the DGLS and the Provincial Livestock Services staff checking the vaccination records and undertook clinical and serological examination of animals in selected villages. Based on the result of the surveillance, South Sulawesi was proclaimed free of FMD in early 1981.
5. 1983–present time

The last reported outbreak of FMD in Java was in 1979 in Cilacap in Central Java when only one animal was affected. It was declared by the livestock authorities in 1982 that during six months until December 1981 there had been one case of FMD in the country.

However, the vaccination program was continued in Central Java until the end of 1982. By this time the provinces of West Java, Yogyakarta and Jakarta would have completed their three years of mass vaccination and these provinces would await evaluation before they would be declared free of FMD.

In July 1983, an evaluation and surveillance team which had been sent to carry out investigation on FMD in Central Java, discovered an outbreak of FMD in Blora, Central Java, at the time when the country was just about to be declared free of FMD. The outbreaks of FMD in Blora in Central Java and in Bojonegoro in East Java in July, 1983 then spread to other parts of the island (see Map 2). No cases were recorded outside Java. During the 6–7 months of the outbreak, 64 districts (Kabupaten) and 246 subdistricts (Kecamatan) were affected in the provinces of West Java, Central Java, East Java, Jakarta and Yogyakarta. The total number of livestock infected was 13,976. Of these 13,628 (97.1%) recovered, 136 (0.97%) died, 13 (0.09%) were destroyed (as part of the stamping-out program) and 199 (1.42%) were slaughtered and the meat disposed of. The latter number was exclusive of those that were slaughtered at the Jakarta Cakung Abattoir.

The above situation prompted DGLS to immediately undertake a series of measures to control the disease. The measures included:

- studies by staff of the Directorate of Animal Health (DAH) to investigate, determine and confirm the clinical nature of the disease;
- collection of the necessary specimens for analysis by the Veterinary Biologies Centre (VBC) in Surabaya and to WRL at Pirbright;
- surveillance and control measures by staff of DAH and VBC and the provincial livestock services (PLS) and district livestock services (DLS) of Central Java, particularly in those areas that were exposed to the infected source; and
- meeting of all heads of PLS in Java and those of disease investigation centres to plan the necessary strategies for the overall control and eradication of the disease.

The control measures were all planned to ensure they were undertaken in a coordinated manner together with the relevant agencies of the government and private organisations, including the provincial and district administrative and livestock services, the Research Institute for Veterinary Science, academic institutions (faculties of veterinary medicine), etc.

The Indonesian Government decided to undertake massive vaccination programs to cover the entire island of Java. To effectively undertake such a gigantic task, strategies were planned, including the establishment of a number of action units such as vaccination teams, disease diagnostic and vaccine production teams, field investigative and epidemiology teams, disease outbreak and field research and evaluation teams and a monitoring and evaluation team.

The control measures that were to be taken at the outbreaks, were as follows:

- stamping out;
- control of livestock movements and disinfection of vehicles;

• closure of infected areas for the purpose of
  restraining livestock movements in and out of the
  area;
• control at the abattoirs including the control on
  slaughter and meat distribution;
• control at the quarantine stations;
• isolation and treatment of livestock and dis-
  infection of livestock premises;
• mass vaccination;
• reporting of cases;
• surveillance; and
• extension services.

In undertaking the above FMD control program,
it was stressed that there must be joint and active
participation from all agencies of the governments
(central, provincial and district) including the police,
the military, the Information Department, the Office
of the Governors, the research institutes, the
veterinary faculties, the academics and the private
organisations including the women, youth, farmers,
community leaders, etc.

Closure of infected areas
As a control measure, 14 districts/cities and 84 sub-
districts were closed to all traffic for livestock and
livestock products. However, some were later re-
opened including the originally infected districts of
Blora and Bojonegoro. The livestock checkpoints
which were situated at various strategic places played
a key role in the control and eradication of FMD
in Java.

Vaccination
In the high-speed mass vaccination campaigns that
ensued, a total of 8.1 million vaccinations were
carried out representing a vaccination coverage of
96.9% of the eligible animal population of 8.3
million. The livestock vaccinated were largely cattle
and buffaloes. A small number of sheep, goats and
pigs were also vaccinated. Each animal was sub-
jected to two vaccinations with an interval of 2-3
weeks. Only animals of over three months of age
were vaccinated. Growing animals (cattle and
buffaloes) on reaching the age of three months, were
vaccinated in the second round of the campaign.
As evidence of vaccinations, all animals had their
ears notched.

Monitoring and evaluation
The monitoring and evaluation group undertook
detailed monitoring and evaluation study of the
FMD situation in the island covering 108 districts
and a total of 756 villages. It was evident from the
visits and the studies undertaken that there was the
imperative need to reach a target of 100% vacci-
nation coverage in the FMD control program. This
need was impressed upon the official vaccinators
and the community participants. The high coverage
was to ensure that there was a much greater pro-
tection and immunity conferred on the livestock
from FMD. As a result of these efforts, an increased
coverage was achieved by the vaccination teams.

Epidemiological studies
The epidemiological studies team was of the view
that the outbreaks in 1983 were the result of virus
infection within the country. As part of its con-
tribution the team established an inventory of the
FMD viruses that had been prevalent in the country
including that which was the causal agent in the 1983
outbreaks.

Research
The Research Institute for Veterinary Science (RIVS)
and VBC had jointly undertaken studies of the
efficacy of the various vaccines that had been used
during the period of the mass vaccination campaigns
in 1983. Comparisons were made with the vaccines,
that had been used earlier, and the later campaign,
i.e. O1 BFS (British field strain), O Campos, O
Malaysia and O Java 83. It was found that O Java
83 was the most protective. As a result, the vaccines
that were used subsequently in the campaigns were
O Java 83, produced by VBC. During the six month
period of the outbreak, a total of 491 specimens
were received, including 123 pathological samples
and 368 serum samples. These specimens were from
Java, Bali, South Sulawesi, Lampung and Bengkulu.
Of the 123 pathological specimens (tongue, buccal
mucosa, esophagus and brain) submitted, 17 were
found positive for FMD. Of the 368 serum samples,
165 were found to have low (0.45-1.0) antibody
titres and 102 samples had variable antibody titres
(1.0-1.8).

Control of livestock movements
The livestock checkpoints, as was stated earlier, had
played an important role in the control of the spread
of the FMD virus. All cattle and buffaloes passing
through had to be vaccinated as evidenced by their
ear notches, and had to be accompanied by the
necessary health certification and movement
permits.

There was increased quarantine security at the air-
port and seaport quarantine stations in Java. During
the period of the FMD outbreaks, no animals were
allowed out of Java. Animals leaving Bali and
Madura, the two islands which had remained
unaffected by FMD, had to undergo vaccination against FMD at their respective quarantine stations at Ketapang and Kalianget.

Animals from other parts of Java destined for the abattoir in Jakarta were subjected to tight surveillance at the collection points. The vehicles in which the animals were transported were subjected to disinfection before and after the transportation of the livestock. These animals had also to undergo FMD vaccination before they were transported.

**Declaration**

As a result of the eradication program during 1974-1981 period, the following areas were declared as FMD-free, by the Minister of Agriculture: Bali and Madura in 1978, South Sulawesi and East Java in 1981. The last case of FMD was reported in Kebumen, Central Java in December 1983, while the last vaccination in Java against FMD was at the end of 1985. Vaccination and production of FMD vaccine in Indonesia are now prohibited. The Minister of Agriculture Decree No. 260 was promulgated in 1986 which proclaimed Java free of FMD. Since the whole country has been declared free of FMD serological and epidemiological surveillance are carried out annually.

