ESTIMATION OF AIRBORNE SPREAD OF FOOT-AND-MOUTH DISEASE VIRUS

Abschätzung der aerogenen Verbreitung von Maul- und Klauenseuche Viren

Az RSZKF vírus levegővel való terjedésének becslése

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ABSTRACT
Recent foot-and-mouth disease (FMD) outbreaks, for example in Great Britain 2001, have demonstrated its enormous economic consequences. The objective of this study is to implement an epidemic model for the prediction of airborne spread of FMD virus to support decision-making on control measures. The application of this epidemic model during the first days after the declaration of an outbreak of FMD should significantly contribute to minimise the costs. To demonstrate the features of an airborne FMD virus transmission a pilot study in Styria, Austria, has been performed. Therefore, a so-called Gaussian dispersion model has been implemented to calculate the 3-dimensional virus plume. A source consisting of one infected premise with 10 swine excreting FMD virus was assumed. The major result of this simulation experiment is the estimation of distances at which animals at neighbouring premises are under risk to be infected. Particular attention has been turned on cattle, which have a very low threshold concentration for infection with FMD virus. Using actual hourly weather data for 25 April 2003, cattle have been estimated to be at risk downwind between 1 and 12 km.
Key words: Veterinary epidemiology, FMD, Gaussian dispersion model, airborne, risk assessment

ZUSAMMENFASSUNG
Aktuelle Ausbrüche der Maul- und Klauenseuche (MKS), zum Beispiel in Großbritannien 2001, haben demonstriert, dass sie enorme ökonomische Verluste verursachen. Ziel dieser Studie ist, ein Epidemiemodell zur Vorhersage der aerogenen Ausbreitung von MKS Viren zu implementieren. Es soll als Entscheidungshilfe die Auswahl von Kontrollstrategien erleichtern. Die Anwendung des Epidemiemodells während der ersten Tage nach der Bestätigung eines MKS Ausbruches sollte wesentlich zur Kostenreduzierung beitragen. Zur Demonstration der Eigenschaften einer aerogenen Verbreitung von MKS Viren wurde in der Steiermark, Österreich, eine Pilotstudie durchgeführt. Dazu wurde ein so genanntes Gauß's ches Ausbreitungsmodell implementiert um die 3-dimensionale Virusfahne zu berechnen. Es wurde eine Quelle bestehend aus einem infizierten Betrieb mit 10 Schweinen, die MKS Viren ausscheiden, angenommen. Das wesentliche Ergebnis dieses Simulationsexperiments ist die Bestimmung der Entfernungen, für welche Tiere benachbarter Betriebe unter Risiko stehen infiziert zu werden. Besonderes Augenmerk wurde auf Rinder gelegt, die bereits bei einer sehr geringen Grenzwertkonzentration mit MKS Viren infiziert werden. Für den 25. April 2003 wurde, unter Verwendung aktueller stündlicher Wetterdaten, ermittelt, dass Rinder in Windrichtung noch in 1 bis 12 km Entfernungen unter Risiko stehen.

ÖSSZEFOGLALÁS
A legutóbbi száj- és körömfájás betegség (SZKF) kitörések (pl. Nagy Britanniában, 2001-ben) rámutattak annak gazdasági jelentőségére. Jelen tanulmány egy epidemiológiai modell alkalmazását

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hivatott bemutatni a SZKF vírus levegővel való terjedésének előjelzésében, amely döntéstámogató eszközként szerepelhet a védekezési és felszámolási folyamatokban. A modell alkalmazása a betegség kitörésének első napjaiban jelentősen csökkentheti a károkból származó költségeket. Ennek bemutatására egy előtanulmányt végeztünk Stájerországban, Ausztriában. A vírus levegővel való szétszóródása háromdimenziós felületének kiszámítására az ún. Gauss modellt használtuk. Vírusforrásként egy olyan telepet választottunk, amelyen 10 sertés ürít vírust. Ennek a szimulációs kísérletnek a fontosabb eredménye annak a távolságnak a becslése, amelyen belül a szomszédos állományok a fertőzés veszélyének lennének kitéve. Különös figyelmet fordítottunk a szarvasmarhák fertőződésének igen alacsony vírus koncentráció szintjére. 2003. április 25-i óránkénti meteorológiai adatokat használva a veszélyeztetett szarvasmarha állományok fertőző forrástól számítva 1 és 12 km távolság közé estek.

