Universiteit Utrecht

Digital Dermatitis (DD) and Udder Cleft Dermatitis (UCD)

Is the one a risk for the other?

Master thesis Veterinary Medicine University Utrecht

C.E. Breedveld
4234308

Feb-Mei 2019

MSc student: Chantal Breedveld (Solis-ID: 4234308), e-mail: c.e.breedveld@students.uu.nl
Master Thesis Veterinary Medicine, University Utrecht, Dept. Landbouwhuisdieren, 2019
Supervisor: A. Vanhoudt

Abstract

INTRODUCTION Udder Cleft Dermatitis (UCD) is an inflammatory skin disease, often located between the front quarters of the udder and the abdomen, which affects milk production and quality, and animal welfare. Several risk factors have been identified and prevalence of UCD in the Netherlands is high. There are multiple ways to categorize UCD based on the severity of the disease. Bovine Digital Dermatitis (DD) is a multifactorial skin disease with an important bacterial component, causing skin damage of the heels, pain and it is an important cause of lameness in dairy cattle, resulting in reduced welfare and economic loss. UCD is often present in herds where DD is endemic. It is suggested that there could be a correlation between UCD and DD.

AIMS The objective of this study is to investigate if there is an association between the prevalence of DD and UCD at the moment of herd hoof trimming on herd-level and on cow-level.

METHODS Seven Dutch dairy herds, selected because of DD being present in their herds, were investigated on the prevalence of DD and UCD. Data were collected during a hoof trimming-session of all lactating cattle of the herd. Hind legs were examined using a scoring system for DD and the udder of the cows was simultaneously scored for UCD, of which a photograph was taken. After correction for missing data, the data were reshaped into binary data; UCD 0 when score 0 was given, and UCD 1 when any of the other scores were given (1 to 3). The data of DD-scores were converted into cow-data by giving the cows a binary score of 0, when M0 was scored on both feet, and as 1 when one or both hind feet had any of the other M-scores (1 to 5). An ordinal scale was also developed. Three classes were made for both DD and UCD. Logistic regression models were used to determine the odds ratio to see if there was an association between the prevalence of DD and UCD.

RESULTS In total 535 cows were inspected. For UCD 90% was healthy (i.e. no UCD, 483/535), 4% (24/535) was suffering from mild UCD and 5% (28/535) was affected by severe UCD. For DD 1070 hind feet were scored: 67% (719/1070) was healthy, 20.7% (221/1070) had active lesions and 10.5% (130/1070) had chronic lesions. DD cow-data showed that out of the 535 cows, 55% (293/535) was healthy (i.e. no DD), 33% (179/535) was suffering from active DD and almost 12% (63/535) was affected by chronic DD. Statistical analysis showed that the odds of having UCD when no DD is present was 0.11 (0.07-0.16) and was found significant. The odds ratio for having UCD when also having DD was 0.88 (0.49 to 1.56), but this was not significant. Adjusting the model with “Farm” as a random variable resulted in a significant odds ratio of 0.097 (0.03-0.21).

CONCLUSION There seems to be an negative association between the prevalence of DD and UCD and having DD does not present a higher risk for the development of UCD (OR 0.11). The OR for chronic DD and UCD was higher than 1 (1.28), so perhaps chronic DD does have some association with UCD, but this was not significant.

Prefatory note

Studying Veterinary Medicine at the University of Utrecht requires Master students to write a research thesis. This is the final report of a research project done by C.E. Breedveld, fulfilled at the department of Farm Animal Health, University of Utrecht. This research was performed to investigate a possible association between the prevalence of Udder Cleft Dermatitis and Digital Dermatitis. My tasks included training for data collection, the actual collecting of data, summarize and statistically analyse the data and lastly interpreting the results.

Introduction

Udder cleft dermatitis

Udder Cleft Dermatitis (UCD) is an inflammatory skin disease, which affects dairy cattle. It is often located between the front quarters of the udder and the abdomen. This disease is well-known but has not been described in veterinary literature very often (Riekerink et al., 2014). Other names for UCD are udder rot and Intertrigo. Characteristic lesions can include but are not limited to, a foul odour, skin necrosis and severe haemorrhage (Warnick et al., 2002).

The severe form of UCD can have consequences for milk production and quality and, perhaps most importantly, animal welfare. In a study about prevalence and risk factors, Riekerink et al., 2014 hypothesized that higher milk production can be associated with large and warm udders and could thereby be a risk factor for the development of UCD. Another risk factor the study found was the udder shape. Udder depth, front quarter size and a small angle between udder and abdomen have a positive association with UCD. Footbaths for dairy cows, more specifically lactating cows, is a risk factor on herd-level, which can be associated with a more-than-double prevalence of UCD (Riekerink et al., 2014).

Udder Cleft Dermatitis is more common in older cows than in younger cows, and it is found in all stages of lactation and in cows that are not in lactation (Warnick et al., 2002). Herd-level prevalence can vary a lot. Waller et al. (2014) found that UCD is very prevalent in the Netherlands (80% of randomly selected herds), which was higher than they expected.