In relation to the international and regional proclamation of the disease-free status of Indonesia, the Food and Agriculture Organisation (FAO)/Animal Production and Health Commission for Asia and the Pacific (APHCA) in Bangkok nominated Dr Osman bin Din to undertake the FAO/APHCA assignment to review the FMD status in Indonesia. In his visit to Indonesia in 1986, he undertook field visits to review and evaluate the present status of the disease. With the assistance of the Government of Indonesia, he also prepared a submission concerning a FMD surveillance program for ensuring the continued FMD-free status of the country. His concluding remarks were as follows:

- the excellent achievement of the Government of Indonesia in successfully controlling and eradicating FMD which had been prevalent for more than 100 years from the republic is worthy of emulation by any other country;
- the government had the will, commitment and the dedication to succeed in the national program of FMD control; and
- the remarkable achievement of Indonesia is perhaps unparalleled in so successfully containing the disease in so wide an area with such a large livestock population.

In 1990, the Association of South-East Asian Nations (ASEAN) FMD Study Team assigned a team which consists of representatives from ASEAN member countries and FAO/OIE to visit Indonesia in order to review the FMD status in the country. A sero-epidemiological approach was undertaken by the team and the result was that the team recommended that Indonesia should be declared free of FMD.
Control of Foot-and-Mouth Disease in Europe

A.I. Donaldson*

Abstract

The European Community (E.C.) consists of 12 member states — Belgium, Denmark, France, Germany, Greece, Holland, Italy, Luxembourg, Portugal, Ireland, Spain and the United Kingdom. The E.C. completed the arrangements for establishment of a single market on 1 January 1993, which abolished border controls and permits free movement of people and goods across frontiers within the community. This free movement includes live animals and animal products. In advance of the implementation of this decision it was recognised that the single market could only be achieved if all member states adopted common disease control policies. In the case of foot-and-mouth disease, the Council of the European Community decided that prophylactic vaccination against FMD in the E.C. should cease by December 31 1991, and, following the completion of the single market, all member states must apply stamping out and specified zoosanitary measures if outbreaks of disease occur. The background leading to these decisions is reviewed in this paper.

Until 1991 the control policies for FMD applied by member states in the European Community (E.C.) were different — essentially according to whether or not prophylactic vaccination was routinely applied. In the event of outbreaks in the countries where prophylactic vaccination was used the policy was to apply total or partial stamping out (slaughter and disposal) on the infected premises and to ring vaccine in the surrounding area. In the non-vaccinating countries stamping out alone was the policy used. In the latter category were the United Kingdom, Ireland, Denmark and Greece; the other member states were in the former (Fig. 1).

During 1988–89 the Commission of the E.C. (CEC), recognising that the Single Market could only be successfully established if there was uniformity of disease control measures in all member states, reviewed the possible options for FMD control: non-vaccination; or pan-vaccination. The risks associated with each policy were assessed and a benefit-cost analysis applied to each strategy. Even allowing for a worst-case prediction of 13 primary outbreaks and 150 secondaries per primary over 10 years the results clearly showed that the benefits would be much greater if there was cessation of prophylactic vaccination (Report of the CEC 1989). This policy would fulfil the double aim of ensuring a high animal health status throughout the E.C. and would permit free movement of live animals and products within the Single Market. Most importantly, the cessation of vaccination would permit export of livestock and animal products, such as fresh meat and milk powder, from the entire Community to other FMD-free, non-vaccinating countries e.g. the United States, Canada, Australia, New Zealand and Japan. This would represent a considerable economic opportunity for those countries which formerly applied prophylactic vaccination against the disease.

The history of vaccination against foot-and-mouth disease in Europe has been mainly one of success. The question arises, therefore, ‘why stop vaccination?’ This can best be answered by reviewing the epidemiology of FMD in Europe over the last 40 or so years and highlighting the changes in disease control policy.

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Epidemiology and FMD in Europe since the 1920s

The European livestock industry was seriously affected by FMD in the 1920s and 1930s. After the Second World War the number of outbreaks declined but in the early 1950s there was a dramatic increase — 1952 being a particularly bad year with most countries experiencing several hundreds of thousands of outbreaks.

A method of producing highly potent FMD vaccine in large quantities was developed in Holland in the late 1940s and early 1950s (Frenkel 1951). This made feasible the mass annual vaccination of cattle, a policy first adopted by Holland. Vaccination together with zoosanitary control very quickly produced a dramatic reduction in the number of outbreaks (Map 1). This success encouraged other European countries to follow suit. France began mass vaccination in 1957 and Germany in 1965. As time went by other countries soon joined in and steadily the overall number of outbreaks in Europe declined, only occasionally being interrupted by major outbreaks, for example during the 1960s and early 1970s. In the 1980s only Italy (1984-87 and 1988-89) and Portugal (1980-84) have experienced large epidemics (Table 1).

The origin of FMD outbreaks in Europe during the period 1977-87 has been investigated by a subgroup of the Scientific Veterinary Committee of the CEC. Of 34 primary outbreaks, 8 were concluded to have originated from outside the E.C., 13 were of unknown origin and the remaining 13 were attributed to origins from within the E.C. (Report of the CEC 1989). It is possible that there were other incursions of virus during this period but they failed to become established due to the immunity of challenged animals or the heat treatment of waste food. In regard to those outbreaks which originated from outside the E.C. in 1977-87, the majority were attributed to the importation of contaminated meat products. One outbreak was probably due to airborne spread of virus from eastern Europe. In 1978 the E.C. introduced a policy requiring that beef

Figure 1. Outbreaks of FMD in Western Europe, 1960-93. Mass vaccination was introduced in the mid-1960s and ceased in 1990-91.
imported from countries where the disease is endemic must mature (i.e. pass through rigor mortis) and be deboned before export. It is believed that this policy has had a very positive benefit as few outbreaks since then have been attributed to the importation of meat (Report of the CEC 1989).

The availability of newer biochemical techniques, in particular dideoxynucleotide sequencing, has permitted the detailed comparison of FMD virus strains from field outbreaks with reference strains. Using such procedures it has been possible to show that for 13 of the outbreaks originating from within the E.C. in the period 1977–87, there were two major sources: the use of vaccines which had not been fully inactivated and contained small amounts of residual infectivity; and escapes of virus from laboratories (Beck and Ströhmaier 1978).
Table 1. Outbreaks (number) of FMD in member states of the E.C., 1980-93.

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<thead>
<tr>
<th>Country</th>
<th>Most recent</th>
<th>1980</th>
<th>81</th>
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<td>France</td>
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<td>Spain</td>
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<td>Portugal</td>
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<td>303</td>
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— No outbreaks

Faulty vaccines have been largely attributed to the use of formalin as an inactivant. This inactivant, unless used under very stringent conditions, can give unpredictable results leading to a risk of the survival of some virus. The mechanisms of escapes from laboratories have been difficult or impossible to pin-point but are thought most likely to have been associated with procedures generating highly concentrated aerosols of virus such as the experimental infection of susceptible livestock or large-scale virus growth for vaccine production (Mowat 1989).

Therefore, while the use of vaccine has undoubtedly played a significant role in reducing FMD outbreaks on continental Europe during the last 40 or so years, a significant proportion of recent outbreaks can be attributed to vaccine or vaccine-related activities. It was this evidence which strongly influenced the decision by the CEC to recommend the use of vaccine be discontinued. Consequently, the Council of the E.C. directed that vaccination was to cease in the E.C. before the 1 January 1992. This allowed a one-year period for vaccinated animals to lose their immunity before the Single Market came into operation. However, some countries decided to stop well in advance of the deadline. Spain stopped at the end of 1990, and Belgium, Holland, Luxembourg and Germany carried out their last rounds of vaccination in the Spring of 1991. France and Italy ceased vaccinating in the Summer of 1991.

