Journal of Dairy Research (2017) **84** 54–60. doi:10.1017/S0022029916000510

Claw disorders in dairy cattle – an unexpected association between energy metabolism and sole haemorrhages

Katrin Wilhelm[1]*, Jürgen Wilhelm[1] and Manfred Fürll[2]

[1] Veterinary Practice of Dr Wilhelm, Plauen, Germany
[2] Large Animal Clinic for Internal Medicine, Faculty of Veterinary Medicine, University of Leipzig, Germany

Received 2 December 2015; accepted for publication 2 July 2016; first published online 3 October 2016

The present study investigated whether changes of energy metabolism *post-partum* (*pp*) are associated with claw health. For this purpose, back-fat-thickness (BFT) was measured and blood samples were taken from 146 cows at four examination times. The serum levels of free fatty acids (FFA), ß-hydroxybutyrate (BHB) and glucose were measured. Furthermore, in the first week post-partum (*pp*) and at 8 weeks *pp*, a claw trimming was done and the presence and extent of sole haemorrhages (SH) was recorded. Animals with high BFT at calving and therefore high fat mobilisation and whose FFA and BHB levels in the first week *pp* exceeded the reference values had fewer pathological changes of the claws than thinner animals whose FFA and BHB levels stayed within reference ranges. The body condition before calving, represented in this study by BFT, plays an important role in non-infectious claw disorders. Poorer body condition was found to be associated with the SH that develop in the first 2 months of lactation.

Keywords: Back-fat-thickness, Claw disorders, Energy metabolism, Fat-mobilisation, Sole haemorrhages.

Lameness is one of the most important reasons for culling in dairy cows (ADR, 2010). Next to infectious claw diseases, non-infectious claw disorders like white line disease and sole ulcer are significant causes of lameness. Corium changes that lead to incorporation of serum, blood or cell detritus in the horn precede the overt expression of these diseases (Mülling & Lischer, 2002; Bergsten, 2003). After 8–12 weeks, the pathologic changes of the corium appear outside the claw as yellowish, crumbly horn or red discolouration of varying intensity (haemorrhages), evident during claw trimming (Lischer & Ossent, 1994). The reasons for these corium changes are not clearly understood. Different internal and external factors seem to have an influence. For example, nutritional status, hormonal changes near the time of calving, diseases of other organ systems, and genetic influences have been discussed (Greenough & Vermunt, 1991; Mülling & Lischer, 2002; Bicalho & Oikonomou, 2013). Mechanical stress to the claws (as a result of housing conditions) seems to be a key factor (Van Der Tol et al. 2002; Knott et al. 2007; Telezhenko et al. 2008), as does body condition. Espejo et al. (2006), Hoedemaker et al. (2009), Green et al. (2014) and Foditsch et al. (2016) found an association between lameness and lower body condition of cows. Bicalho et al. (2009) and Machado et al. (2011) observed that, when the body condition score (BCS) decreases, the digital cushion within the claw becomes thinner and its shock absorbing function declines. Because thinner cows seem to be more prone to claw disorders, an unanswered question concerning body condition is the extent to which changes in fat mobilisation *pp* plays an aetiological role in claw pathology. Cows with a high BCS at calving often suffer from fat mobilisation syndrome with many negative effects. High FFA and BHB as well as low glucose concentrations can be used as markers for negative energy balance, with resulting fat mobilisation syndrome and ketosis (Drackley, 1999; Van Knegsel et al. 2007). The present study investigated whether changes in energy metabolism *pp* especially increased mobilisation of fat *pp* are associated with claw health. For example, a possible mechanism might be the release of mediators, accumulated in fat tissue, which could influence blood vessels in the corium (Fürll, 2000; Andersen, 2003; Fischer, 2004).

Materials and methods

The study group consisted of the same animals from a study on the use of thermography to monitor sole haemorrhages that has already been reported (Wilhelm et al. 2015).