Categorizing udder cleft dermatitis lesions

The most important characteristic for differentiating between mild and severe UCD lesions is thought to be skin integrity (Bouma et al., 2016; Waller et al., 2014). Multiple ways of categorizing have been used in different studies. Riekerink et al., 2014, for example, used a system of six categories (0 to 5). Score 3 or higher was deemed positive for UCD.

In a study about topical treatments, by van Werven et al. (2018), UCD lesions were classified as absent, mild or severe (Table 1).

Table 1. *Scoring system for udder cleft dermatitis by van Werven et al., 2018*

Score	Description
0	No UCD present.
1	Mild UCD present. Skin is intact or granulation tissue <2 cm². Erythema, transudate, sebum, crusts or scar tissue.
2	Severe UCD present, lesions < 5 centimetre. Skin is broken and there is an open wound. Necrosis, blood, granulation or exudate.
3	Severe UCD present, lesions ≥ 5 centimetre. Skin is broken and there is an open wound. Necrosis, blood, granulation or exudate.

Digital dermatitis

Bovine Digital Dermatitis (DD) is a multifactorial skin disease with an important bacterial component, affecting the skin on heels of cattle. It causes skin damage, pain and it is an important cause of lameness in dairy cattle (R. A. Laven & Logue, 2006; R. A. Laven & Proven, 2000), reducing welfare and causing economic loss (R. Laven, 2001). The infection seems to have a polymicrobial etiology, especially *Treponema* (Choi et al., 1997). Holzhauer et al. (2006) found that the prevalence of DD on cow level is about 20%, and on herd level around 80% in the Netherlands.

The common ground

UCD is often present in herds where DD is endemic (Stamm, Walker, & Read, 2009). Both diseases cause economic loss and reduce animal welfare. UCD lesions are erythematous, necrotic and in the severe form also exudative. DD lesions are often red ulcerative, moist and erosive (Read & Walker, 1998). Some may find these wounds to look similar. But it is not just the visual representation that makes us associate these diseases, it is also the overlapping risk factors that could be the connection. As mentioned above, footbaths are found to be associated with a higher prevalence of UCD. These footbaths may be a proxy for DD problems. Warnick et al. (2002), showed that the two diseases are negatively associated, but it could be that DD is controlled by footbaths, while the risk for and prevalence of UCD remain high (Riekerink et al., 2014). Footbaths are not the only factor that has been associated with UCD and DD. The following are risk factors for both diseases: high milk production, shorter cubicles with a mattress as base and lactation stage (Amersfort, 2013; Ekman et al., 2006; Somers et al., 2005; Waller et al., 2014).

Material and methods

Objective

The objective of this study is to investigate if there is an association between the prevalence of DD and UCD at the moment of herd hoof trimming on herd-level and on cow-level. In other words, is there a higher risk of having UCD, when DD is present?

> H0 = Cows with DD at the moment of hoof trimming do not have a higher risk of also having UCD.

Ha = Cows with DD at the moment of hoof trimming have a higher risk of also having UCD

Herd selection

In total seven farms/herds were selected based on having a high estimated prevalence of DD in the herd, initially for another research project by J. Hesseling. Within that project three Master student of Veterinary Medicine have done their master thesis. Other criteria that were used to select the herds were the presence of a functioning and safe trimming chute and the willingness of the farmer to have a herd hoof trimming on a specific date. All seven farmers agreed to the research protocol and received a report with a summary of all the data collected.

Data collection

Data collection for this study was performed by multiple Master students of Veterinary Medicine. These students were first educated and trained by a DD-expert, A. Vanhoudt, on DD-scoring. Every first time the students visited a farm with a hoof trimmer was named day 0. On day 0 a herd hoof trimming was performed, where all lactating dairy cows in the herd were examined. No dry cows or young cattle were examined. The herd hoof trimmings were performed by six different hoof trimmers, as farm 5 and 7 shared the same trimmer. While the cows were held in the trimming chute, hind legs were examined using a scoring system for DD developed by Döpfer et al., 1997 and adapted by Berry et al., 2012. For this study the system was modified slightly, see table 2.

Table 2. *The scoring system used for this study Döpfer et al., 1997 and adapted by L Berry et al., 2012.*

M-score	Description
0	Healthy. No sign of pre-existing lesion. Normal skin.
1	Small (<2 cm across) focal active state. Circumscribed lesion. Surface is moist, ragged, mottled red–grey with scattered small (~1 mm diameter) red foci.
2	Larger (>2 cm across) ulcerative active stage. Extensively mottled red–gray. Can be painful upon manipulation.
3	Healing stage. Typically seen within a few days after antibiotic treatment. The ulcerated surface is now transformed to a dry brown, firm rubbery scab. No pain on manipulation.
4	Chronic stage. Surface is raised by tan, brown, black, rubbery, irregular, proliferative hyperkeratotic growths that vary from papilliform to mass-like projections.
5	Also known as M4.1. Chronic stage with small active painful M1 focus.

