Results of epidemic simulation modeling to evaluate strategies to control an outbreak of foot-and-mouth disease

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Objective—To assess estimated effectiveness of control and eradication procedures for foot-and-mouth disease (FMD) in a region of California.

Sample Population—2,238 herds and 5 sale yards in Fresno, Kings, and Tulare counties of California.

Procedure—A spatial stochastic model was used to simulate hypothetical epidemics of FMD for specified control scenarios that included a baseline eradication strategy mandated by USDA and supplemental control strategies of slaughter or vaccination of all animals within a specified distance of infected herds, slaughter of only high-risk animals identified by use of a model simulation, and expansion of infected and surveillance zones.

Results—Median number of herds affected varied from 1 to 385 (17% of all herds), depending on type of index herd and delay in diagnosis of FMD. Percentage of herds infected decreased from that of the baseline eradication strategy by expanding the designated infected area from 10 to 20 km (48%), vaccinating within a 50-km radius of an infected herd (41%), slaughtering the 10 highest-risk herds for each infected herd (39%), and slaughtering all animals within 5 km of an infected herd (24%).

Conclusions and Clinical Relevance—Results for the model provided a means of assessing the relative merits of potential strategies for control and eradication of FMD should it enter the US livestock population. For the study region, preemptive slaughter of highest-risk herds and vaccination of all animals within a specified distance of an infected herd consistently decreased size and duration of an epidemic, compared with the baseline eradication strategy. (*Am J Vet Res* 2003;64:205–210)

The epidemic of **foot-and-mouth disease (FMD)** in the United Kingdom in 2001 illustrated the need for well-developed control-and-eradication strategies that consider the potential effectiveness and feasibility of various methods available for control and eradication of the disease. A prerequisite for developing such plans would be an understanding of the manner in which various strategies would affect progression of an epidemic by considering unique features of the livestock population, methods of husbandry and management, and dynamics of movement of animals and personnel among herds. Because FMD has not occurred in the United States since 1929, specific data on **FMD virus (FMDV)** transmission and factors that may contribute to transmission for livestock management conditions found in the United States are not available for use in developing strategic plans. An alternate approach is to model the manner in which an epidemic of FMD may unfold in a livestock region that has been characterized with respect to husbandry practices, contact with infective animals or materials, and movement of people and animals; this model would also incorporate known information on FMDV transmission.

In another study[1] conducted by the authors, we developed a spatial stochastic simulation model designed to characterize size and duration of an FMD epidemic in a 3-county region of California that had been characterized with respect to herd type, animal density, herd location, and movement of people and animals to and from herds. The objective of the study reported here was to evaluate that model for use in assessing relative merits of various strategies to minimize simulated FMD epidemics for the specific 3-county region. A baseline eradication strategy mandated by the USDA (FMD emergency response guidelines) was used as a basis for comparing supplemental strategies of vaccination within a specified radius of an infected herd, preemptive slaughter of all herds within a specified distance of an infected herd, preemptive slaughter of high-risk herds, and expansion of designated infected and surveillance zones.

Materials and Methods

Simulation model—A spatial stochastic epidemic simulation model described elsewhere[1] was used to compare effects of a baseline eradication strategy and 3 supplemental strategies that included vaccination of herds within 5, 10, 25, or 50 km of each infected herd; slaughter of herds within 1, 3, or 5 km of each infected herd; and slaughter of 1, 5, or 10 herds with the highest expected exposure to FMDV (as determined by use of the model) for each infected herd.

Model outputs—Each epidemic scenario was iterated 1,000 times, and results were summarized as total number of infected herds, duration of epidemic, and number of additional noninfected herds that were slaughtered or vaccinated. Duration of the epidemic was the time from when the index

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herd entered a subclinically infectious modeling state (time 0) to when the last infected or preemptively slaughtered herd was removed by the model. Additional outputs included the number of noninfected herds that were affected by an eradication strategy, such as the total number of herds vaccinated or, for slaughter strategies, the total number of noninfected herds slaughtered.

Statistical analysis—The model was programmed by use of commercially available software[a] and included Monte-Carlo sampling capabilities developed from commercial software.[b] Distributions of the size and duration of epidemics for 1,000 iterations for the baseline control eradication strategy were visually compared by use of Box-Cox plots with distributions of simulated epidemics that considered the supplemental control strategies. Distributions of size and duration of epidemics were tested for normality by use of the Anderson-Darling method. Means, medians, and 95% **probability intervals (PIs)** were compared. The nonparametric Kruskal-Wallis 1-way ANOVA by ranks with a 1-sided test of significance adjusted for multiple comparisons was performed by use of commercially available statistical software.[c,d] Values for selected variables were varied in a sensitivity analysis to assess their independent influence on modeling results. For all analyses, the probability of a type-I error was set at $P < 0.05$, which was considered significant.