*For correspondence; e-mail: kwilh@gmx.de

Farms and management

The study was carried out in 2008 on 146 Holstein Friesian cows from three dairy farms in eastern Germany (Saxony and Thuringia) with herd sizes of 562 (farm A), 530 (farm B) and 623 (farm C). All lactating cows were kept in free-stall barns and the average milk yield in 2007 was around 9000 kg for all farms. All farms had calving boxes with concrete and straw litter. In farm A, lactating cows were kept on solid mastic asphalt with automatic scrapers and cow mattresses in cubicles leading to a 24 stall rotary parlour. Late lactating and dry cows were kept on rubber instead of mastic asphalt. Heifers were kept on concrete covered with straw litter. Walkways to the milking parlour and the holding pen were slatted concrete. In farm B, the flooring was concrete and cleaned by tractor with a front scraper twice daily and the cubicles straw bedded. Walkways, holding pen and rotary were the same as in farm A. In farm C, the walkways and holding pen had a slatted rubber floor. The 24-stall side-by-side-milking parlour was also rubber coated. The free-stall alleys had rubber flooring and cow mattresses in cubicles. Exceptions were the dry cows and heifers; they were kept in concrete alleys and free-stalls with straw litter. All three farms had an animal: feeding place ratio as well as an animal:cubicle ratio of no more than 1:1. The alleys and cubicles were the same in all three farms and within recommended dimensions.

All cows were offered a total mixed ration (TMR) twice daily in performance-adapted feeding groups (dry group I and II, lactation groups). The diets met the nutrient requirements for cows (GfE, 2010). In all farms the rations were based on grass and maize silage. The dry group I in farm A received both, whereas in farms B and C no maize silage was offered to dry group I. In farm B a performance-adapted dairy concentrate was additionally offered via automatic feeding stations to lactating cows. In all three farms cows stayed in the same feeding and housing group for the examination period until 8 weeks *pp*. In all farms, cows were milked twice daily. All cows received regular hoof trimming twice a year. The routine claw trimming in farms A and B was performed by the same claw trimmer at the time of dry off and in mid-lactation. Farm C used a different claw trimmer; here the claw trimming was performed independently of the lactation stage, twice a year. All three farms commenced routine claw trimming only after first calving. There was no routine claw trimming done on the study animals for the period of examination.

Data collection and study design

Repeated examinations were undertaken on 146 animals of the three farms. Measurement of back-fat-thickness was undertaken at four examination times on all available animals, though as can be seen from Table 2, two were not available due to bad measurability. The BFT was measured using the method described by Staufenbiel (1997) at the point with the highest measurable layer of fat in the sacral region between the tuber ischia and tuber coxae (at the transition from the caudal one-quarter to one-fifth) (Schröder & Staufenbiel, 2006). A portable ultrasound scanner (Honda Electronics HS-101 V, Aichi, Japan) with a 5 MHz rectal probe was used. As a contact agent, 70% diluted alcohol was used.

The back-fat-thickness (BFT) was measured four times: 3–2 weeks *pre- or ante-partum* (*ap*), 1 week *pp*, 4 weeks *pp*, and 8 weeks *pp* and to calculate the reduction in BFT, the value measured at 8 weeks *pp* was subtracted from the value measured at 3–2 weeks *ap*. The daily decrease in BFT should not exceed 0·14 mm to prevent health problems resulting from negative energy balance (Schröder, 2000). This implies a cut-off value of 10·3 mm in the examination period (10–11 weeks). Animals were thus classified into two groups: one group with less than and one group with greater than a 10·3 mm decrease in BFT.

Blood was taken from the jugular vein immediately after restraining the animal in the trimming chute or feeding fence. Some 123 cows (75 cows, 48 heifers) were used for analysis: 51 (40 cows, 11 heifers) from farm A, 33 (9 cows, 24 heifers) from farm B, and 39 (26 cows, 13 heifers) from farm C. The 23 cows that were excluded left the farms for different reasons before the end of the 2 months in lactation. All animals that calved in the examination period were enrolled (simple random sampling).

The blood samples were centrifuged at 3800 ***g*** for 10 min. The serum was pipetted into microfuge tubes and stored at −18 °C until the laboratory analyses. The analyses were done in the laboratory of the Large Animal Clinic for Internal Medicine of the University of Leipzig. The following "normal" reference ranges were used: <150 μM/l *ap* and <620 μM/l *pp* for FFA; <0·62 mM/l for BHB irrespective of stage of lactation; and similarly within 2·22–3·3 mM/l for glucose (Fürll, 2004).