Present E.C. Policies for Control and Prevention of FMD

In the event of outbreaks in the E.C. the main disease control policy is total stamping out, i.e. slaughter and disposal of all affected and in-contact susceptible animals on the infected premises. This is supported by zoosanitary measures including disinfection and movement restrictions. A E.C. contingency fund has been established to compensate farmers in the event of outbreaks.

In addition to stamping out, emergency strategic vaccination may be undertaken in certain circumstances. In anticipation of this possibility vaccine banks will soon be established in which concentrated inactivated FMD virus antigens will be stored over liquid nitrogen. It has been decided that there will be four banks — located in France, Germany, Italy and the United Kingdom. It is intended that the equivalent of 5 million vaccine doses of each of 10 different strains will be stored.

Additional technical support is provided by a Community Co-ordination Institute for FMD Vaccines (CCI) which tests vaccines produced for use in the E.C. and in Community-supported vaccination campaigns in non-E.C. countries which export to the E.C. The CCI also evaluates vaccine innocuity and potency testing systems and trains experts in vaccine technology. The Central Veterinary Laboratory, Lelystad, Holland has been designated as the CCI.

In 1990 the Institute for Animal Health, Pirbright Laboratory, was appointed as a Community Reference Laboratory (CRL). Its main duties are to ensure liaison between national FMD laboratories in the E.C. in regard to the standards and methods of diagnosis and differential diagnosis of FMD; to receive field samples when necessary from member states and certain non-E.C. countries; to identify and characterise any isolates of FMD virus; and to
build up and maintain a reference collection of FMD virus strains and specific antisera. The CRL is also responsible for the supply to national FMD laboratories of reagents for diagnosis, for providing diagnostic training, for standardising FMD diagnosis and differential diagnosis in the E.C. and for collecting and disseminating related data and information to the CEC and the member states.

The CCI and the CRL are both responsible for formulating guidelines for disease security in the respective national FMD laboratories. At present 13 laboratories are manipulating FMD virus in the E.C. Three are vaccine production plants and the remainder hold virus for diagnostic or research purposes. To lessen the risk of virus escapes those establishments manipulating virus, whether for diagnostic purposes or for vaccine production, are subjected to inspection by representatives acting on behalf of the CEC and they have to demonstrate that they comply with specified microbiological security standards.

The cessation of prophylactic FMD vaccination in the European Community has resulted in a significant reduction in the number of vaccine production plants. Both of these factors together with stricter security measures have greatly reduced the risk of 'home-grown' outbreaks within the E.C.

Importation from Third Countries
Since the completion of the Single Market all imports of live animals, meat and other animal products such as milk, hides, wool, offal, biological products and materials (including veterinary vaccines and pharmaceutical products) and feedstuffs, are only permitted through specified ports of entry located around the periphery of the E.C.

Animal importations
The importation of animals from non-E.C. countries is freely permitted if those countries apply control measures equivalent to those of the Community. The former eastern bloc countries, for example, have been accorded similar status to member states of the E.C. since they have implemented the same policies for the control of FMD — in particular cessation of vaccination. The other countries of Europe, namely the Scandinavian countries, Switzerland and Austria fall into the same category, so in regard to FMD essentially all of Europe has the same trading arrangements.

Animals from non-E.C. countries of a lower health status or where the control measures are not as stringently applied are either prohibited entry or are isolated in quarantine and tested to ensure an absence of both virus and circulating antibody.

Meat and meat products
These products are considered on an individual basis. If they originate from a non-E.C. country of equivalent FMD status to the E.C., i.e. non-vaccinating and FMD-free, entry is usually freely permitted. However, if they come from a country of lower health status either the product is prohibited or certain safeguards are required before entry is allowed.

References
Patterns of National and International Livestock Movement in Southeast Asia: Implication for a Regional Foot-and-Mouth Disease Control Program

Masao Sasaki*

Abstract

The movement of livestock, in particular cattle, within and beyond international boundaries has been a long tradition in Indo-China countries. Without any effective control mechanisms for livestock movement, cattle and, to some extent, buffaloes move to the place where they can be sold at a better price. Therefore, it is extremely important to understand prevailing patterns of national and international livestock (mainly cattle) and to implement a proper control mechanism to complement programs for FMD control and eventual eradication. This paper reviews animal movement patterns in the Indo-China peninsula countries of Myanmar, Thailand, Laos, Cambodia and Vietnam. It is suggested that international cattle movement should not be banned or regarded as 'illicit'. Instead, liberalized livestock trade should be encouraged under certain conditions for the benefit of both exporting and importing countries. In this regard, effective animal quarantine systems both at the international border and along important transportation routes within a country become necessary. Bilateral agreements and closer contact between neighboring countries at both national and local levels are essential to develop proper animal movement control systems which are convenient and practicable for livestock owners.

In the context of any programs for FMD control and eventual eradication in Southeast Asia, it is important to have strategies to deal with animal movements within a country as well as across international boundaries. It has been a long tradition in this region that cattle and buffaloes move almost freely from one place to another sometime covering distances of more than 1000 km on foot and often crossing international borders. This is due to the economic principle that all commodities including live animals move to the point where their prices are highest, as long as there are no restrictive measures (or effective control mechanisms) to regulate this movement.

Animal Movement Patterns

Animal movement patterns of five Indo-China Peninsular countries (i.e. Myanmar, Thailand, Laos, Cambodia and Vietnam) are shown in the respective country papers included with these proceedings and in Map 1 of Ozawa (these proceedings). The information presented in this paper is based mainly on the Report on the Second Meeting of the Coordination Group for the Control of FMD in Southeast Asia, Bangkok in February 1993.

In Southeast Asia, animal movement involves mainly cattle, and to much less extent, buffaloes. Movement of sheep and goats, and swine also exists but their effects in terms of FMD control and eradication is much less. With the possible exception of raw hide, there is hardly any significant movement of meat and other animal products by-products.

Myanmar

Myanmar is divided into seven divisions, predominantly populated by Burmese, and seven states where other ethnic groups reside.

Of a total cattle population of 9.3 million in 1992, most were in five divisions and one state: Sagaing Division (1.6 million), Mandalay Division (1.5),

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The country is land-locked and surrounded by three neighbours: China, Vietnam and Thailand. The cattle population has grown steadily in the past 10 years with the average annual growth of 7.5% (total population in 1993 of 1 million) and is distributed evenly over the country, while the buffaloes (1.2 million) are found mainly in the south (Mekong Basin). The major function of both cattle and
buffaloes is to provide draft power. Meat production is still regarded as a by-product operation of much less importance than draft use. However, in recent years export earnings from cattle and buffaloes have become important with estimated earning of over US$10 million in 1992. Live cattle and buffaloes and their raw hide are exported. While bovine movement is in one direction towards Thailand, live animals, mainly cattle, come into Lao territory from China, Vietnam and Cambodia. Some cattle arrive in the Lao provinces from Vietnam and continue to move into Thailand. It has been reported that there are some mechanisms to control animal movement (quarantine stations and check posts) both at international borders and on the major inland animal trading routes but their effectiveness is to be evaluated. There is a national FMD control program whose major activity is FMD vaccination. Only 50,000 animals (out of over 2 million of bovine species) are vaccinated yearly just to reduce or confine outbreak incidences. There are no particular provinces (areas) identified yet where a future FMD-free zone will be created.