INTRODUCTION

The motivation for this study is to assess the risk of infection with airborne foot-and-mouth disease (FMD) virus for animals downwind. To assess this risk an atmospheric dispersion model has been implemented and applied within the framework of a pilot study in Styria, Austria. Goal is to develop a decision support tool for veterinary epidemiology that combines geo-referenced agricultural databases and epidemic models (Rubel et al., 2003) by a geographical information system (GIS). Recent applications of decision support systems in veterinary epidemiology have been described by Morris et al. (2002).

The conditions which influence airborne spread of FMD are well known. It requires that FMD virus remain in the atmosphere long enough and in sufficiently high concentrations to infect other susceptible livestock downwind. The main governing factors are: Route of infection, emission rate of virus, virus survival and characteristics of the virus plume. For a discussion on this topic see for example Gloster et al. (1981).

Thus, airborne infection takes place in livestock by inhalation or ingestion of FMD virus, however cattle are more easily infected by inhalation than ingestion. Moreover, the virus concentration needed to infect cattle is significantly lower than for sheep and swine, since with a respiratory rate of about 170 m^3/d cattle sample more air than sheep or swine (10-50 m^3/d).

Airborne virus is emitted from infected animals over a 4-7 day period. The emission rate depends on the species of animal, the number of infected animals, the stage of the disease (day of clinical signs) and the strain of the virus. At the time of peak excretion a swine emits $10^{8.6}$ infectious units of virus per day, here referred as to 8.6 logTCID50/d[1]. Cattle and sheep emit 3 orders of magnitude less FMD virus. Their maximum emission rate is 5.1 logTCID50/d (S renson et al., 2000). These emission rates are valid for virus strain $C_{Noville}$. Lower yields of FMD virus were obtained from animals infected with O_1, O_2, A_5, A_{22} and $C_{Lebanon}$ virus strains (Donaldson et al., 1970; Garner and Cannon, 1995).

The survival of airborne FMD virus is mainly related to the relative humidity of the atmosphere. Above a relative humidity of 55 % the virus is stable but below 55 % it is rapidly inactivated. Therefore, in this study the airborne spread has been only estimated for atmospheric conditions with relative humidity above 55 %.

The last parameter determining the risk of infection for animals downwind is the characteristics of the virus plume. This virus plume depends mainly on atmospheric parameters such as wind direction and speed, atmospheric stability and orography. The latter has not been applied for this study. Further, in this study we focus only on local virus transmission (0-15 km range); long distance airborne FMD virus transmission has been studied by e.g. Gloster et al. (1982).

[1] TCID50/d = 50 % Tissue Culture Infectious Doses per Day

Materials and methods

Within the framework of a pilot study a premise with about 900 swine has been selected to simulate the airborne spread of FMD virus. For this simulation experiment it was assumed that 10 swine are excreting FMD virus and the weather data needed for the calculation of the virus plume are available in real time.

The airborne spread of FMD virus has been calculated by applying the following Gaussian dispersion model:

$$C(x,y,z) = \frac{Q}{2\pi u\,\sigma_y(x)\sigma_z(x)}\,exp\left(-\frac{y^2}{2\sigma_y^2(x)} - \frac{(z-h)^2}{2\sigma_z^2(x)}\right) \tag{1}$$

$C(x,y,z)$......... average concentration at distance x, y and z in $TCID_{50}/m^3$
Q.................... source or emission rate of FMD viruses in $TCID_{50}/s$
h...................... height of the source m
u...................... average wind speed in m/s
$\sigma_y(x)$, $\sigma_z(x)$.... horizontal and vertical dispersion parameter

$$\sigma_y(x) = B\left(\tfrac{x}{u}\right)^{\beta} \qquad \sigma_z(x) = A\left(\tfrac{x}{u}\right)^{\alpha} \tag{2}$$

Eq. 1 determines the 3-dimensional distribution of the FMD virus concentration C around a source Q (virus emitting animals at a pre-defined geographical location). The source Q depends on the species, the number of animals and the day of the clinical signs and has to be specified in units of TCID50/s. Note that usually emission rates of virus are tabled in units of logTCID50/d and have to be converted.