In the first week *pp* and 8 weeks later, the animals were restrained in the trimming chute and the hoofs were trimmed by one of the research team members (farm veterinarian). An angle grinder with trimming disc with blades (Bosch GWS 11–125 CIE Professional, Bosch, Leinfelden-Echterdingen, Germany, aluminium, 7 hard-metal-cutting blades) as well as a left and right hoof knife were used. Then the ground contact area of the claws was photographed with a digital camera (Kodak V705 Dual Lens Digital Camera, Kodak, Rochester, USA) for later assessment (lens parallel to the ground contact area at a distance of about 30 cm, with flash).

In total, 984 photographs (123 cows – 4 photographs per cow, 2 examinations) were evaluated blinded on two consecutive days by the same person. The following scores were assigned: 0 = no signs of alteration; 1 = slight haemorrhages in a specific area of the sole horn (white line and/or sole-bulb junction); 2 = yellow discolouration, softening of the whole sole horn (waxy appearance); 3 = clear haemorrhages in a specific area of the sole horn (white line and/or sole-bulb junction); 4 = slight haemorrhages of the whole sole horn; 5 = severe haemorrhages in a specific

https://doi.org/10.1017/S0022029916000510 Published online by Cambridge University Press

area of the sole horn (white line and/or sole-bulb junction); 6 = clear haemorrhages of the whole sole horn, presence of sole ulcers. Sole in this context means the ground contact area of the claws.

For each animal, all eight claws (fore and hind limbs, lateral and medial) were evaluated and a total (score) was created. Afterwards the difference between the score at 8 weeks *pp* and the score at 1 week *pp*, hereafter termed the claw-score-increase, was calculated to obtain a meaningful value of the change in claw situation over the first 2 months of lactation. For example, if the value was in the negative range or 0, then an improvement or no change in the first 2 months of lactation had occurred. The higher the score in the positive range, the more the claw health had decreased.

Statistical analysis

The statistical analyses were done in WinSTAT® for Microsoft® Excel 2007.1. The variables were tested for normal distribution by the Kolmogorov-Smirnov-test. If they were normally distributed, the paired t-test was used to determine differences between the examination times. In the case of non-normally distributed variables, the Wilcoxon-test was used. Relationships between the measured blood parameters and the claw-score-increase were determined by Pearson-correlation. To calculate differences at the same examination time between groups, the unpaired t-test or Mann-Whitney-U-test was used. To test for differences between the 3 farms and between cows and heifers, the ANOVA procedure and, as post-hoc test, the Least Significant Difference test were used. Alpha was set at $P < 0{\cdot}05$.

Results

The assigned claw-scores are shown in Table 1. Overall, a deterioration of claw health occurred in the first 2 months of lactation ($P < 0{\cdot}001$). The mean claw-score-increase of all animals (cows and heifers combined) was $\bar{x} = 10{\cdot}92 \pm 9{\cdot}75$. In comparison, cows had a mean claw-score-increase of $\bar{x} = 7{\cdot}93 \pm 7{\cdot}8$, and thus fewer claw horn changes in the form of haemorrhages than heifers ($\bar{x} = 15{\cdot}58 \pm 10{\cdot}7$) ($P < 0{\cdot}001$). Comparing the three farms, farm C showed the lowest claw-score-increase ($\bar{x} = 8{\cdot}7 \pm 6{\cdot}8$) followed by farm A ($\bar{x} = 10{\cdot}6 \pm 10{\cdot}9$) and farm B ($\bar{x} = 14{\cdot}0 \pm 10{\cdot}2$). The difference between farm C and farm B was significant ($P < 0{\cdot}05$) but not between A and B or A and C.

The difference between cows and heifers in farm A was highly significant ($\bar{x}_{cows\ A} = 7{\cdot}18 \pm 8{\cdot}15$; $\bar{x}_{heifers\ A} = 23{\cdot}09 \pm 11{\cdot}01$; $P < 0{\cdot}001$), in farm B as well ($\bar{x}_{cows\ B} = 7{\cdot}33 \pm 8{\cdot}8$; $\bar{x}_{heifers\ B} = 16{\cdot}54 \pm 9{\cdot}69$; $P < 0{\cdot}02$) but no difference could be found in farm C ($\bar{x}_{cows\ C} = 9{\cdot}31 \pm 6{\cdot}99$; $\bar{x}_{heifers\ C} = 7{\cdot}46 \pm 6{\cdot}59$).