Cows with a score of M1, M2 or M5 (active lesions) were treated. Front legs were not routinely scored by the students, because 82% of the time DD occurs on one or both hind legs (Read & Walker, 1998). However, when the hoof trimmer found an active lesion on a front leg, it was not excluded from treatment. While the cows were in the trimming chute the scorer used a headlight, a spatula with a small mirror and the scoring system in *table 1* to determine if the cows were affected by Udder Cleft Dermatitis (UCD). If present, a photograph was taken (*figure 1*) and UCD was then treated

according to the farm's treatment protocol. A few healthy udders were also photographed to use as reference material. A laminated sheet with the scoring system for UCD, complete with pictures (*see Appendix 1*), was provided for the scorers, so uniformity was ensured. In order to ensure safety, scorers always worked in pairs. Data was collected on paper and later entered into a spreadsheet in MS Excel.

Figure 1. *Pictures of the different UCD scores. Top left= 0, top right= 1, bottom left= 2, bottom right= 3. Note: pictures were taken from different cows, on different farms.*

Data analysis

The collected data were corrected for missing data and cows that were entered as duplicates. Pictures of UCD lesions were collected and scored by one person (C. Breedveld) to determine a definitive score for that picture. The data were first copied and reshaped into binary data. UCD was defined as 0 when score 0 was given, and as 1 when any of the other scores were given (1 to 3). DD data were collected for the hind feet, meaning two scores were given per cow. These data were converted from feet-data into cow-data by giving the cows a binary score of 0, when M0 was scored on both feet, and as 1 when one or both hind feet had any of the other M-scores (1 to 5). This resulted in one score per cow.

An ordinal scale was also developed. The original data were divided into three classes of UCD and three classes of DD. This was done to be able to investigate if there is an association between severity of UCD and the severity of DD.

Table 3. *UCD and DD classes used for data analysis. UCD classes are similar to the classes in table 1. DD class 0 was defined as both hind feet having score M0. DD class 1 was defined as one or both hind feet having score 1, 2 or 5. DD class 3 was defined as both hind feet having score M3 or 4, OR one hind foot having M3 or 4 and one hind foot having M0. L; left hind foot, R; right hind foot*

UCD group	UCD score	DD group	M score
1 = healthy (i.e. no UCD)	0	**1= healthy (i.e. no DD)**	L + R M0
2 = mild	1	**2 = active**	L and/or R M1-2-5
3 = severe	2 and 3	**3 = chronic**	L + R M3-4
			L M3-4 + R M0
			L M0 + R M3-4

Statistical analysis

Statistical analysis was done using the software RStudio (version 3.5.3 (2019-03-11)). Binary data and an unadjusted logistic regression were used to determine the odds ratio to see if there was an association between the prevalence of DD and UCD. Then a generalized linear mixed-effects model was made and a logistic regression was done, accounting for the different farms as a random variable. Finally, the odds ratios (OR) for the ordinal data (classes) were manually calculated using the following equation:

$$Odds\ ratio = \frac{\frac{p1}{(1-p1)}}{\frac{p0}{(1-p0)}}$$

p0= the odds of the healthy group, p1= the odds of the affected group.

Results

Data analysis

The number of lactating cows in the herds that were hoof trimmed varied between 43 and 108 cows. Out of the seven herds, two used an automatic milking system. The herds consisted mostly of Holstein Friesian dairy cows, next to Red Holstein Friesians and a few Blaarkop cows. One of the farmers, farm 1, had selected his lame cattle for the hoof trimming at day 0. All cows were housed in cubicles, although size and bedding differed.

UCD was present in six out of seven herds (85.7%). In total 535 cows were inspected for udder clef dermatitis and DD. Of these 535 cows, 90% was healthy (i.e. no UCD, 483/535), a little over 4% (24/535) was suffering from mild UCD and a little over 5% (28/535) was affected by severe UCD. All seven herds were affected by DD (100%). Foot-data showed that, in total, 1070 hind feet were scored and out of those 1070 feet 67% (719/1070) was healthy, 20.7% (221/1070) had active lesions (score M1, M2 and M5) and 10.5% (130/1070) had chronic lesions. Cow-data showed that out of the 535 cows, 55% (293/535) was healthy (i.e. no DD), 33% (179/535) was suffering from active DD and almost 12% (63/535) was affected by chronic DD. UCD is most

prevalent when DD is chronic (score 3) and least prevalent when DD is active (score 2). *Table 4* shows all the numbers of cows in all the different classes [1].