Results

Baseline control strategy—For the baseline eradication strategy, median duration of an epidemic was 71 days (95% PI, 25 to 109 days), and median size of an epidemic was 46 herds (95% PI, 1 to 148 herds, which represented 46/2,238 [2%] herds in the 3-county study region; **Table 1**). Distribution of values for size of an epidemic for the baseline control strategy was skewed to the right and not normally distributed ($P < 0.001$). Of the 2,238 herds and 5 sale yards in the region, dairies represented 547 of 2,238 (24%) herds, but they represented a disproportionately higher percentage of the infected herds (73% of infected herds; **Fig 1**). Backyard herds (ie, herds with < 10 animals; 788/2,238 [35%] herds;) represented a disproportionately lower percentage of the infected herds (10% of infected herds), and beef herds, swine herds, and sale yards each represented 5% of all infected herds.

Vaccination strategy—Median number of herds infected when considering the baseline eradication strategy (46 herds) and a vaccination strategy that involved all herds within a radius of 5, 10, 25, or 50 km of an infected herd was 36 (1.6%; 95% PI, 1 to 128 herds), 34 (1.5%; 95% PI, 1 to 127 herds), 29 (1.3%; 95% PI, 1 to 128 herds), and 27 (1.2%; 95% PI, 1 to 130 herds), respectively (Table 1). Number of herds infected for any model simulations that considered use of a vaccination strategy was significantly ($P = 0.001$) fewer than the number of herds infected (46 herds) when only the baseline eradication strategy was considered. Simulations for vaccination within a radius of 25 or 50 km also yielded epidemics that were significantly ($P = 0.048$) smaller in size than those for vaccination within a radius of 5 or 10 km. Median duration of epidemics when considering vaccination was significantly ($P = 0.001$) shorter than the duration of epidemics eradicated when only the baseline control strategy was applied, and median duration of epidemics associated with each vaccination strategy was significantly less for each sequential increase in size of the radius ($P = 0.001$). Median percentage of all herds vaccinated during implementation of the vaccination strategies varied

Table 1—Median, mean, and 95% probability interval (PI) of number of herds infected, duration of epidemics, and number of herds vaccinated or slaughtered because of implementation of supplemental eradication strategies that involved vaccination and preemptive herd slaughter for control of an outbreak of foot-and-mouth disease (FMD)

	Size of epidemic (No. of infected herds)			**Additional herds***			**Duration of epidemic (d)**		
Strategy	**Median**^{a}	**Mean**	**95% PI**	**Median**	**Mean**	**95% PI**	**Median**^{a}	**Mean**	**95% PI**
Baseline eradication									
	46^{a}	55	1–148	NA	NA	NA	71^{a}	69	25–109
Vaccination of all herds within specified radius (km)									
5	36^{b}	46	1–128	612	578	0–1,152	56^{b}	57	26–88
10	34^{b}	45	1–127	1,182	1,043	0–1,663	51^{c}	52	26– 75
25	29^{c}	42	1–128	1,801	1,512	0–2,101	48^{d}	47	26– 60
50	27^{c}	42	1–130	2,164	1,845	0–2,209	47^{e}	45	25– 54
Slaughter of all herds within specified radius (km)									
1	$43^{a,d}$	53	1–145	58	69	1–184	68^{a}	67	26–107
3	40^{d}	48	1–126	334	335	8–721	60^{f}	61	26–95
5	35^{e}	42	1–106	608	582	23–1,077	56^{g}	57	27–85
Slaughter of highest-risk herds†									
1	37^{f}	45	1–118	29	32	1–79	59^{h}	59	26–89
5	31^{g}	40	1–111	106	120	5–288	52^{i}	52	27–81
10	28^{g}	37	1–97	178	191	10–419	49^{j}	50	27–72

All simulations assumed that there were 2,238 herds and 5 sale yards in the 3-county region with a 21-day delay in diagnosis of FMD for the index herd followed by implementation of a baseline eradication control strategy that consisted of slaughtering herds in which FMD was diagnosed, closure of sale yards, and implementation of an infected area of 10 km and a surveillance zone of 20 km around each infected herd.