Development of BFT throughout lactation

The BFT values of cows and heifers of the three farms are shown in Table 2.

A slight (non-significant) increase in BFT occurred from the time of drying off until about 3–2 weeks *ap*. With the onset of lactation, BFT steadily decreased. The decreases in relationship to the respective previous examination times are highly significant ($P < 0{\cdot}001$).

Altogether, cows had a higher starting level of back-fat ($P < 0{\cdot}001$) at dry off (3–2 weeks *ap* in heifers), as well as 1 week *pp*. After 4 and 8 weeks in lactation, no differences were found between cows and heifers.

A strong correlation ($r = 0{\cdot}839$, $P < 0{\cdot}001$) was found between the BFT at 3–2 weeks *ap* and the BFT decrease throughout the first 2 months of lactation (BFT 3–2 weeks *ap* – BFT 8 weeks *pp*) ($\bar{x}_{BFT\ decrease} = \underline{8}$ (5/13) mm).

By grouping the animals into low BFT (3–2 weeks *ap* < 18 mm) and high BFT (3–2 weeks *ap* ≥ 18 mm) cohorts, a slight, significant difference ($P = 0{\cdot}03$) in claw-score-increase was revealed (Fig. 1). Animals in the low BFT group showed more severe claw horn changes.

When considering cows and heifers separately, the difference was also seen (but it is not significant).

When looking at the intensity of the BFT decrease, it was found that animals that showed a greater decrease were non-significantly less prone to SH than animals that showed a slighter decrease ($P = 0{\cdot}02$: Fig. 2). A significant difference was observed for heifers considered separately ($P = 0{\cdot}04$), but not for cows considered separately.

When comparing the three farms, the BFT in farm B was significantly lower compared to farm A at all examination times, and compared to farm C in two examination times (1 week *pp*, 4 weeks *pp*). Between farm A and C, only at 4 weeks *pp* was a significant difference seen ($P < 0{\cdot}05$).

A slight and non-significant negative correlation between BFT-decrease and claw-score-increase could be found when considering all animals (−0·17; $P < 0{\cdot}03$). When looking at the farms this is confirmed by farm A (−0·25; $P < 0{\cdot}04$), but not by the other ones. Also when looking at cows and heifers separately no significant effect was observed.

Animals having FFA concentrations above the reference range in the first week *pp* had a lower claw-score-increase ($\bar{x}_{above\ ref.} = \underline{8{\cdot}4} \pm 8{\cdot}7$) compared to animals that stayed within the reference range ($\bar{x}_{within\ ref.} = \underline{13{\cdot}7} \pm 10{\cdot}2$) ($P < 0{\cdot}01$). (Cows: $\bar{x}_{above\ ref.\ cows} = 5{\cdot}7 \pm 7$; $\bar{x}_{within\ ref.\ cows} = 10{\cdot}6 \pm 7{\cdot}4$; $P < 0{\cdot}01$; Heifers: $\bar{x}_{above\ ref.\ heifers} = 13{\cdot}9 \pm 9{\cdot}3$; $\bar{x}_{within\ ref.\ heifers} = 17{\cdot}2 \pm 11{\cdot}9$; n.s.)

Comparing the three farms, a difference was found between farm A and B ($P < 0{\cdot}02$) and between C and B ($P < 0{\cdot}001$) at 4 weeks *pp* ($\bar{x}_A = 534$ µM/l; $\bar{x}_B = 279$ µM/l; $\bar{x}_C = 709$ µM/l), and between farm B and C ($P < 0{\cdot}02$) at 8 weeks *pp* ($\bar{x}_A = 282$ µM/l; $\bar{x}_B = 192$ µM/l; $\bar{x}_C = 402$ µM/l).

Between cows and heifers, a difference was found at 1 week *pp* ($P < 0{\cdot}05$) ($\bar{x}_{heifers} = 660$ µM/l; $\bar{x}_{cows} = 892$ µM/l).