			UCD class			UCD binary			
		N	1	2	3	0	1	OR	95% CI
DD binary	0	293				363 (0.90)	30 (0.10)	0.11*	0.08-0.16
	1	242				220 (0.91)	22 (0.09)	0.88	0.49-1.56
DD class	1	293	263 (0.90)	11 (0.04)	19 (0.06)	263 (0.90)	30 (0.10)	0.11*	0.07-0.16
	2	179	165 (0.92)	8 (0.05)	6 (0.03)	165 (0.92)	14 (0.08)	0.74	0.37-1.42
	3	63	55 (0.87)	5 (0.08)	3 (0.05)	55 (0.87)	8 (0.13)	1.28	0.52-2.81
Farm	1	43	41 (0.95)	1 (0.02)	1 (0.02)	41 (0.95)	2 (0.05)		
	2	60	51 (0.85)	3 (0.05)	6 (0.10)	51 (0.85)	9 (0.15)		
	3	70	62 (0.87)	5 (0.07)	3 (0.04)	62 (0.87)	8 (0.13)		
	4	106	100 (0.95)	4 (0.04)	2 (0.02)	100 (0.95)	6 (0.05)		
	5	66	53 (0.80)	5 (0.08)	8 (0.12)	53 (0.80)	13 (0.20)		
	6	108	94 (0.87)	6 (0.06)	8 (0.07)	94 (0.87)	14 (0.13)		
	7	82	82 (1.00)	0 (0.00)	0 (0.00)	82 (1.00)	0 (0.00)		

Table 4. *A summary of the numbers in each DD- and UCD-class and binary group. N stands for number of cows and behind the number of cows in each UCD class or binary group is the proportion. The odds ratios are calculated using the DD and UCD binary scores and also using the DD classes and de UCD binary score.* = significant p-value (0)*

Statistical analysis

First, the binary data from UCD and DD were used to define an unadjusted linear model, disregarding any effect farm might have. DD was used as the independent variable and the UCD was used as the outcome/dependent variable, and the effect of DD on the prevalence of UCD was investigated. An odds ratio of 0.88 was found, which means that the odds of having UCD when also having DD is 0.88 times higher than having UCD when no DD is present. In other words, a cow that is affected by DD has a smaller odds of being affected by UCD. However, the 95% confidence interval (CI) shows an odds ratio from 0.49 to 1.56 and it was not significant. The odds ratio for UCD when DD was not present was 0.11 (0.07-0.16) and was found significant. Then the model was adjusted for the different farms, with "Farm" as a random variable. This resulted in a significant odds of 0.097 (0.03-0.21) of having UCD when no DD was present. The OR for having UCD when DD was present was 0.81 (0.43-1.49) but was not found significant. Lastly, a logistic regression model was made with the ordinal data from the DD classes and the binary UCD data. The calculated OR's can be found in *table 4.*

Discussion

In this study 86% (6/7) of the herds were affected by UCD, which is higher than what Waller et al., 2014 found (80%). This may have been caused by the fact that the selected herds had a high prevalence of DD and Waller et al., 2014 used randomly selected herds. However the logistic regression showed that DD does not necessarily give a

[1] All other tables and figures can be found in Appendix 2.

higher odds for UCD. The prevalence of UCD within herds varied between 0% to 20%. The highest prevalence of UCD found lies between the prevalences found in other studies, 15% (Riekerink et al., 2014) and 22% (Beattie & Taylor, 2000). Most cows were not affected by UCD and there were only small proportions of mild and severe cases.

DD was found in 100% of the herds with a herd-level prevalence varying from 36% to 73%. The current study found a cow-level prevalence of 45%. This is a much higher cow prevalence than Holzhauer et al. (2006) previously found (20%). The reason for this is most likely the selection process, investigating farms that were known for having a DD problem. Furthermore, the differences between herds could be explained by for example management, treatment protocol and the usage of preventive/treatment footbaths (Somers et al., 2005).

This study showed an odds ratio of 0.88 (0.49-1.56) between DD and UCD. This means a cow affected by DD at the moment of the herd hoof trimming has a smaller odds of being affected by UCD, which concurs with the negative association from Warnick et al., (2002). The mixed model showed only little change in the OR (0.81).
Cows that were scored positive for DD were split into two of the three classes, as described in Material and Methods. These classes were ‘active’ and ‘chronic’. Biemans et al., (2018) concluded that over 88% of the reproduction ratio is caused by the chronic M4-stage. The same study said that 70% of the infectious time is spend in this M4-stage The OR for DD class 3 (chronic) and the binary UCD score 1 was the highest (1.28 (0.52-2.81)), so there is a higher odds of having UCD when DD is chronic. However, these results were not significant. There are many studies about the risk factors for these diseases, but this study is one of only few that have investigated the relationship between DD and UCD. Statistically investigating the prevalence rates of DD and UCD on the farms was not possible in this study, because of the limited amount of data, but Waller et al., (2014) found that herds with a lower prevalence of DD (<0.054) had a higher prevalence rate of UCD.

Limitations

One of the farms had selected their lame lactating cattle for the hoof trimming. That particular farm had planned another hoof trimming for the rest of his cattle a few weeks later, but it appeared that, by that time, enough cows had been studied for the other student’s research. Therefore, no extra data collection was conducted on that farm and their dry cows would not be investigated. Therefore, it was decided to exclude all dry cows from this study. For the future it is recommended to investigate the prevalences of UCD and DD in dry cows.
As mentioned in Material and Methods, the farms were visited by six different hoof trimmers. It cannot be said for sure that every hoof trimmer indicated the presence of DD the same way. One might have indicated a cow when it was affected by a chronic DD lesion (score M4), while the other could have labelled that same cow as healthy.