*Additional noninfected herds vaccinated or slaughtered, depending on supplemental eradication strategy. †Slaughter of 1, 5, or 10 herds with the highest risk for exposure to FMD virus (FMDV) for each FMD-infected herd. [a–j]Within a column, values with different superscript letters differ significantly ($P < 0.05$) as determined by comparison with the baseline eradication strategy and within each strategy by use of the Kruskal-Wallis 1-way ANOVA by ranks with a 1-sided test of significance. NA = Not applicable.

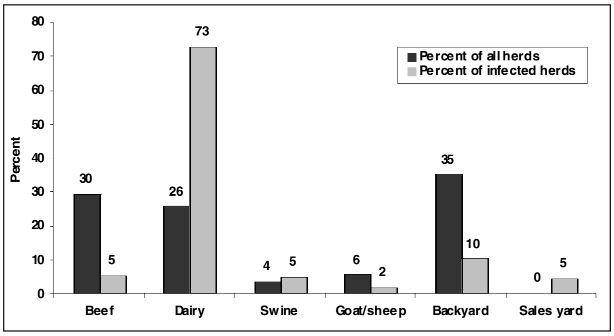

Figure 1—Distribution of the percentage of all herds in a 3-county region in California (dark bar) and percentage of all herds subsequently infected with foot-and-mouth disease (FMD) in the 3-county region (light bar) for 1,000 simulations that included a 21-day delay for diagnosis of FMD in the index herd and subsequent implementation of the baseline eradication control strategy. The model assumption was that baseline control strategy was established 1 day after FMD was diagnosed in the index herd.

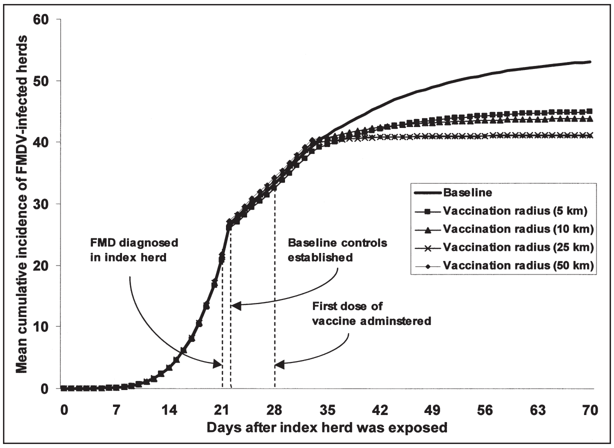

Figure 2—Mean cumulative incidence of herds infected with FMD virus (FMDV) assuming a baseline eradication strategy and a supplemental strategy that involved vaccination of all herds within 5, 10, 25, or 50 km of an infected herd. Baseline eradication strategy included a 21-day delay in diagnosis of FMD in the index herd, slaughter of known infected herds, closure of sale yards, and implementation of an infected area of 10 km and a surveillance zone of 20 km around each herd in which FMD had been diagnosed. Vaccination was initiated 7 days after FMD was diagnosed in the index herd.

from 612 of 2,238 (27%) herds for a 5-km radius to 2,164 of 2,238 (97%) herds for a 50-km radius. Mean cumulative number of herds infected by day for each vaccination strategy was determined **(Fig 2)**.

Preemptive herd slaughter strategies—Slaughter of herds within 1, 3, or 5 km of infected herds resulted in fewer herds becoming infected (median size of epidemics ranged from 35 to 43 herds), compared with the baseline eradication strategy (median, 46 herds; Table 1). Median number of herds infected for a slaughter strategy of susceptible herds within 1 km of an infected herd, however, was not significantly (P = 0.158) different from that for the baseline eradication strategy, although median number of herds infected for