Cambodia

Cambodia has 22 provinces and according to the latest Food and Agriculture Organisation (FAO) statistics, the cattle population in Cambodia has more than doubled in the past decade (956,000 head in 1981 vs over 2.1 million in 1991) with an average annual growth rate of 8.6%. The buffalo population has also increased significantly from 0.4 million in 1981 to 0.8 million in 1991 with a growth rate of 6.7%. The provinces with the largest number of cattle are Kampong Cham (330,000), Takeo (314,000), Kampong Speo (273,000), Kandal (248,000) and Prey Veng (182,000), all located around the capital, Phnom Penh. For buffaloes, Prey Veng has the largest population (133,000), followed by Kampong Cham (109,000) and Svay Rieng (100,000). As is the case for Thailand, Laos, and the southern part of Vietnam, most FMD outbreaks coincide with the monsoon season, during which period cattle and buffaloes are required to work as draft animals for rice paddy production. The movement of animals occurs mainly during the dry season. Internal movement of cattle is from the northeastern to the central provinces and international movement of animals, including a significant number of buffaloes, is from the central provinces to Thailand (on foot or by boat), to Vietnam and, to some extent for cattle, to Laos. The major gates for animal movement are: Poipet (Aranyaprathet in Thailand) in Banteay Meanchey Province; and Bavel in Battambang Province. Three provinces (Koh Kong, Kampong Song and Kampot) facing the Gulf of Thailand are assumed to export a significant number of live animals and some quantities of meat products by sea.

There exists a law (Decree on Sanitary Control of Animals and Animal Products) under which animal movement can be regulated inside the country as well as at the border. Due to many confronting problems, the enforcement of the law has not been practised.

Vietnam

Vietnam is divided into seven regions, three in the north and four in the south. Cattle are densely populated in two central coastal regions but relatively less in the two delta (Red River and Mekong) regions. More buffaloes are found in the north, particularly the North Mountains and Midlands Regions. The country's cattle population increased from 1.7 million in 1981 to 3.3 million in 1991 with an average annual growth rate of 7.5%. The increase in buffalo population is, on the other hand, rather nominal with an annual growth rate of 2.4% (2.3 million in 1981 vs 2.9 million in 1991).

No FMD outbreaks were reported in recent years in either the north or the central areas of Vietnam. Major outbreaks were reported in provinces in the Mekong Delta and some in the South-Central Region. In the north, cattle move into Hanoi for slaughter while some move out into China and Laos. In the south, both cattle and buffaloes move to Ho Chi Minh City for slaughter. Some cattle are also transported into Lao territory and end up in Thailand. Movement across the Cambodia-Vietnam border is in both directions depending on the price of animals at any particular time.

A reorganisation of field veterinary services was completed in 1992. The provincial subdepartment can now directly manage the district animal stations, resulting in an improved vaccination campaign, epidemiological survey and disease reporting system. There are animal check posts along the major provincial borders and those on the international border with Cambodia. However, the animal movement both within the territory and at the international border is not effectively regulated except for the emergency area where the severe FMD outbreaks are taking place.

Livestock Movement Control: Effective Animal Quarantine Practices

As already described, cattle movement in the Indo-China region traditionally involves long-distance journeys frequently crossing international
boundaries. Traditionally such movement of animals was on foot and this is still practised. However, trucks are now widely used to ship animals faster over long distances. An ocean route is also of considerable importance in the case of Cambodia.

It is therefore difficult and rather impractical to try to enforce a total ban on so-called 'illicit' movement of cattle across the borders. Furthermore, it seems to be a rather out-of-date concept to call this kind of movement illicit since it has been practised for such a long time. In the long run, a more liberalised movement of cattle across the border would benefit both cattle producers in exporting countries and beef consumers in importing countries. However, at present, cattle-crossing at an international border is considered to be an illegal action in all five countries and practical strategies therefore have to be worked out under these circumstances.

Some animal quarantine stations and check posts have already been set up in all these countries. The role of such stations are to make sure that animals passing through the quarantine point cause no threat of introducing specified infection(s) in a new location. For international quarantine stations further functions are:

- to regulate the movement of animals and their products/by-products so that a possible entry of any undesirable diseases/infections can be prevented — i.e. protecting own country; and
- to make sure that animals and the products/by-products are free from diseases and of an acceptable standard of veterinary health for receiving countries as well as the exporting country itself — i.e. protecting the partner country.

In practice, however, existing animal quarantine stations/posts in the region are not functioning properly. There are many reasons for this failure of the existing quarantine systems. Poor facilities, lack of enforcement power, shortage of personnel, budget constraints and lack of cooperation by animal owners and traders are just a few of them. Probably the largest problem for animal movement control through quarantine systems, however, relates to ignorance amongst the general public, other government agencies and in some cases, the livestock department itself on why quarantine stations are needed and their responsibility/duty to enforce regulations.

Without doubt, bilateral and regional cooperation is essential and indispensable to the proper implementation of animal movement control mechanisms which are one of the most important strategies on FMD control and eradication in the region.

In this respect, it is very gratifying to learn that Laos and Thailand made a tentative agreement to establish several cattle holding sites close to the Laos side of the border where animals destined for Thailand are held and properly quarantined by both Lao and Thai veterinarians.

**Conclusion**

It can not be overemphasised that without proper control of animal movement within countries and across international boundaries, FMD control and eventual eradication programs will not succeed. Cattle movement from one place to another, sometimes involving the crossing of international borders, has been a long tradition and is considered as an indispensable activity in the daily life of people in the region. Thus, it may be necessary to recognise this and, instead of tightening the existing laws to ban such animal movement, it would be more practical and beneficial to encourage this movement as a legitimate livestock trade in the region.

For this purpose bilateral and regional level cooperation is essential and the following measures are required:

- **field veterinary services, which include effective inland and international animal quarantine systems, need to be improved;**
- the role, function and real effectiveness of all existing animal quarantine stations/check posts should be reviewed with a well defined, narrowly targeted objective of their existence. It is wasteful to pay much attention to many endemic diseases whose local distribution has not yet been well established. In most inland and international border stations, FMD would be the only disease of special concern;
- formal as well as informal contacts should be developed with neighbouring countries at both national and local levels to discuss the practical mechanisms of animal movement control;
- animal owners and traders should be given more information on FMD so that they can understand why their animals need to be quarantined; and
- government quarantine procedures (issuing animal health and moving certificates, holding animals at a station, animal inspection, etc.) should be, as long as they are technically sound, simpler, less time consuming and with a minimum cost involved so that animal owners and traders are encouraged to move their animals in a legalised way, instead of smuggling them.
Strategy Options for the Control of Foot-and-Mouth Disease in Southeast Asia

Y. Ozawa*

Abstract

The past involvement of the Office International des Épizooties (OIE) in efforts for the control of foot-and-mouth disease (FMD) in Southeast Asia is briefly described. Strategy options for the control of FMD are discussed emphasising that the most economical and effective option is to organise an internationally coordinated eradication campaign against FMD in Southeast Asia covering the countries between Myanmar and the Philippines. The outline of the OIE plan for the FMD campaign in Southeast Asia is described. The proposed plan includes the formation of a sub-commission for the control of FMD in Southeast Asia as a part of the OIE Commission for FMD and Other Epizootics. The proposed plan also includes a justification of the campaign; proposed strategies; duration of the campaign, which is divided into three phases; the organisational structure; and the proposed budget.