Some hoof trimmer were impatience and wished to quickly continue their work, thereby possibly wrongfully labelling cows as healthy. This means the prevalence of the M-scores could be different than they appeared in this study. There were four student scorers who practiced in scoring DD lesions, but personal interpretation may have caused more variance in the scoring than initially intended (Vanhoudt et al., 2019). UCD scoring was far less affected by this, as the pictures were later evaluated by one scorer (C. Breedveld). However, when safety could not be ensured during the scoring of UCD no photographs were taken, so the final scorer had to trust the scores given by the others.

The number of cows in the three UCD classes and the DD classes are low. Doing statistics on these numbers, would most likely not be very significant or relevant and would be hard to do. It is because of this reason further class statistics were not done.

For future research it is strongly recommended to investigate with a much larger sample size. Because of the nature of the selected herds, these results are biased for DD and cannot be extrapolated to a 'standard' Dutch dairy herd. In the future, more random selected herds need to be investigated.

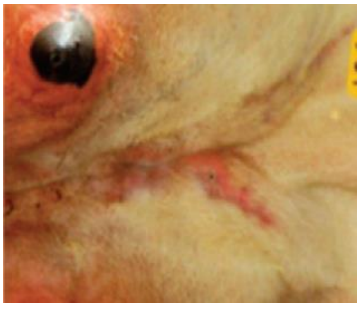
Conclusion

The odds of being affected by UCD when DD is present is 0.88 times the odds of not being affected by UCD when DD is present. In other words, DD has a so-called protective effect for UCD. However this result was not statistically significant. The OR for chronic DD and UCD was higher than 1 (1.28 (CI 0.52-2.81)), so perhaps chronic DD does have some positive association with UCD. But this result was also not significant. It seems that the null hypothesis is correct. Cows with DD at the moment of hoof trimming do not have a higher risk of also having UCD. For any future research it is recommended to use a much larger sample size and randomized herds.

Acknowledgements

I would like to thank my supervisor, A. Vanhoudt, for his assistance and feedback during this research project. I felt very comfortable to ask questions and I learned a lot from him. Also, I would like to thank J.C.M. Vernooij for all of his help with the statistical analysis, and the other Master students, Jessie Hesseling, Simone Leeuwestein and Alger Hiemstra, who made this project more fun than I could have hoped it to be. Lastly, I want to thank all the farmers and hoof trimmers for their cooperation, their effort and enthusiasm.

Appendix 1

Score	Description	Example
0	No UCD present	
1	Mild UCD present Skin is intact or granulation tissue <2 cm². Erythema, transudate, sebum, crusts or scar tissue.	 
2	Severe UCD present < 5 centimetre Skin is broken and there is an open wound. Necrosis, blood, granulation of exudate.	
3	Severe UCD present > 5 centimetre Skin is broken and there is an open wound. Necrosis, blood, granulation of exudate.	 

Appendix 2

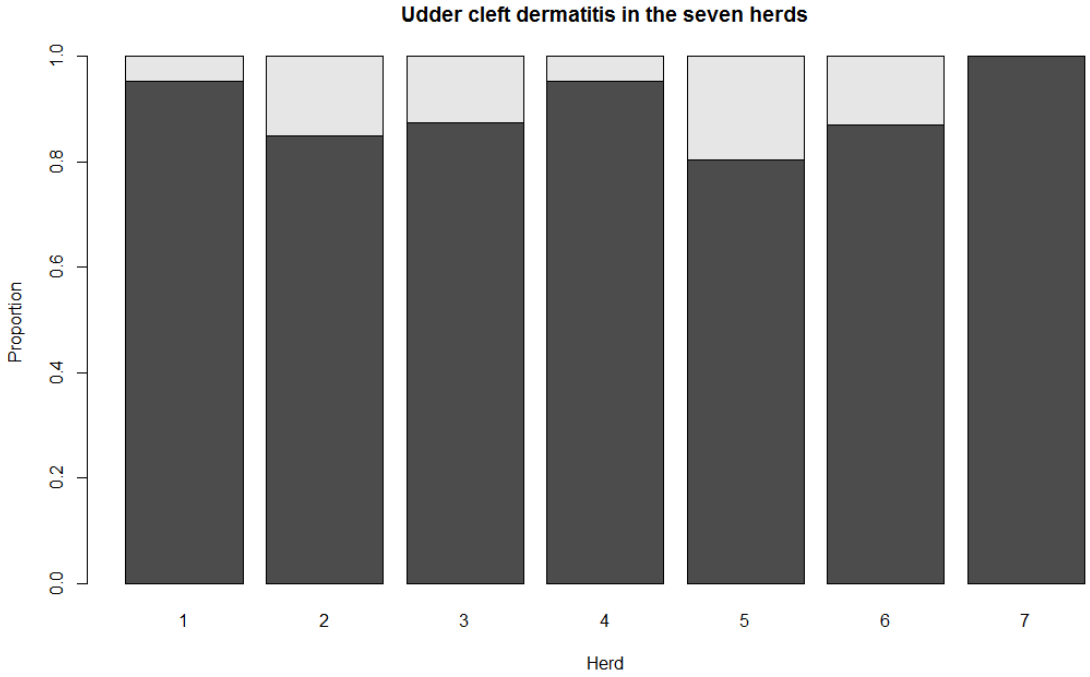


Figure A2.1. *This figure shows the proportionate distribution of UCD in the seven herds studied. Binary data was used. The dark grey bars indicate the UCD score 0, and the light grey bars indicate the UCD score 1.*

