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Digital Dermatitis in dairy cattle: The contribution of different disease classes to transmission

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ABSTRACT

Digital Dermatitis (DD) is a claw disease mainly affecting the hind feet of dairy cattle. Digital Dermatitis is an infectious disease, transmitted via the environment, where the infectious "agent" is a combination of bacteria. The standardized classification for DD lesions developed by Döpfer et al. (1997) and extended by Berry et al. (2012) has six distinct classes: healthy (M0), an active granulomatous area of 0–2 cm (M1), an ulcerative lesion of > 2 cm (M2), an ulcerative lesion covered by a scab (M3), alteration of the skin (M4), and a combination of M4 and M1 (M4.1).

We hypothesize that classes M1, M2, M3, M4, and M4.1 are the potentially infectious classes that can contribute to the basic reproduction ratio (R_0), the average number of new infections caused by a typical infected individual. Here, we determine differences in infectivity between the classes, the sojourn time in each of the classes, and the contribution of each class to R_0.

The analysis is based on data from twelve farms in the Netherlands that were visited every two weeks, eleven times.

We found that 93.89% of the transitions from M0 was observed as a transition to class M4, and feet with another *class-at-infection* rapidly transitioned to class M4. As a consequence, about 70% of the infectious time was spent in class M4. Transmission rate parameters of *class-at-infection* M1, M2, M3, and M4 were not significantly different from each other, but differed from *class-at-infection* M4.1. However, due to the relative large amount of time spend in class M4, regardless of the *class-at-infection*, R_0 was almost completely determined by this class. The R_0 was 2.36, to which *class-at-infection* M4 alone contributed 88.5%.

Thus, M4 lesions should be prevented to lower R_0 to a value below one, while painful M2 lesions should be prevented for animal welfare reasons.

1. Introduction

Digital Dermatitis (DD) is a claw disease discovered in 1974 in cattle in Italy by Cheli and Mortellaro (Cheli and Mortellaro, 1974). The disease (mainly) affects the hind feet of dairy cattle (Read and Walker, 1998; Sogstad et al., 2005). Round lesions occur along the coronary band of the claws, above the interdigital space next to the heel bulbs (Walker et al., 1995). Lesions can be painful, prone to bleed, develop filiform papillae, and can be surrounded by hyperkeratotic skin with hairs longer than normal (Read and Walker, 1998).

Digital Dermatitis is an infectious disease that is transmitted via the "environment"; environment is defined as any possible pathogen reservoir through which the infection can spread. The infectious "agent" is a combination of bacteria (Demirkan et al., 1999; Read and Walker, 1998; Rodríguez-Lainz et al., 1996; Sogstad et al., 2005; Vink et al., 2009), the most common bacteria present in DD lesions are spirochetes of the genus *Treponema* spp. (Clegg et al., 2015). Digital Dermatitis is associated with lameness; cows that are severely affected bear their weight on the toes of the affected foot, shake the foot as if in pain, and show reluctance to move (Bassett et al., 1990; Collighan and Woodward, 1997; Read and Walker, 1998).

A standardized classification for DD lesions was developed by Döpfer et al. (1997) and was more extensively described by Berry et al. (2012). This classification comprises six distinct classes (M0, M1, M2, M3, M4, and M4.1). Class M0 is described as skin where lesions are macroscopically absent, class M1 as an active granulomatous area of 0–2 cm, class M2 as an ulcerative lesion of > 2 cm, class M3 as an ulcerative lesion covered by a scab, class M4 as alteration of the skin with hyperkeratotic lesions that can have a proliferative aspect, and class M4.1 as altered skin (M4) with a painful focus (M1) (Berry et al., 2012;

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Döpfer, 2009; Döpfer et al., 1997). Class M1, M2, and M4.1 are classes that describe circumscribed, red-greyish, moist, painful, and prone to bleed lesions (Berry et al., 2012; Speijers et al., 2010; Zinicola et al., 2015). Studies on DD tend to focus on these lesions because they can cause lameness.

Here, we investigate what the contribution of the different classes to transmission is with the basic reproduction ratio R_0. The R_0 is the expected number of secondary cases that arise from one typical infectious individual in a fully susceptible population during its entire infectious period (Diekmann et al., 1990). When $R_0 < 1$, a typical infectious individual infects on average less than one other individual and the disease dies out. We hypothesize that classes M1, M2, M3, M4, and M4.1 are the infectious classes that contribute to R_0. When there is variation between classes in infectivity or in sojourn time, the contribution of each class to R_0 may differ. We determine how R_0 is composed by investigating the distribution of the first observed classes after infection, the average sojourn time in each class, and the infectivity of each class.

2. Material and methods

2.1. Data collection

Between November 2014 and April 2015, twelve farms in the Netherlands were visited eleven times with a two-week interval between visits. Criteria for farms to be selected included a ≥20% DD prevalence based on hoof trimming records from the previous year, and the presence of a milking parlour. Two trained observers scored the hind feet of all lactating cows in the milking parlour. Feet were cleaned with a medium pressure water hose, and were macroscopically examined with the use of a strong flashlight and a swivelling mirror (Relun et al., 2011). Feet were scored according to the classification developed by Döpfer et al. (1997) and Berry et al. (2012). Both observers were always present at a farm. An observer either rinsed and scored the feet, or recorded cow ID and the disease class. The role of an observer could alter between farms.