Further, the spatial distribution of the virus emitted depends on the atmospheric parameters wind direction, wind speed and stability. While the wind speed determines the virus transmission in wind direction, the atmospheric stability determines the horizontal and vertical dispersion parameter that are particularly relevant for the virus spread normal to the wind direction. The dispersion parameters (Eq. 2) are functions of the distance from the source in wind direction x and are calculated from the average wind speed u as well as from regression coefficients , B, , and A. These regression coefficients are defined for different atmospheric stability classes, estimated after the Austrian norm ÖNORM (1992), as depicted in Tab. 1.

Tab 1 Coefficients , B, , and A as function of the atmospheric stability (ÖNORM, 1992) for the calculation of horizontal and vertical dispersion parameters.

stability class	atmosphere	β	B	α	A
2	unstable	0.900	1.270	1.456	0.086
3	lightly unstable	0.868	1.105	0.889	0.834
4	neutral	0.835	1.067	0.762	0.900
5	lightly stable	0.796	0.943	0.699	0.640
6	moderate stable	0.799	0.504	0.566	0.737
7	highly stable	0.728	0.458	0.500	0.316

Results

The first results presented here are from a sensitivity study. In this study it was investigated up to which distance cattle might be infected by airborne spread of FMD virus. Fig. 1 depicts the virus concentration in TCID50/m^3 as function of distance downwind from the source in metres. Applying a threshold concentration of 0.06 TCID50/m^3 for an infection of cattle (S rensen et al., 2000), distances for which cattle are under risk may be determined from the diagrams.

Fig. 1a depicts the sensitivity of the dispersion model for different stability classes (Input parameters: 1 infected animal with Q=$10^{8.6}$ $TCID_{50}$/d and a wind speed of u=5 m/s). While FMD virus is transported over long distances when the atmosphere is stable, in an unstable atmosphere (turbulent, well mixed atmosphere) the virus transmission occurs only at short distances. It is clear that a higher number of animals lead to higher virus concentration (Fig 1b). The impact of several emission rates on the dispersion process is depicted in Fig 1c. Finally, Fig. 1d shows the influence of the wind speed.