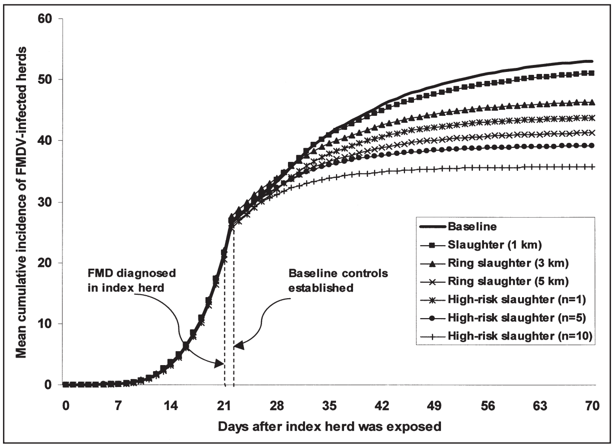

Figure 3—Mean cumulative incidence of herds infected with FMDV assuming a baseline eradication strategy and supplemental herd slaughter strategies. Slaughter strategies involved slaughter of all herds within 1, 3, or 5 km of an infected herd or slaughter of 1, 5, or 10 herds with the highest risk of exposure to FMDV, as determined by use of the model, for each infected herd. The baseline eradication strategy included a 21-day delay in diagnosis of FMD in the index herd, slaughter of known infected herds, closure of sale yards, and implementation of an infected area of 10 km and a surveillance zone of 20 km around each herd in which FMD was diagnosed. Herds were slaughtered 1 to 5 days after FMD was diagnosed in that herd or 1 to 5 days after the herd was designated for slaughter in accordance with the implemented slaughter strategy, depending on size and type of herd.

Table 2—Median, mean, and 95% PI for number of herds infected and duration of an epidemic on the basis of variation of the interval between initial exposure and diagnosis of FMD in the index herd and variation in the radius of the infected area around each herd with FMD

Interval until diagnosis (d)	Radius of infected area (km)	Size of epidemic (No. of herds)			Duration of epidemic (d)		
		Median[a]	Mean	95% PI	Median[a]	Mean	95% PI
Baseline eradication (initial assumptions)							
21	10	46^{a}	55	1–148	71^{a}	69	25–109
Delay in diagnosis of index herd (d)							
1	10	1^{b}	2	1–6	10^{b}	14	8–40
7	10	1^{c}	5	1–35	12^{c}	21	11–79
14	10	12^{d}	21	1–68	50^{d}	50	18–100
28	10	111^{e}	156	6–451	75^{e}	76	48–111
Radius of infected area (km)							
21	5	115^{b}	112	1–196	91^{f}	87	26–133
21	20	24^{c}	42	1–145	56^{g}	56	25–91
21	30	$20^{c,d}$	38	1–123	$54^{g,h}$	53	26–85
21	40	$20^{c,d}$	39	1–140	53^{h}	52	25–85
21	50	19^{d}	40	1–131	52^{h}	52	25–85

[a-h] Within a column, values with different superscript letters differ significantly ($P < 0.05$).

the slaughter strategies within 3 and 5 km was significantly ($P = 0.010$) lower than that of the baseline eradication strategy. Median number of noninfected herds slaughtered by use of a slaughter strategy with a radius of 1, 3, and 5 km was 58, 334, and 608, respectively. For slaughter strategies involving a radius of 3 and 5 km, median duration of epidemics was 60 and 56 days, respectively, which was significantly ($P = 0.001$) less than that of the baseline eradication strategy (71 days), and duration of epidemics was significantly ($P = 0.001$) shorter as size of the slaughter radius increased.

Simulations considering strategies to slaughter 1, 5, or 10 herds with the highest risk of exposure to FMDV, as calculated by the model, for each herd in which FMD was diagnosed resulted in median sizes of epidemics ranging from 28 to 37 herds, which was significantly ($P = 0.001$) less than that of the baseline eradication strategy (46 herds; Table 1). Median duration of epidemics ranged from 49 to 59 days, which was significantly ($P = 0.001$) less than the median duration of epidemics for the baseline eradication strategy (71 days), and duration of epidemics for all strategies was significantly ($P = 0.001$) less than those that considered strategies in which additional highest-risk herds were slaughtered. Mean cumulative number of herds infected for each herd slaughter strategy was determined **(Fig 3)**.