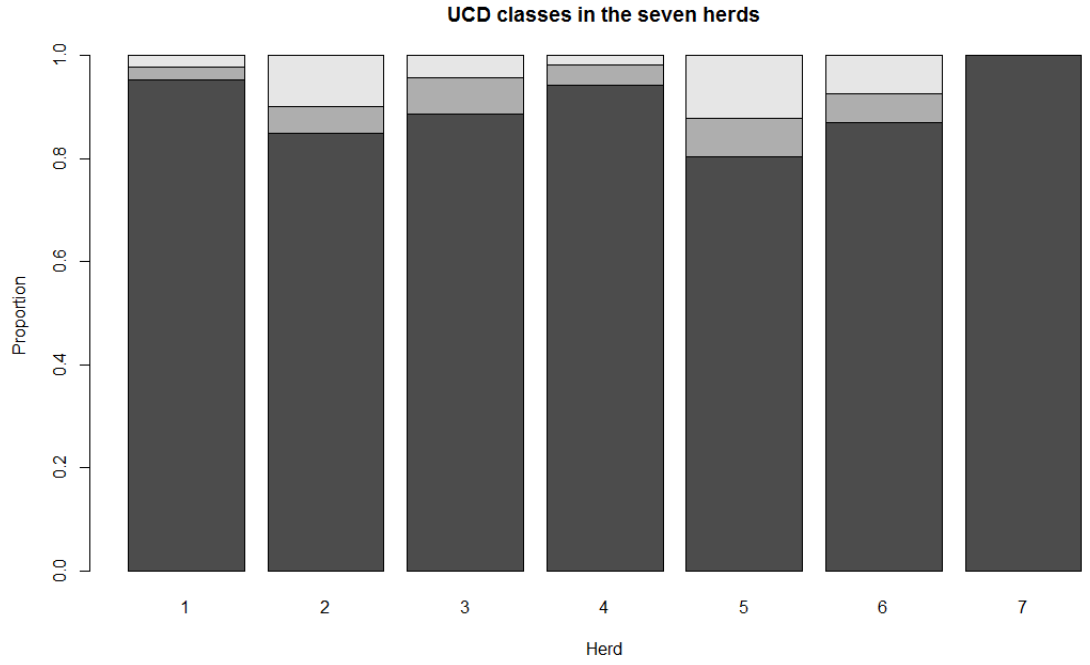


Figure A2.2*. The proportionate distribution of the three different UCD classes in the seven herds. The dark grey bars show UCD class 1= no UCD, the middle grey bars show UCD class 2= mild and the lightest grey bars show UCD class 3= severe.*

Table A2.1. *Overview of the prevalence of the different M scores for the seven herds. The number under the M scores is in rounded percentages. Note: this data is from all examined hind feet.*

Herd	N hind feet	0 (%)	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
1	86	60	1	26	0	10	2
2	120	39	8	29	0	16	8
3	140	58	1	7	4	29	1
4	212	71	4	12	0	13	0
5	132	74	4	17	3	0	2
6	216	76	4	12	6	1	2
7	164	77	7	9	0	7	0

Table A2.2. *Overview of the prevalence of the different DD classes on the seven farms in percentages. 1= healthy (no DD), 2= active DD and 3= chronic DD*

Herd	N cows	1 (%)	2 (%)	3 (%)
1	43	47	51	2
2	60	27	60	13
3	70	49	19	33
4	106	60	28	11
5	66	61	36	3
6	108	64	28	8
7	82	63	27	10