Missing values occurred when a cow was dried off or removed from the population for another reason. Farmers were not informed on the disease status of the cows. Farmers were, however, allowed to identify lesions themselves, and treat cows using their normal routine. Table 1 gives an overview of the characteristics of the farms enrolled in the study.

To assess agreement between observers, Cohen's kappa coefficient (Viera and Garrett, 2005) was calculated once immediately before, and two times during data collection. Kappa's coefficient is a measure of the difference between the observed and expected agreement. It is expressed on a −1 to 1 scale, where negative values indicate systematic disagreement between observers, 0 is agreement that would be expected by chance, and 1 is perfect agreement.

2.2. Methodology

We calculated R_0 based on methods of Diekmann et al. (2009) and Döpfer et al. (2012b). Digital Dermatitis has multiple infected classes that can all be consecutively presented by a single cow. The *sojourn* time in the infectious classes needs to be taken into account when calculating R_0. The class that is first observed upon infection will be called the *class-at-infection* (Diekmann et al., 2009). After the *class-at-infection*, a foot may reside in multiple other classes before returning to the susceptible class (M0). The sojourn time in the other classes can depend on the *class-at-infection*. So for each *class-at-infection,* the length of the infectious period in each class can be unique. During the infectious period feet with *class-at-infection i* have a certain average infectivity, measured by the transmission rate parameter β_i, i denoting *class-at-infection* Mi. For a foot with *class-at-infection* Mi, the β_i is a function of the infectivity of all the classes weighted by the sojourn time in these classes.

We account for the transmission of DD via the "environment" (Laven, 2001). Here, the environment is defined as any possible pathogen reservoir through which transmission can occur, including *e.g.*, the gastrointestinal tract, the nasal cavity, human caretakers or the actual environment. We assume that feet that are infected contribute fully to the current environmental reservoir, while feet that were infected at an earlier stage still contribute partly to the current environmental reservoir. The contribution to the environmental reservoir of feet that were infected earlier is assumed to decrease each interval Δt with factor λ, which may be interpreted as a survival rate. So from a foot that was infectious at t, the amount of pathogens that are in the environment at $t + 1$is a fraction λ, at $t + 2$ a fraction λ^2, at $t + 3$ a fraction λ^3, etc.

The R_0 is the expected number of secondary cases that arise from one typical infectious individual in a fully susceptible population during its entire infectious period (Diekmann et al., 1990). In general, R_0 is the product of a transmission rate parameter (β) and the average infectious period (x), $R_0 = \beta x$. Because DD has multiple *classes-at-infection*, each with a possibly unique transmission rate parameter and infectious period, we need to take into account all the *classes-at-infection* in the calculation of R_0. The R_0 is, therefore, a function of the probability with which *class-at-infection* Mi is entered (θ_i), and the transmission rate parameter and infectious period of the *classes-at-infection*, $R_0 = \sum_i \theta_i \beta_i x_i$. Furthermore, feet that were infectious previously can

Table 1
Characteristics of the farms enrolled in the study.

Farm	#Cows examined[a]	Outdoor access[b]	Floor type	Manure#		# Obs.	# Transitions observed	Average Δt (days)	Prevalence (SD)[d]	
				scraper	Footbaths[c]				Cow level	Foot level
A	134	Yes	Concrete slatted	No	7	11	2700	14	78.0 (5.4)	69.6 (6.6)
B	105	Yes	Concrete slatted	Yes	0	11	2140	14	56.3 (7.5)	46.9 (7.9)
C	159	No	Concrete + rubber slatted	Yes	5	11	3280	14	49.7 (2.8)	40.2 (1.9)
D	118	Yes	Concrete slatted	Yes	7	11	2380	14	57.8 (5.0)	49.2 (5.1)
E	102	Yes	Concrete slatted	Yes	9	11	2040	13.60	62.8 (5.0)	54.6 (5.4)
F	133	No	Concrete slatted	Yes	10	10	2448	15.56	59.2 (10.0)	48.7 (10.4)
G	100	Yes	Concrete slatted	No	3	11	2000	14	65.6 (8.1)	58.2 (7.6)
H	189	Yes	Concrete slatted	Yes	7	11	3780	14	64.9 (6.2)	56.7 (5.8)
I	104	Yes	Concrete slatted	No	0	11	2080	14	56.4 (5.1)	45.6 (4.9)
J	88	Yes	Concrete slatted	No	0	11	1760	14	65.8 (10.8)	58.1 (10.9)
K	130	Yes	Concrete slatted	Yes	13	9	2144	14	63.6 (9.6)	52.5 (8.5)
L	151	No	Concrete slatted	Yes	3	11	3040	13.90	70.9 (7.2)	62.0 (7.7)

[a] Total number of different cows examined during the study period.
[b] During the study period all cows were housed indoors.
[c] Number of footbaths given during the study period.
[d] Average percentage scored as class M1, M2, M3, M4, or M4.1 and the standard deviation (SD).