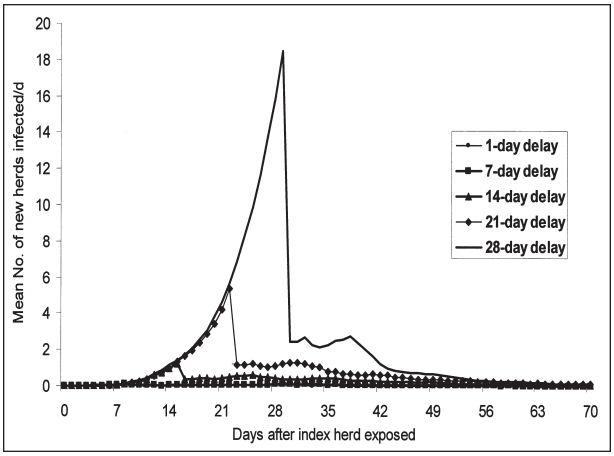

Figure 4—Incidence of herds infected with FMDV in a 3-county region in California with 2,238 herds and 5 sale yards for simulations with a 1-, 7-, 14-, 21-, or 28-day delay in diagnosis of FMD in a randomly identified index herd. One day following diagnosis of FMD, a baseline eradication strategy was implemented that consisted of slaughter of herds in which FMD was diagnosed, closure of sale yards, and establishment of an infected area of 10 km and a surveillance zone of 20 km around each herd in which FMD was diagnosed.

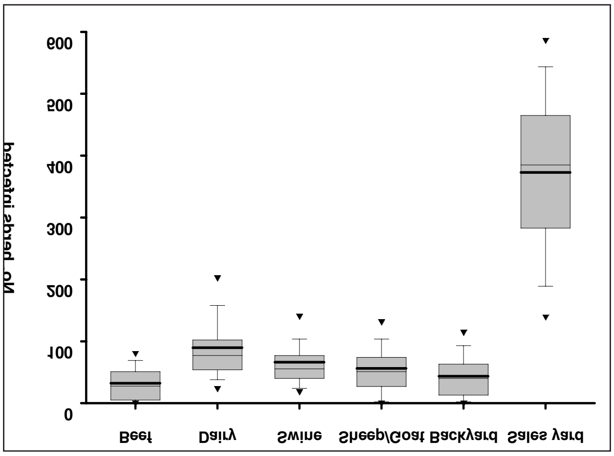

Figure 5—Distribution of size of epidemics of FMD when considering scenarios that depended on the type of herd that was the index herd (beef, backyard [herds with < 10 animals], sheep or goat, dairy, swine, or sale yard). Simulations were performed for 250 epidemics with a 21-day delay in diagnosis of FMD in the index herd. Black triangles indicate the 95th and 5th percentiles. Whiskers represent the 90th and 10th percentiles. Shaded area represents the 75th to 25th percentiles. Thick horizontal line = Mean value. Thin horizontal line = Median value.

Sensitivity analysis—Size and duration of epidemics were significantly sensitive to delay in diagnosis of FMD in the index herd, radius of the infected area, radius of the surveillance zone, and herd type for the index herd **(Table 2)**. Median number of herds infected was 1, 1, 12, 46, and 111 when considering a delay of 1, 7, 14, 21, or 28 days for diagnosis of FMD in the index herd, respectively **(Fig 4)**. Pair-wise comparisons of size and duration of epidemics for each delay period all differed significantly ($P = 0.001$) from each other. Increasing the size of the radius of the infected area from 5 to 10 km and from 10 to 20 km resulted in a significant ($P = 0.001$) decrease in median size of epidemics of 60% ([115 – 46]/115 herds) and 48% ([46 – 24]/46 herds), respectively. Subsequent incremental increases of the infected area from 20 to 50 km, however, reduced median size of epidemics by only 5 additional herds (11%) and did not differ significantly from each another. Median duration of epidemics of 56 to 52 days for an infected area of 20 to 50 km was significantly ($P = 0.001$) less than the median duration of epidemics for the baseline eradication strategy (71 days), and strategies that used an infected area of 40 or 50 km had a median duration of epidemics that was significantly less than the median duration of epidemics for strategies that had an infected area of 5 or 20 km. Median size of epidemics was highest (385 herds) when a sale yard was the index herd and lowest (28 herds) when a beef herd was the index herd **(Fig 5)**.

Discussion

The model in the study reported here allowed analysis of various eradication strategies for FMD that could be used to slow or prevent FMDV transmission in a 3-county region of California. The model first simulated FMD epidemics without consideration of supplemental eradication strategies and then with implementation of a new eradication strategy, which allowed measurement of the effectiveness of that supplemental strategy in terms of reducing the number of infected herds and the duration of the epidemic. The greatest incremental strategic benefit was found by increasing the radius of the designated infected area from 10 to 20 km and the designated surveillance zone from 20 to 40 km, which resulted in a 48% ([46 – 24]/46 herds) decrease in the median size of epidemics (Table 2). Subsequent increases in the radius of the infected area from 30 to 50 km decreased the median size of epidemics by only 1 herd.