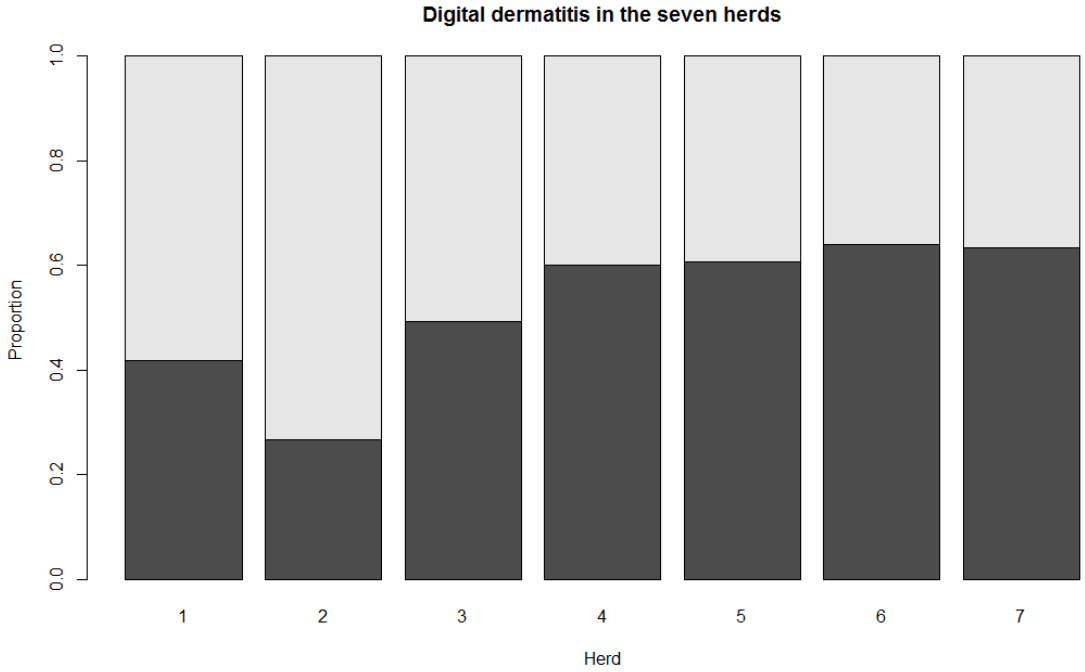


Figure A2.3. *The proportionate distribution of DD in the seven herds studied. Binary data was used. The dark grey bars indicate the DD score 0, and the light grey bars indicate the DD score 1.*

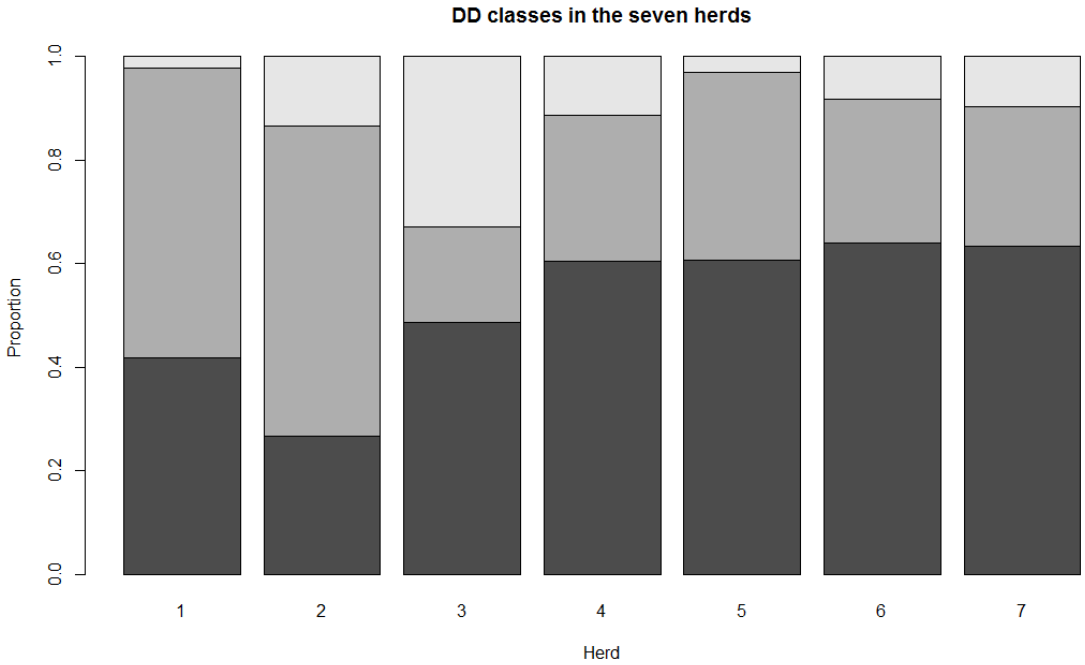


Figure A2.4. *The proportionate distribution of the three different DD classes in the seven herds. The dark grey bars show DD class 1= no DD, the middle grey bars show DD class 2= active and the lightest grey bars show DD class 3= chronic.*

References

Amersfort, K. van. (2013). *Prevalence and risk factors of Udder Cleft Dermatitis in 20 Dutch dairy herds*.

Beattie, G., & Taylor, D. J. (2000). *An investigation into intertrigo (necrotic dermatitis or "foul udder") in dairy cows* (Vol. 8).

Biemans, F., Bijma, P., Boots, N. M., & de Jong, M. C. M. (2018). Digital Dermatitis in dairy cattle: The contribution of different disease classes to transmission. *Epidemics*, *23*, 76–84. https://doi.org/10.1016/j.epidem.2017.12.007

Bouma, A., Nielen, M., Soest, E. van, Sietsma, S., Broek, J. van den, Dijkstra, T., & Werven, T. van. (2016). Longitudinal study of udder cleft dermatitis in 5 Dutch dairy cattle herds. *Journal of Dairy Science*, *99*(6), 4487–4495. https://doi.org/https://doi.org/10.3168/jds.2015-9774

Choi, B. K., Nattermann, H., Grund, S., Haider, W., & Göbel, U. B. (1997). Spirochetes from digital dermatitis lesions in cattle are closely related to treponemes associated with human periodontitis. *International Journal of Systematic Bacteriology*, *47*(1), 175–181. https://doi.org/10.1099/00207713-47-1-175