In Asia, foot-and-mouth disease (FMD) has been a subject of great concern to all the countries. Since its inception in 1976, the Food and Agriculture Organisation (FAO)/Animal Production and Health Commission for Asia (APHCA) has made continuous efforts to control the disease. Several missions were fielded, and a comprehensive review of the situation and recommendations were published in 1984 (FAO/APHC 1984). There was a proposal to organise a coordinated international campaign in Asia in the APHCA region, but this did not materialise.

Although some good progress has been achieved in some island countries such as Indonesia, most of the countries in Asia which share land borders continue to suffer because of the movements of infected animals. Civil strife and wars in Indo-China, resulted in the interruption of disease control programs in this subregion for several years.

However, in recent years, as the political and economic climate has begun to improve in Indo-China, there has been a marked increase in both legal and illegal movements of animals across international borders, and the FMD situation in some of the countries in Southeast Asia has taken a turn for the worse. Under these circumstances, the OIE Symposium on the Control of Major Livestock Diseases in Asia was held in Pattaya, Thailand, in November 1990, and the FMD control strategy in Southeast Asia was discussed. The symposium recommended that the OIE should form a sub-commission for the control of FMD in Southeast Asia in order to promote internationally coordinated campaigns against FMD in the region.

This recommendation was approved by the OIE International Committee in 1991, and the first meeting of the Coordinating Group for the Control of FMD in Southeast Asia was held in Bangkok under the OIE/Japan Trust Fund Program in February 1992 with the participation of FAO.

The second meeting of the same group was in February 1993. The group consisted of Myanmar, Thailand, Malaysia, Laos, Cambodia, Vietnam and the Philippines. The participants agreed that common overall strategies for the control/eradication of FMD should be taken by these countries, and also agreed to develop national plans based on the agreed strategies.
Strategy Options

There are at least three options for FMD affected countries which are discussed below.

• **Do nothing.** This option means that no special efforts are made to control FMD. If a country takes this option, FMD will spread all over the country and also to its neighbours, causing serious economic losses in all infected countries.

• **Maintain the current status.** This option means that a country has to live with the disease forever, and will have to continue to allocate high levels of funds to keep the disease under reasonable control. Annual expenses for the control or prevention of FMD will increase as trade in animals increases in the region.

• **Eradication campaign.** This option may cost more during the campaign, but in a long run the benefit–cost ratio may reach between 5:1 and 8:1 in favour of the campaign (Ellis and James 1979). It is essential that such campaigns should be internationally coordinated in order to prevent the re-entry of FMD from neighbouring countries.

From the above, it is obvious that the eradication campaign is the best choice for all the countries in Asia. The success of a national campaign depends on the efficiency of veterinary services if the country is isolated by sea or natural barriers. However, if a country shares land borders with other affected countries, the success of a national campaign depends on many other factors, such as the control of international movements of animals and their products, synchronisation of vaccination campaigns along the borders, tracing back the origin of FMD virus across the borders, the exchange of information about the FMD situation between countries. For this reason FMD control campaigns in the countries of Southeast Asia should be well coordinated if the campaigns are aiming at the eventual eradication of the disease.

It is known that FMD is endemic in Myanmar, Laos, Cambodia, Thailand, Malaysia, Vietnam and the Philippines (OIE 1993). With the exception of the Philippines, all other countries share land borders, and movements of animals crossing national borders are increasing year by year as shown in Map 1.

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**Map 1.** Movement patterns of cattle and buffaloes in Southeast Asia (OIE 1993).
Under these circumstances, the countries between Myanmar and Vietnam should be considered as a community, and an internationally coordinated program should be developed before individually-planned national campaigns are launched. At the same time, measures to prevent the entry of FMD into the community of countries should be strengthened. The entry of susceptible animals from India, Bangladesh and China should be prohibited to avoid the introduction of FMD through those countries.

Prior to launching an FMD campaign in Southeast Asia, national and international campaign strategies within the community of countries should be developed, based on the epidemiological studies and the trade patterns of susceptible animals including illegal trade across land, river and sea borders.

There will be several strategy options for a regional campaign such as this, but it is usual that vaccination programs start in the areas that are found to be the source of infection by epidemiological studies. Then, all animals for trade should be immunised and earmarked prior to their departure. Importation of susceptible animals and their products from FMD-infected countries outside the community should be banned.

National vaccination campaigns should continue until the number of outbreaks is reduced to a few, and then a stamping-out policy with full compensation to the owners should be applied where it is feasible. When this policy cannot be applied, strict movement control of animals and ring vaccination should be carried out. Then, FMD-free zones in each country should be established and the free zone should be gradually expanded until the entire country becomes FMD-free. If a free zone is created near a national border, internationally coordinated efforts should be planned in order to expand the FMD-free zone along the border. These are just a few basic strategies to be considered, but the actual strategy to be applied in a regional campaign will be far more complicated.

OIE Plan for the Campaign against FMD in Southeast Asia

Objectives

The immediate objective of the OIE plan is to improve the standards of veterinary services in FMD-affected countries in Southeast Asia. The intermediate objectives are to improve the productivity of animals by keeping FMD under control and to increase the income of livestock producers in Myanmar, Laos, Cambodia, Thailand, Malaysia, Vietnam and the Philippines. The long-term objective is to facilitate and promote the international trade of animals and animal products by creating FMD-free regions in Southeast Asia.

Justification

In the last decade, FMD control efforts in the countries of Southeast Asia have received a great deal of attention, and individual national control programs were carried out. Funds, equivalent to several millions of dollars, have been spent annually for these programs but without much success mainly due to the fact that there were no common overall strategies and that there were no internationally coordinated programs.

Recent changes in the political and economic climate in the region encouraged the commercial sectors of many countries to pursue international market-oriented trade in livestock and its products. A sudden increase in both legal and illegal trade of animals crossing national borders resulted in the expansion of the FMD-infected areas due to the movement of infected animals.

The countries of Southeast Asia have shown during the first and the second meetings of the Coordinating Group for the Control of FMD in Southeast Asia (held in Bangkok in 1992 and 1993) that they are ready to work together with confidence, and that they are all anxious to start an internationally-coordinated campaign with a common overall strategy.

A study made in 1977 (Ellis and James 1979) in South Asia on the benefit-cost analysis of FMD control programs showed the ratio between 5:1 and 8:1 in favour of control programs. This impressive ratio is likely to be even higher in Southeast Asia where the eradication of FMD is considered feasible and permanent improvements in the production systems can be safely introduced. However, the rising costs of FMD control programs require the development of the most efficient and economical strategy through rigorous evaluations and regular benefit–cost analyses of national programs.

Strategy of the campaign

A common strategy for the control and eventual eradication of FMD in the region includes the following elements:

- establishing a regional reference laboratory and a regional coordinating unit;
- strengthening veterinary services in individual countries;
- active involvement of the private sector (e.g. farmers’ unions and livestock producers and traders) in the planning and implementation of control programs;
- developing effective FMD surveillance and reporting systems;
- establishing national diagnostic capabilities for virus identification and serotyping;
- implementing mass vaccination programs as the primary method for reducing the incidence of the disease to low levels; and
- implementing other control methods for individual outbreaks, as appropriate.

These elements of the strategy were accepted by the participants of the second meeting of the Coordinating Group for the Control of FMD in Southeast Asia held in Bangkok in February 1993.

In order to coordinate activities in Southeast Asia for FMD control, it is essential to establish an efficient regional reference laboratory/regional coordinating unit in Bangkok as soon as possible. Also, as a matter of urgency, each country included in the campaign should develop action plans based on the above measures. Each country should also identify the areas in which external assistance is required.