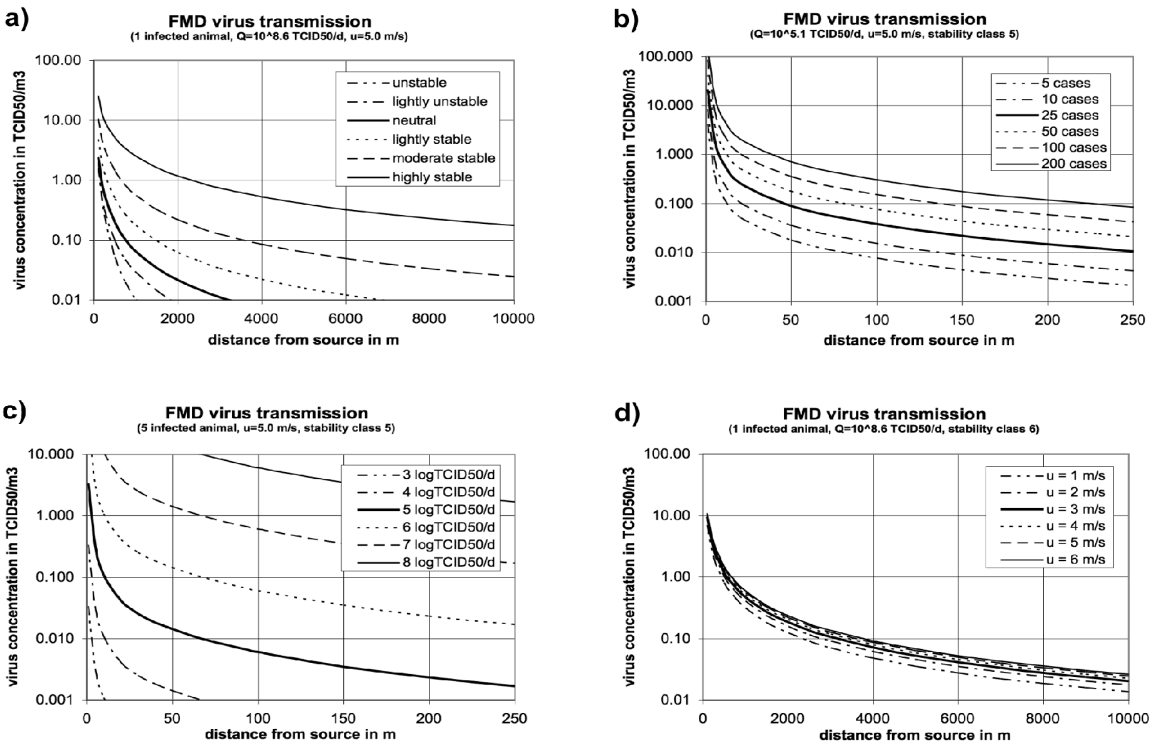

Fig. 1 Concentration of FMD virus in $TCID_{50}$/m^3 as function of distance from the source. Model sensitivity for different atmospheric stability classes (a), number of virus emitting animals (b), emission rates (c) and wind speeds (d). Distance from the source is given in meters. Note that the minimum concentration for infection of cattle is about 0.06 TCID50/m^3.

The results of the case study for an infected premise in Styria (Austria) are shown in Tab. 2. It was assumed that 10 out of 900 swine are infected and that each swine excrete virus with an emission rate of 8.6 logTCID50/d. Note that this is a worst case scenario due to the 1000 times higher emission rate of swine compared to cattle. On the other hand, cattle are the most susceptible species for FMD virus infection. To simulate real time conditions, atmospheric data from the German Weather Service, available for the entire region of Central Europe, have been applied. These data comprise air temperature T and relative humidity rh (determines whether the virus is active or inactive), wind direction, wind speed, and cloud fraction. The latter is needed to estimate the stability class according to ÖNORN (1992). A threshold concentration for infection of 0.06 for cattle, 1.11 for sheep and 7.70 for swine corresponding to S rensen et al. (2000) has been applied. As depicted in Tab. 2 cattle are under risk to be infected up to 5 km downwind at 01:00 UTC, while the corresponding distance for sheep and swine is less than 1 km. With the beginning daytime all atmospheric parameters – relative humidity, wind speed and stability – decrease and therefore also the distances at which animals are at risk decrease. After 08:00 UTC the FMD virus gets inactive due to the low values of the relative humidity. In the evening both the relative humidity and the atmospheric stability increase again and particularly cattle will be infected over long distances. The maximum distance of 12 km has been calculated for 21:00 UTC. Note that the given distances are extreme values; in practice emission rates might be significantly lower than 8.6 logTCID50/d. For example Donaldson et al. (2001) measured the maximum amounts of airborne virus excreted by swine and sheep infected with the virus from the current FMD epidemic in the UK, 2001. The amount of airborne virus excreted by swine was 6.1 logTCID50/d and for sheep 4.3 logTCID50/d.

Tab. 2 Hourly calculated distances (right columns) at which cattle, sheep and swine are at risk to be infected due to airborne spread of FMD virus. Input parameters are: One infected premise in Styria (Austria) with 10 infected swine, a virus emission rate per swine of 8.6 logTCID50/d as well as actual hourly meteorological parameters such as relative humidity and wind speed. Date: 25 April 2003.

time UTC	Q log TCID50/d	cases	rh %	u m/s	stability class	cattle m	sheep m	swine m
01:00	8.6	10	86.1	3.08	5	5 000	700	200
02:00	8.6	10	85.9	2.67	5	5 000	700	190
03:00	8.6	10	87.2	2.37	5	4 500	650	180
04:00	8.6	10	87.0	2.31	5	4 500	650	180
05:00	8.6	10	91.5	1.97	5	4 500	600	170
06:00	8.6	10	85.2	1.83	5	4 500	600	170
07:00	8.6	10	73.4	1.62	3	1 000	190	70
08:00	8.6	10	59.7	1.85	3	1 000	200	70
09:00 ... 18:00	FMD virus inactive due to relative humidity < 55 %							
19:00	8.6	10	59.3	1.83	4	2 000	300	100
20:00	8.6	10	68.6	1.86	5	4 500	600	170
21:00	8.6	10	72.4	1.22	6	12 000	1 300	330
22:00	8.6	10	75.8	0.62	6	9 000	1 100	270
23:00	8.6	10	74.7	0.57	6	9 000	1 100	260
00:00	8.6	10	76.4	0.20	6	7 000	830	200

DISCUSSION

The introduced Gaussian dispersion model will be applied for the first time during the Austrian real time exercise on FMD, collocated by the European Union, in autumn 2004. A limitation of the present model version is that effects on the virus plume due to orography have not been considered. On the other hand, this seems currently not to be of major importance because the majority of premises in Austria are located in flat country.

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