A similar relationship to that for FFA was found for BHB. The claw-score-increase was significantly ($P < 0{\cdot}0001$) higher in animals that stayed within the reference range ($\bar{x}_{within\ ref.} = \underline{14{\cdot}0} \pm 10{\cdot}5$; $\bar{x}_{above\ ref.} = \underline{7{\cdot}4} \pm 7{\cdot}5$). (Cows: $\bar{x}_{above\ ref.\ cows} = 6{\cdot}4 \pm 6{\cdot}8$; $\bar{x}_{within\ ref.\ cows} = 10{\cdot}5 \pm 8{\cdot}8$; $P < 0{\cdot}03$;

https://doi.org/10.1017/S0022029916000510 Published online by Cambridge University Press

Table 1. Descriptive statistics of claw-scores

	N	Mean	SD	Median	Minimum	Maximum
Claw-score-increase	123	10·92	9·75	10	−10	45
Farm **A**						
Cows	40	7·18	8·15	5·5	−5	30
Heifers	11	23·09	11·01	21	2	45
Farm **B**						
Cows	9	7·33	8·80	4	−2	22
Heifers	24	16·54	9·69	16·5	0	39
Farm **C**						
Cows	26	9·31	6·99	10	−10	25
Heifers	13	7·46	6·59	7	−1	20
Claw-score **1** week pp	123	8·51	6·46	8	0	29
Claw-score **1** week pp **front** claws	123	3·15	3·51	2	0	13
Claw-score **1** week pp **hind** claws	123	5·73	4·20	5	0	18
Claw-score **8** weeks pp	123	19·43	9·78	20	0	52
Claw-score **8** weeks pp **front** claws	123	7·54	5·30	8	0	26
Claw-score **8** weeks pp **hind** claws	123	11·89	5·83	11	0	34
Farm **A**						
Cows						
Claw-score 1 week pp	40	10·85	7·43	10	0	26
Claw-score 8 weeks pp	40	18·03	7·84	19	0	36
Heifers						
Claw-score 1 week pp	11	6·55	4·95	6	1	18
Claw-score 8 weeks pp	11	29·64	10·42	30	8	52
Farm **B**						
Cows						
Claw-score 1 week pp	9	11·00	4·06	12	6	17
Claw-score 8 weeks pp	9	18·33	6·78	16	10	29
Heifers						
Claw-score 1 week pp	24	8·00	5·67	7	0	20
Claw-score 8 weeks pp	24	24·54	9·50	24	8	46
Farm **C**						
Cows						
Claw-score 1 week pp	26	8·00	6·26	7·5	0	29
Claw-score 8 weeks pp	26	17·31	9·61	17·5	3	44
Heifers						
Claw-score 1 week pp	13	3·23	3·59	2	0	13
Claw-score 8 weeks pp	13	10·69	6·26	9	0	23

Heifers: $\bar{x}_{\text{above ref. heifers}} = 10{\cdot}3 \pm 9{\cdot}2$; $\bar{x}_{\text{within ref. heifers}} = 17{\cdot}5 \pm 10{\cdot}7$; $P < 0{\cdot}05$).

For the three farms, a difference at 3–2 weeks *ap* was found between farms A and C, and between A and B ($P < 0{\cdot}001$) ($\bar{x}_A = 0{\cdot}63$ mM/l; $\bar{x}_B = 0{\cdot}37$ mM/l; $\bar{x}_C = 0{\cdot}41$ mM/l). In the first week *pp* ($\bar{x}_A = 0{\cdot}97$ mM/l; $\bar{x}_B = 0{\cdot}54$ mM/l; $\bar{x}_C = 0{\cdot}68$ mM/l), differences between farm A and B and between A and C ($P < 0{\cdot}01$) were found. At 8 weeks *pp*, farm A was different from C ($\bar{x}_A = 0{\cdot}72$ mM/l; $\bar{x}_B = 0{\cdot}58$ mM/l; $\bar{x}_C = 0{\cdot}46$ mM/l) ($P < 0{\cdot}001$).

Between cows and heifers, differences at all examination times were found: 3–2 weeks *ap* ($\bar{x}_{\text{heifers}} = 0{\cdot}44$ mM/l; $\bar{x}_{\text{cows}} = 0{\cdot}56$ mM/l); 1 week *pp* ($\bar{x}_{\text{heifers}} = 0{\cdot}52$ mM/l; $\bar{x}_{\text{cows}} = 0{\cdot}92$ mM/l); 4 weeks *pp* ($\bar{x}_{\text{heifers}} = 0{\cdot}51$ mM/l; $\bar{x}_{\text{cows}} = 0{\cdot}71$ mM/l); 8 weeks *pp* ($\bar{x}_{\text{heifers}} = 0{\cdot}50$ mM/l; $\bar{x}_{\text{cows}} = 0{\cdot}66$ mM/l) ($P < 0{\cdot}01$).