Duration of the campaign

The duration of the campaign is approximately 12 years. The campaign is divided into the following three phases:

**Phase 1 (the preparation phase)** — 3 to 4 years for reducing FMD outbreaks;

**Phase 2 (the control phase)** — 5 years for the expansion of low prevalence areas; and

**Phase 3 (the eradication phase)** — 3 to 4 years for the eradication and conservation of FMD-free status.

It is intended that phase 1 of the campaign begins in 1995, phase 2 in 1998 and phase 3 in 2003. The major activities of the three phases are summarised below.

**Phase 1 (preparatory phase)**
- Establish a regional reference laboratory and a coordinating unit.
- Strengthen both field veterinary services and laboratory services in each country.
- Collect FMD samples from each outbreak for typing.
- Investigate further the movement of animals, and develop better systems for animal health control at national borders.
- Carry out epidemiological surveillance on FMD and improve the disease reporting system.
- Improve public awareness of the importance of FMD through communication campaigns with special emphasis on disease reporting by livestock owners.
- Encourage active involvement of the private sector in the planning and implementation of control programs.
- Strengthen cold-chain systems in each country.
- Introduce earmarking systems for vaccinated animals.
- Increase FMD vaccine production capacity in the region after identification of the most suitable vaccine strains and to introduce a strict vaccine quality control system.
- Develop national and international plans for the control of FMD.

**Phase 2 (FMD control phase)**
- Step up communication and vaccination campaigns and to encourage the active participation of the private sector and farmers in the campaigns.
- Implement progressively stamping out in areas as epidemiologically indicated.
- Evaluate the efficacy of FMD vaccination by taking adequate numbers of serum samples.
- Strengthen the movement control of animals from infected areas or countries (only vaccinated and earmarked animals are allowed to move).
- Carry out investigation and each outbreak including strain identification and epidemiological tracing.
- Create disease-free zones including the surrounding buffer zones, and expand the zones step by step to cover entire countries.

**Phase 3 (eradication and consolidation phase)**
- Establish solid buffer protection zones to prevent the entry of FMD from countries not included in the campaign.
- Strengthen further the movement control of animals and animal products, and prevent the entry of FMD through sea/air ports and smuggling operations.
- Cease vaccination in areas where other preventive measures are consolidated and no outbreaks have occurred.
- Intensify clinical surveillance in these areas.
- Carry out serological surveillance of FMD in the areas where vaccination has ceased for more than two years.
- Maintain and strengthen legal and financial measures for stamping out FMD outbreaks.
- Maintain producers and public information campaigns in order to prevent the reintroduction of FMD.
• As soon as OIE requirements for FMD-free status are fulfilled by a country/zone, the country may request the OIE to verify the status before the country makes an official declaration of FMD-free status.

Over the three phases, the veterinary services must continuously be strengthened, and public awareness for the importance of animal health with special emphasis on the major epidemic disease must be improved.

Organisational structure
A proposed organisational structure is shown in Figure 1. The OIE Sub-Commission for the Control of FMD in Southeast Asia will be formed from delegations of the governments of Myanmar, Laos, Thailand, Malaysia, Cambodia, Vietnam and the Philippines. This sub-commission will be part of the OIE Commission for the Control of FMD and Other Epizootic Disease, and is supported by the OIE Regional Commission for Asia, the Far East, and Oceania; the OIE Central Bureau; OIE Tokyo Office; FAO Regional Office in Bangkok; the International Atomic Energy Agency (IAEA) and donor agencies. The annual meeting of the sub-commission will be held in a place decided during the previous meeting of the sub-commission.

The Executive Committee will consist of two of the above seven countries elected by the sub-commission, the Head of the Regional Coordination Unit and an OIE Representative. The committee will meet once a year (usually just before the annual meeting of the sub-commission).

The Advisory Committee is formed by the representatives of OIE, FAO, IAEA and major donor agencies. The committee will meet on an ad hoc basis and the chairman of the Executive Committee and the Head of the Regional Coordination Unit will be requested to take part in the meeting.

The main functions of the Regional Coordination Unit are:
• coordination of FMD control activities in Southeast Asia;
• coordination of FMD reporting in the region;
• coordination of epidemiological studies of FMD in the region;
• coordination of research/training activities;
• formulation of FMD control strategies in the region; and
• provision of advice to national FMD campaign coordinators.

The main functions of the Regional Reference Laboratory will include:
• identification and antigenic characterisation of FMD virus samples received;
• introduction of new laboratory methods for FMD virus typing and serological tests;
• provision of standard diagnostic reagents for use in the region;
• investigation of vaccine failure by laboratory tests; and
• quality control of vaccines used in the campaign as required.

In each country, a National Coordination Unit for the FMD campaign will be established to

![Figure 1. Proposed organisational structure for the OIE campaign against FMD in Southeast Asia.](image)
coordinate national activities related to FMD control/eradication. The activities include:
• strategic planning of the campaign based on epidemiological studies and cost-benefit analysis;
• epidemiological investigation of FMD, and reporting the disease situation;
• execution of FMD surveillance and control programs;
• movement control of susceptible animals and their products;
• vaccination of animals, and monitoring of the efficacy of vaccines used;
• laboratory investigation of all FMD-like disease and vaccine failures;
• establishment of FMD-free zones/countries; and
• strengthening of preventive measures, etc.

Finance
Each country of the OIE sub-commission will allocate annually funds necessary for the national campaign. A separate allocation of funds (in local currency) shall be made to cover the costs such as travel expense of national coordinators to attend international meetings, travel expenses for trainees to attend international courses, travel and per diem expense of international coordinators and technical advisers during their stay in the country.

In addition to the above, assistance from international organisations such as the OIE, FAO, IAEA, United Nations Development Program, European Community, Asian Development Bank, etc, and also from bilateral aid agencies will be sought to meet the financial requirements for both national campaigns and international coordination of the campaign.

The costs of national campaigns and regional activities will be made by national officials in consultation with international advisers.

References
DIAGNOSIS OF FOOT-AND-MOUTH DISEASE

The focus of this session was the diagnosis of foot-and-mouth disease (FMD) and the first speaker, Dr Ab Kongthon of the Department of Livestock Development, Thailand, described the development of diagnostic facilities in Thailand since the late 1950s when the complement fixation test was first used. Use of the enzyme-linked immunosorbent assay (ELISA) was developed in Thailand in 1986 as a result of a collaborative Thai-Australian project. Initially the reagents were obtained from the World Reference Laboratory at Pirbright, United Kingdom, but since 1987 the reagents have been produced by the FMD Center at Pak Chong in Thailand. As the virus cannot be detected in a proportion of the samples it is necessary to have the ability to isolate the virus prior to typing. Virus isolation capabilities are therefore necessary to be included in national diagnostic laboratories.

Dr Laurence Gleeson of the Australian Animal Health Laboratory described strain differentiation studies carried out as part of the Thai-Australian FMD project in Northern Thailand. The principal goals of the study were to examine the serological relationships between a large sample of recently isolated field strains and existing vaccine viruses so as to attempt to identify problems arising from continued use of established vaccine strains; determine epidemiological relationships between outbreak virus strains; and suggest candidates for vaccine selection. The results of the study illustrate the need for continued monitoring of field virus strains so as to ensure that the most appropriate vaccines are used.