Vaccinating all herds within 50 km of an infected herd was the most effective supplemental strategy among those considered for reducing size and duration of epidemics within the 3-county region. Median number of herds infected decreased by 41% ([46 – 27]/46 herds), and median duration decreased by 34% ([71 – 47]/71 days). However, 2,161 of 2,238 (97%) of the herds in the study region would need to be vaccinated within a few days after the vaccine became available. Although unprecedented in the United States, implementation of such a scenario may be possible if adequate human, financial, and vaccine resources were available and if there were a modification of current USDA guidelines, which recommend use of vaccine only when an FMD epidemic persists for 6 months, 1 million susceptible animals have been slaughtered, wildlife in multiple states have endemic infection, or the cost-benefit ratio favors vaccination.[2]

Until recently, it was not possible to serologically distinguish a herd naturally infected with FMDV from a herd vaccinated against FMD, because vaccine-induced antibodies could not be distinguished from infection-induced antibodies. Consequently, herds vaccinated under emergency vaccination orders may be slaughtered after FMDV transmission is believed to be under control, because it would not be possible to differentiate between vaccinated animals and potential carrier animals. Therefore, a critical decision regarding use of FMD vaccine in the United States will be whether vaccinated herds will eventually be slaughtered.

In considering preemptive slaughter of herds as a supplemental eradication strategy, slaughter of the 5 or 10 highest-risk herds was found to be more effective than slaughter of all herds within a radius of 1 to 5 km. Depending on the ratio of highest-risk noninfected herds that were slaughtered for each infected herd, approximately 19% ([46 – 37]/46 herds for a 1:1 ratio) to 39% ([46 – 28]/46 herds for a 10:1 ratio) fewer herds would become infected by slaughtering only highest-risk herds. These reductions were similar to those for vaccination (Table 1); however, 29 to 178 noninfected herds would hypothetically be slaughtered during the 1:1 and 10:1 highest-risk herd slaughter strategies, respectively. Choice of the strategy to slaughter highest-risk herds would depend on the confidence in the model correctly selecting herds with the highest likelihood of having adequate contact to potentially contract the disease. In accordance with USDA guidelines,[2] herds with direct or indirect contacts[3] with an FMDV-infected herd would be considered close contacts (or dangerous contacts) and would be closely monitored and potentially slaughtered as a precautionary measure. The highest-risk herds, as determined by the model, were those herds located near an infected herd or those that had frequent direct or indirect contacts; thus, the model probably selected herds similar to those that would be deemed close-contact herds during an actual trace-back investigation during an outbreak.

Slaughter of all herds located within 3 or 5 km of an infected herd was projected to significantly decrease the size and duration of epidemics, compared with results for the baseline eradication strategy. These slaughter strategies, however, would require the slaughter of 334 (15%) or 608 (27%) noninfected herds and would result in only a 13% ([46 – 40]/46 herds) or 24% ([46 – 35]/46 herds) decrease in the expected size of an epidemic, respectively (Table 1). A contiguous cull eradication strategy, which is similar to the slaughter strategy considered here, was used in the United Kingdom in 2001. This contiguous cull strategy required that all susceptible animals in herds adjacent to an FMD-infected herd be slaughtered. Initial data for the epidemic in the United Kingdom on distributions of infected herds suggested that most of the risk of infection was among herds located within approximately 3 km of an infected herd.[4] One could project from those results that immediate slaughter of herds within 3 km of an infected herd would substantially decrease transmission and would be an appropriate strategy to pursue. However, spatial considerations for the model reported here, which were derived from analysis of direct and indirect contacts among livestock facilities in the 3-county study region,[3] indicated that direct and indirect contacts in this 3-county region of California would occur most frequently within an area up to 40 km from an infected herd. Therefore, although the model used in the study reported here found that herds located within 3 km of an infected herd would have a high likelihood of adequate contacts, herds much farther away also were likely to have adequate contacts. Consequently, strategies that slaughtered all herds within 1 to 5 km of an infected herd were found to be less successful than strategies that slaughtered only the highest-risk herds or that vaccinated susceptible herds.