Animals with glucose concentrations within the reference range showed a lower claw-score-increase than animals above the reference range ($\bar{x}_{\text{within ref.}} = \underline{7{\cdot}8} \pm 6{\cdot}9$; $\bar{x}_{\text{above ref.}} = \underline{11{\cdot}8} \pm 10{\cdot}3$) ($P < 0{\cdot}05$). (Cows: $\bar{x}_{\text{above ref. cows}} = 8{\cdot}3 \pm 8{\cdot}3$; $\bar{x}_{\text{within ref. cows}} = 6{\cdot}6 \pm 5{\cdot}9$; n.s.; Heifers: $\bar{x}_{\text{above ref. heifers}} = 15{\cdot}6 \pm 10{\cdot}9$; $\bar{x}_{\text{within ref. heifers}} = 15{\cdot}3 \pm 9{\cdot}6$; n.s.).

For the three farms, differences between farm A and B ($P < 0{\cdot}002$) and between C and B ($P < 0{\cdot}05$) at 3–2 weeks *ap* ($\bar{x}_A = 3{\cdot}75$ mM; $\bar{x}_B = 4{\cdot}04$ mM/l; $\bar{x}_C = 3{\cdot}84$ mM/l) as well as 8 weeks *pp* ($\bar{x}_A = 3{\cdot}71$ mM/l; $\bar{x}_B = 3{\cdot}44$ mM/l; $\bar{x}_C = 3{\cdot}75$ mM/l) ($P < 0{\cdot}005$) were found.

Between cows and heifers, a difference at 1 week *pp* was found ($P < 0{\cdot}001$) ($\bar{x}_{\text{heifers}} = 4{\cdot}09$ mM/l; $\bar{x}_{\text{cows}} = 3{\cdot}54$ mM/l).

Discussion

In the present study, animals with a higher body condition (represented as a higher BFT) had fewer and less severe SH than animals with a lower body condition. If it is assumed that SH are a preliminary stage of lameness, then these results are in line with those of Espejo et al. (2006), Hoedemaker et al. (2009) and Green et al. (2014), who found that under-conditioned cows or cows with BCS < 3

https://doi.org/10.1017/S0022029916000510 Published online by Cambridge University Press

Table 2. Descriptive statistics of backfat-thickness (BFT).

BFT (mm)	Farm A			Farm B			Farm C			All farms		
Examination time	Cows + heifers	Cows	Heifers	Cows + heifers	Cows	Heifers	Cows + heifers	Cows	Heifers	Cows + heifers	Cows	Heifers
3–2 weeks ap												
Median	20	21	15	16	16	15·5	18	19	16	18	20	15·5
25-percentile	16	18	15	13·5	12·5	13·25	13	13	13	15	15	14
75-percentile	25	25	20	19	20	18	24	26·25	22	23	25	20
N	51	40	11	33	9	24	39	26	13	123	75	48
1 week pp												
Median	21	21	14	12	15	12	15	15	14	15	18	13
25-percentile	15	18	12	10	8·5	10	10	10	10·5	11	12	10·25
75-percentile	25	26	21	15	16	14·75	20	18·5	20·5	21	23	15
N	50	39	11	33	9	24	39	26	13	122	74	48
4 weeks pp												
Median	13	13·5	12	10	10	10·5	11	10	11	11	12	11
25-percentile	10	11	9	8·5	8	9	9	7·75	10	9	9	9
75-percentile	15	16	14	11	13	11	13	13	12·5	14	15	12·75
N	51	40	11	33	9	24	39	26	13	123	75	48
8 weeks pp												
Median	10	10	9	8	7	8	9	9	10	9	9	9
25-percentile	8	8	8·75	7	7	7	8	7	8·5	7·75	7	8
75-percentile	13	13	11·75	10	10·5	9·75	12	12	12	12	12	11
N	50	40	10	33	9	24	39	26	13	122	75	47