Clegg, S. R., Mansfield, K. G., Newbrook, K., Sullivan, L. E., Blowey, R. W., Carter, S. D., & Evans, N. J. (2015). Isolation of Digital Dermatitis Treponemes from Hoof Lesions in Wild North American Elk (Cervus elaphus) in Washington State, USA. *Journal of Clinical Microbiology*, *53*(1), 88–94. https://doi.org/10.1128/JCM.02276-14

Döpfer, D., Koopmans, A., Meijer, F. A., Szakáll, I., Schukken, Y. H., Klee, W., … ter Huurne, A. A. (1997). Histological and bacteriological evaluation of digital dermatitis in cattle, with special reference to spirochaetes and Campylobacter faecalis. *The Veterinary Record*, *140*(24), 620–623.

Ekman, L., Nyman, A.-K., Landin, H., Magnusson, U., & Waller, K. P. (2018). Mild and severe udder cleft dermatitis—Prevalence and risk factors in Swedish dairy herds. *Journal of Dairy Science*, *101*(1), 556–571. https://doi.org/10.3168/jds.2017-13133

Holzhauer, M., Hardenberg, C., Bartels, C. J. M., & Frankena, K. (2006). Herd- and cow-level prevalence of digital dermatitis in the Netherlands and associated risk factors. *Journal of Dairy Science*, *89*(2), 580–588. https://doi.org/10.3168/jds.S0022-0302(06)72121-X

L Berry, S., Read, D., R Famula, T., Mongini, A., & Döpfer, D. (2012). *Long-term observations on the dynamics of bovine digital dermatitis lesions on a California dairy after topical treatment with lincomycin HCl* (Vol. 193). https://doi.org/10.1016/j.tvjl.2012.06.048

Laven, R. (2001). Control of digital dermatitis in cattle. *In Practice*, *23*(6), 336–341. https://doi.org/10.1136/inpract.23.6.336

Laven, R. A., & Logue, D. N. (2006). Treatment strategies for digital dermatitis for the UK. *Veterinary Journal (London, England: 1997)*, *171*(1), 79–88. https://doi.org/10.1016/j.tvjl.2004.08.009

Laven, R. A., & Proven, M. J. (2000). Use of an antibiotic footbath in the treatment of bovine digital dermatitis. *The Veterinary Record*, *147*(18), 503–506.

Read, D. H., & Walker, R. L. (1998). Papillomatous Digital Dermatitis (Footwarts) in California Dairy Cattle: Clinical and Gross Pathologic Findings. *Journal of Veterinary Diagnostic Investigation*, *10*(1), 67–76. https://doi.org/10.1177/104063879801000112

Riekerink, R. G. M. O., Amersfort, K. van, Sampimon, O. C., Hooijer, G. A., & Lam, T. J. G. M. (2014). Short communication: Prevalence, risk factors, and a field scoring system for udder cleft dermatitis in Dutch dairy herds. *Journal of Dairy Science*, *97*(8), 5007–5011. https://doi.org/https://doi.org/10.3168/jds.2013-7651

RStudio, version 3.5.3 (2019-03-11)

Somers, J. G. C. J., Frankena, K., Noordhuizen-Stassen, E. N., & Metz, J. H. M. (2005). Risk factors for digital dermatitis in dairy cows kept in cubicle houses in The Netherlands. *Preventive Veterinary Medicine*, *71*(1), 11–21. https://doi.org/10.1016/j.prevetmed.2005.05.002

Stamm, L. V., Walker, R. L., & Read, D. H. (2009). Genetic diversity of bovine ulcerative mammary dermatitis-associated Treponema. *Veterinary Microbiology*, *136*(1), 192–196. https://doi.org/10.1016/j.vetmic.2008.10.022

Vanhoudt, A., Yang, D. A., Armstrong, T., Huxley, J. N., Laven, R. A., Manning, A. D., … Bell, N. J. (2019). Interobserver agreement of digital dermatitis M-scores for photographs of the hind feet of standing dairy cattle. *Journal of Dairy Science*. https://doi.org/10.3168/jds.2018-15644

Waller, K. P., Bengtsson, M., & Nyman, A.-K. (2014). Prevalence and risk factors for udder cleft dermatitis in dairy cattle. *Journal of Dairy Science*, *97*(1), 310–318. https://doi.org/10.3168/jds.2013-7186

Warnick, L. D., Nydam, D., Maciel, A., Guard, C. L., & Wade, S. E. (2002). Udder cleft dermatitis and sarcoptic mange in a dairy herd. *Journal of the American Veterinary Medical Association*, *221*(2), 273–276. https://doi.org/10.2460/javma.2002.221.273

Werven, T. van, Wilmink, J., Sietsma, S., Broek, J. van den, & Nielen, M. (2018). A randomized clinical trial of topical treatments for mild and severe udder cleft dermatitis in Dutch dairy cows. *Journal of Dairy Science*, *101*(9), 8259–8268. https://doi.org/https://doi.org/10.3168/jds.2017-13778