To promote animal health and the spread of disease through international trade the Food and Agriculture Organisation and the Office International des Epizooties have designated reference laboratories for important infectious diseases including FMD. Dr Alex Donaldson from the World Reference Laboratory, Pirbright gave a global overview of these reference laboratories and their role at national, regional and international levels for diagnosis (serotyping), virus isolation and other technologies, epidemiological data analysis, provision of vaccine advice for prophylaxis and emergency control, training and other activities related to FMD control. The Institute of Animal Health at Pirbright, United Kingdom has been designated by the OIE/FAO as the World Reference Laboratory for FMD and the FMD Center, Pak Chong is the Regional Laboratory for Southeast Asia.

Finally, Dr Ana Maria Espinoza from the National Institute of Health in Peru described a study of FMD virus infection-associated (VIA) antibodies in Peruvian cattle and camelids (llamas, alpacas, vicunas). The study compared the use of the standard agar gel immunodiffusion test (AGID) with the more recently developed liquid phase enzyme-linked immunosorbent assay (ELISA) and concluded that the ELISA technique is more sensitive for detecting the presence of VIA antibodies and is therefore a better test to support prevention and control programs for FMD.
Development of Laboratory Diagnosis of Foot-and-Mouth Disease in Thailand

Ab Kongthon*

Abstract

Confirmation of a clinical diagnosis of foot-and-mouth disease (FMD) is initially attempted by demonstrating the presence of the viral antigen in samples of vesicular epithelium. The complement fixation test (CFT) has been employed since 1959. The method was subsequently modified resulting in a simple, sensitive and reliable assay. Testing by the enzyme-linked immunosorbent assay (ELISA) was started in 1986 as part of a collaborative project of the Thai and Australian Governments. With a proportion of samples, viral antigen cannot be demonstrated by either CFT and/or ELISA. In these circumstances virus isolation subsequent to virus typing must be performed. Attempts to isolate the virus were carried out in suckling mice and in cell culture, e.g. BHK-21 and foetal lamb lung (FLL) cell lines or primary bovine thyroid (BTy) cells. The requirement for national diagnostic laboratories in Southeast Asia must be appreciated due to the need for virus typing capability from field samples. Key factors for consideration in the establishment of a national laboratory are facilities, methodology, equipment, staff and budget.

Laboratory Diagnosis

Complement fixation test

Laboratory diagnosis of foot-and-mouth disease (FMD) was established in Thailand in 1959 using the complement fixation test (CFT). Reagents were locally produced and testing carried out at the FMD Center, Pak Chong. The results of the testing for 1959 to 1990 are shown in Table 1.

Enzyme-linked immunosorbent assay

The antigen trapping typing enzyme-linked immunosorbent assay (ELISA) was introduced as part of the ACIAR-sponsored Thai–Australian FMD project. This test has been used at the Northern Veterinary Research and Diagnostic Center, Hang Chat, since 1986 and has recently replaced the CF test as the routine typing test at the FMD Center, Pak Chong. The test is carried out by the indirect double antibody sandwich method. The reagents originally used were derived from the World Reference Laboratory, Pirbright, England, and supplied via the CSIRO Australian Animal Health Laboratory, Geelong, Australia, but since 1987 have been produced at the FMD Center in Pak Chong. Antiserum are prepared in rabbits (for capture) and in guinea-pigs (for detection) by inoculation with purified 146S antigen of selected Thai field isolates or with reference strains. The antibody concentrations to be used in typing by ELISA were determined by titration against homologous strains. These reagents have been found to be as sensitive as the original reagents from WRL.

Virus isolation

Diagnosis of FMD can be achieved by direct detection of the virus in field samples by immunological methods (CFT and ELISA). However, with some samples it is not possible to detect virus directly in this way, because of either the poor quality of the sample or the low sensitivity of the test. In these cases virus isolation is necessary before identification of the virus type can be carried out. FMD virus isolation has been carried out in suckling mice and more recently in cell culture.

* Department of Livestock Development, Phyathai Road, Bangkok 10400, Thailand.
Table 1. Results of complement fixation testing of field samples at the FMD Center, Pak Chong, 1959-90.

<table>
<thead>
<tr>
<th>Years</th>
<th>Total no. of samples</th>
<th>Virus type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>O</td>
</tr>
<tr>
<td>1959-80</td>
<td>2769</td>
<td>56.9</td>
</tr>
<tr>
<td>% of samples</td>
<td>11.6–84.2</td>
<td>0–30.2</td>
</tr>
<tr>
<td>1981–90</td>
<td>1772</td>
<td>44.1</td>
</tr>
<tr>
<td>% of samples</td>
<td>10–84.5</td>
<td>0.9–57.1</td>
</tr>
</tbody>
</table>

The cell cultures which have been used for virus isolation are the baby hamster kidney (BHK)-21 cell line; a foetal lamb lung (FLL) cell line derived by Japanese collaborators; and primary cultures of bovine thyroid cells (BTy). Although the most reliable method for virus isolation is inoculation into primary bovine thyroid cell cultures, primary cell cultures are complicated to prepare and maintain for routine virus isolation. The cell lines, which are comparatively simple to prepare and maintain, might therefore have an advantage over the primary cells provided that a similar sensitivity is obtained.

Various experiments have been carried out to compare the sensitivity of the different procedures used at the FMD Center. Isolation of FMD virus in BHK-21 cells was compared with the detection of antigen by the CFT. The results are summarised in Table 2. Attempts to isolate virus from samples which were not identified by the CF test were also made in suckling mice. Comparison of the results of isolation in BHK-21 cells and suckling mice are shown in Table 3.

Table 2. Comparison of isolation of FMD virus in BHK-21 cells, and the complement fixation test.

<table>
<thead>
<tr>
<th>Virus isolation</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF TEST</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>96 (41.2%)</td>
<td>31 (13.3%)</td>
</tr>
<tr>
<td>Negative</td>
<td>50 (21.5%)</td>
<td>56 (24.0%)</td>
</tr>
<tr>
<td>Total</td>
<td>146 (62.7%)</td>
<td>87 (37.3%)</td>
</tr>
</tbody>
</table>

Table 3. Isolation of FMD virus from complement fixation negative samples in BHK-21 cells and suckling mice.

<table>
<thead>
<tr>
<th>Mouse inoculation</th>
<th>Positive</th>
<th>Negative</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHK-21 cells</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>12 (19.0%)</td>
<td>23 (36.5%)</td>
<td>35 (55.6%)</td>
</tr>
<tr>
<td>Negative</td>
<td>2 (3.2%)</td>
<td>26 (41.3%)</td>
<td>28 (44.4%)</td>
</tr>
<tr>
<td>Total</td>
<td>14 (22.2%)</td>
<td>49 (77.8%)</td>
<td>63 (100%)</td>
</tr>
</tbody>
</table>

In another study comparative titrations of 21 field FMD virus samples in the three different cell culture systems (BHK-21 and FLL cell lines; primary BTy cells) were made and the results of are shown in Table 4. The FLL and BTy cells did not detect virus from 2 (9.5%) and 4 (19%) samples respectively and BHK-21 cells failed to detect virus from 11 (64.7%) out of 17 samples examined. The FLL and BTy cells detected virus in the field samples readily even at the first passage whereas BHK-21 cells did not always detect virus at the first passage, and so a number of passages of the sample were required. The average log₁₀ virus titre in six samples positive in BHK-21, FLL and BTy cells were 2.9, 2.9 and 4.5 respectively, while 16 samples positive to FLL and BTy cells gave average log₁₀ virus titres of 2.4 and 4.1 respectively.