Among all eradication strategies considered in the study reported here, implementation of an infected area of 50-km radius was most effective in decreasing the median size of epidemics, which decreased from 46 to 19 herds (59% reduction) for the baseline eradication strategy that had an infected area of 10 km. Even though there was overlap of the 95% PIs, the distributions differed significantly, because the distributions were not normally distributed. However, median size of epidemics decreased by only 5 herds when the radius of the infected area was increased from 20 to 50 km. A possible reason for such a slight decrease is that most of the herds in the study region were incorporated into the designated infected area or surveillance zone. If FMD were diagnosed in 2 herds located 40 km apart, the subsequently established infected areas around each infected herd would encompass most of the herds in the region, because most herds were located within a 100 × 100-km area. Another possible reason for the improved effectiveness from expansion of the infected area was that the model was sensitive to inputs obtained from experts, which were included in the model to account for the reduction in the number of direct and indirect contacts within the infected area and surveillance zone. For example, increasing the size of the infected area from 5 to 10 km resulted in a 60% (from 115 to 46 herds) decrease in median size of epidemics, indicating that expanding the area of mandatory control over livestock and personnel movement would be expected to substantially reduce the size of an epidemic.

Other models of FMD have considered potential introduction of FMD and produced similar expected size of epidemics (32 herds in Australia[5] and 52 herds in the Netherlands[6]). Median number of herds infected in the study reported here (46 herds) represented 2% (46/2,238) of all herds in the region, which is a similar order of magnitude of herds infected in the United Kingdom in 2001 (1.4% [2,030/144,000),[7,8] but it was considerably less than the estimated 12% (2,057/16,507) of herds affected in a specific region of the United Kingdom during the epidemic of 1967–1968.[9] If an epidemic of FMD occurred in the region described in the study reported here, it is highly probable that FMDV would spread to other regions and states, which was a scenario not considered here. Inferences about the effectiveness of FMD eradication strategies in other regions in the United States on the basis of results reported here may not be appropriate because of the unique herd density, extensive animal movement among herds, and environmental and geographic characteristics of the 3-county region. If 2% of the herds were infected in a statewide epidemic of FMD, approximately 440 of California's 22,000 herds[10] would be expected to become infected with FMDV. The model was constrained by not accounting for the potential effects of weather, transmission among wildlife, transmission beyond the boundaries of the 3-county region, and transmission of FMDV that may have originated from outside the study region. All simulations also were initiated by infecting only 1 index herd. Considerably larger epidemics would be expected if multiple index herds were simultaneously infected with FMD.

Results of sensitivity analysis indicated that the model was highly sensitive to delay in diagnosis of FMD in the index herd. Median size of an epidemic increased from 1 herd when the diagnosis was made within 7 days to 111 herds when the diagnosis were not made until 28 days after introduction of FMDV. The potential for widespread transmission of FMDV in such a short time period emphasizes the necessity for surveillance and rapid diagnosis of FMD and subsequent implementation of an emergency response. As a first line of defense, the US government relies primarily on passive observation for clinical signs that are consistent with signs of vesicular disease and subsequent reporting of a suspected case of FMD by animal health personnel. With FMD, however, clinical manifestations may be extremely mild, particularly among small ruminants, and may be misdiagnosed as a common indigenous disease, such as sore mouth or bovine viral diarrhea. Without an active surveillance system for FMDV, results of the model suggest it may be possible for FMDV to circulate among many herds before it is diagnosed, potentially leading to wide-spread dissemination of the disease.

Additional justification for an active FMD diagnostic surveillance system is indicated when considering epidemic scenarios for which a sale yard is the index herd. For epidemic simulations with a 21-day delay in diagnosis of FMD and a sale yard as the index herd, median size of epidemics was 385 herds (837% [385/46] herds), which is larger than the median size of epidemics for simulations with a randomly selected index herd (46 herds). Therefore, sale yards may be important amplifiers of an epidemic of FMD and would justify specific focus for diagnostic surveillance as well as being targeted for improvements in education and training in disease awareness and identification.

The study reported here illustrated the manner in which a simulation model can be used to compare various potential control-and-eradication strategies for an outbreak of FMD for populations and regions that have not had FMD and for which specific FMDV transmission data are not available. Results of simulations can provide information about relative magnitudes of epidemics and number of herds vaccinated or slaughtered for various control scenarios, which may be useful in developing cost-effective eradication programs.

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[a] Visual Basic, version 6.0, Microsoft Corp, Redmond, Wash.
[b] Risk development kit, version 3.5, Palisades Corp, Newfield, NY.
[c] SAS/STAT, version 8.1, SAS Institute Inc, Cary, NC.
[d] BMDP, version 7.0, BMDP Statistical Software Inc, Cork, Ireland.

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