BHK-21 and FLL cells were further compared to determine at what passage level they initiated cytopathic effect (CPE) upon inoculation with field samples. In this study a total of 175 field samples
Table 4. Titrations of field FMD virus in BHK-21 or foetal lamb lung (FLL) cell lines and primary bovine thyroid (BTy) cell cultures.

<table>
<thead>
<tr>
<th>Type</th>
<th>Sample</th>
<th>Virus titre (TCID 50/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BHK-21</td>
</tr>
<tr>
<td>O</td>
<td>36/89</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>38/89</td>
<td>UD</td>
</tr>
<tr>
<td></td>
<td>49/89</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>56/89</td>
<td>UD</td>
</tr>
<tr>
<td></td>
<td>68/89</td>
<td>UD</td>
</tr>
<tr>
<td></td>
<td>71/89</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>72/89</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>85/89</td>
<td>UD</td>
</tr>
<tr>
<td></td>
<td>177/89</td>
<td>ND</td>
</tr>
<tr>
<td>A</td>
<td>161/87</td>
<td>UD</td>
</tr>
<tr>
<td></td>
<td>28/88</td>
<td>ND</td>
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<tr>
<td></td>
<td>37/88</td>
<td>UD</td>
</tr>
<tr>
<td></td>
<td>63/88</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>5/89</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>48/89</td>
<td>UD</td>
</tr>
<tr>
<td>Asia I</td>
<td>40/88</td>
<td>UD</td>
</tr>
<tr>
<td></td>
<td>52/88</td>
<td>UD</td>
</tr>
<tr>
<td></td>
<td>61/88</td>
<td>UD</td>
</tr>
<tr>
<td></td>
<td>431/88</td>
<td>UD</td>
</tr>
<tr>
<td></td>
<td>432/88</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>433/88</td>
<td>ND</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>No. of UD</strong></td>
<td>17</td>
</tr>
</tbody>
</table>

UD Undetected
ND Not tested

were submitted for FMD diagnosis and identified by CFT as types O, A and Asia I for 103, 38 and 24 samples, respectively. Nine samples were not type identified. All samples were simultaneously inoculated in BHK-21 and FLL cells as mentioned earlier. The passage level from which the CPE occurred was recorded and the infectious fluid was collected and the virus confirmed by CFT. The FLL cells detected virus in 170 (97.1%) out of 175 samples examined. Furthermore, 162 (92%) samples were detected in the first passage and the remaining 8 samples (4.5%) gave positive results in the second passage. The FLL cells did not detect one sample from a CFT-positive specimen, while it detected five out of nine CFT-negative samples. BHK-21 cells detected virus in 156 (89.1%) of the samples but more passages of the samples were needed compared to the FLL cells. The numbers of virus-detected samples in the first to fifth passages were 116 (66.8%), 36 (14.9%), 9 (5.1%), 4 (2.3%) and 1 (0.6%), respectively. Among the 19 samples non-detected by BHK cells, 14 samples were from CFT-positive and five from CFT-negative specimens. However, four samples detected by BHK 21 cells were from CFT-negative samples.

In conclusion, the modified CFT and isolation of FMD virus in BHK-21 cells have a similar sensitivity for detecting FMD virus in diagnostic samples. BHK-21 cells are not as sensitive as FLL or BTy cells, which have a similar sensitivity. While isolation of FMD virus in primary BTy cells is regarded as the most sensitive procedure for detecting infectious FMD virus, it would seem, in our hands, that FLL cells are a suitable substitute.

Comparison of ELISA, CF Test and Virus Isolation for FMD Diagnosis

Laboratory confirmation of FMD can be achieved by CFT, ELISA, or virus isolation with subsequent typing of the virus. It has been suggested that CFT is not the method of choice because of its insensitivity and problems with anti-complementary effects. However, the sensitivity of the CFT routinely used at Pak Chong has been increased by modification of the test. The ELISA is generally regarded as more sensitive than the CFT and not influenced by anti-complementary factors in samples and so is recommended for routine FMD diagnosis by international bodies. However, in spite of its sensitivity, in this study the ELISA still failed to detect virus in some virus positive samples and so in some instances virus isolation was still required. In this work the sensitivity of the modified CFT and the ELISA (based on locally produced reagents), and the isolation of virus in FLL cells were compared in order to develop a strategy for typing diagnostic specimens.

A total of 437 field samples submitted to the laboratory from September 1988 to July 1990 for FMD diagnosis was used in the study. A summary of the results is shown in Tables 5-7. The data in Table 5 indicates that the performance of the two tests against FLL cell isolation was very similar. Table 6 indicates that the modified CFT and ELISA perform similarly when compared to each other. There also does not appear to be any particular bias in the performance of the tests in relation to the virus isolation results in FLL cells (Table 7). Running both the CFT and ELISA in conjunction can increase the percent serotyping to 68.4% overall. Isolation of virus in FLL cells increased the percent serotyping from 64% for CFT and 63% for ELISA, to 73% overall. Whether a laboratory can justify the cost of maintaining a tissue culture facility for this improvement in the number of viruses serotyped from clinical specimens will depend very much on
the number of outbreaks occurring in the field and
the importance attached to laboratory confirmation
and serotyping of an outbreak. Experience in
Thailand has shown that the probability of obtaining
a positive result (on an outbreak basis) using an
immunological serotyping test is greatly enhanced
by increasing the number of samples submitted from
the outbreak.

Table 5. Examination of tissue samples for FMD virus
by CFT, ELISA and virus isolation in FLL cells.

<table>
<thead>
<tr>
<th>Virus isolation</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF TEST Positive</td>
<td>284</td>
<td>45</td>
</tr>
<tr>
<td>Negative</td>
<td>35</td>
<td>73</td>
</tr>
<tr>
<td>ELISA Positive</td>
<td>281</td>
<td>43</td>
</tr>
<tr>
<td>Negative</td>
<td>38</td>
<td>75</td>
</tr>
</tbody>
</table>

Table 6. Comparison of FMD virus detection by a
modified CFT or ELISA.

<table>
<thead>
<tr>
<th>CF test</th>
<th>Positive</th>
<th>Negative</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELISA Positive</td>
<td>303</td>
<td>21</td>
<td>324</td>
</tr>
<tr>
<td>Negative</td>
<td>26</td>
<td>87</td>
<td>113</td>
</tr>
<tr>
<td>Total</td>
<td>329</td>
<td>108</td>
<td>437</td>
</tr>
</tbody>
</table>

Table 7. Performance of a modified CFT and ELISA
compared to virus isolation.

<table>
<thead>
<tr>
<th>Test results</th>
<th>Virus isolation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF Test</td>
<td>ELISA</td>
</tr>
<tr>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>Positive</td>
<td>Negative</td>
</tr>
<tr>
<td>Negative</td>
<td>Positive</td>
</tr>
<tr>
<td>Negative</td>
<td>Negative</td>
</tr>
</tbody>
</table>

Establishment of a National Diagnostic
Laboratory

To establish a national diagnostic laboratory key
factors which have to be considered are:
• facilities — purpose-built laboratory, quality
  water supply, air conditioning, security;
• equipment — e.g. ELISA plate reading equipment
  with computer linkages, incubators, freezers;
• staff — trained staff with required expertise are
  needed and may require special training.
  Prospects for staff need to be good to attract
  suitably qualified personnel;
• budget — needs to be secured for facilities, equip­
  ment and staff costs.

National laboratories can obtain reagent supplies
and receive training at either a regional veterinary
laboratory or World Reference Laboratory. The
testing procedures of national laboratories should
be checked by a reference laboratory from time to
time.