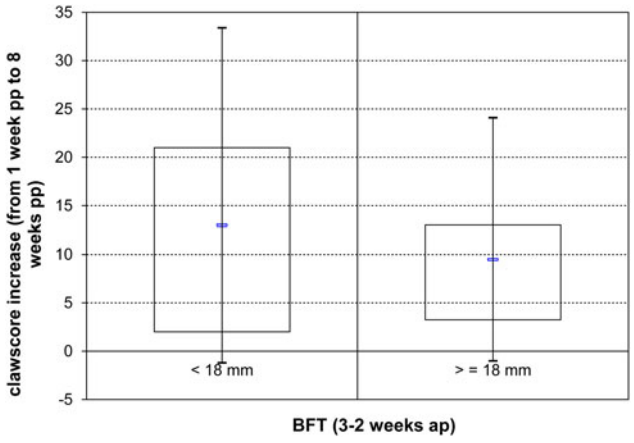

Fig. 1. Differences in claw-score-increase between animals with low back-fat-thickness (BFT) ($n = 55$) and high BFT ($n = 68$).

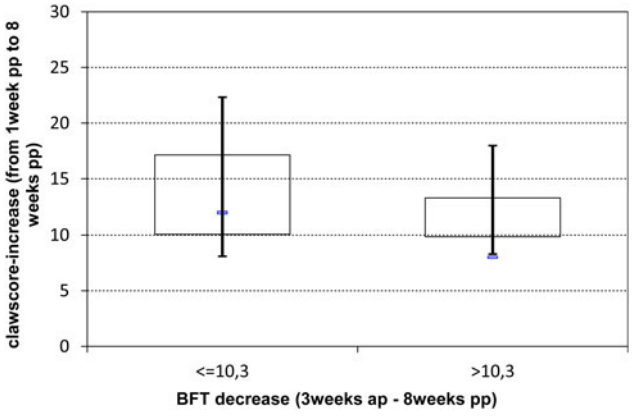

Fig. 2. Differences in claw-score-increase between animals with a higher back-fat-thickness (BFT) decrease (>10·3 mm) ($n = 46$) and animals with a lower BFT decrease (<=10·3 mm) ($n = 77$).

at calving were afflicted more often with lameness than cows with higher BCS, or that cows with BCS < 2·5 had an increased risk of treatment for lameness in the following 4 months. Bicalho et al. (2009) showed that cows with higher BCS had thicker digital cushions with better shock absorbance.

In the present study, animals with high fat mobilisation suffered less from SH than animals with normal fat mobilisation. Thus, a decrease in body fat seems not to have a negative effect on the development of SH in the first 2 months of lactation.

Having demonstrated a strong correlation between BFT at dry off and BFT decline through the first 2 months of lactation, it can be assumed that animals with high fat mobilisation had a higher starting body fat content than animals with normal fat mobilisation. This maybe explains why animals with normal fat mobilisation are more prone to claw disorders. A low body fat content at calving seems to be worse for claw health than is high fat mobilisation in the first 2 months of lactation. This is also confirmed by the observed relationships between blood concentrations of FFA or BHB and claw health. Animals that exceeded the reference values of FFA and BHB in the first week *pp*, that is animals with metabolic disorders like fat mobilisation syndrome and/or ketosis, had fewer claw changes in the first 2 months of lactation than animals that stayed within the

https://doi.org/10.1017/S0022029916000510 Published online by Cambridge University Press

reference range. So, whilst too high fat mobilisation has many negative consequences for the cow, including disturbed reproductive performance, ketosis, milk-fever, mastitis, metritis, dislocation of the abomasum or placental retention (Mulligan & Doherty, 2008), for the claws the outcome seems worse if the cow starts with less body fat reserves in lactation. When considering cows and heifers separately the described relationships can only partially be reproduced (for instance, there is no significance between excessive FFA and claw-score-increase in heifers). This may be due to the absence from the study group of very high BFT heifers.

Considering heifers and cows separately, the connection between higher claw-score-increase and lower BFT decrease is significant only for heifers. Cows with high and normal fat mobilisation showed no difference in the development of SH. Because the heifers started with a lower BFT in lactation than cows, and because the constitution of the digital cushion of heifers is still somewhat rudimentary (Räber et al. 2006), it seems that heifers especially suffer when they have a body condition that is too low. Bicalho et al. (2009) found significantly thinner digital cushions in heifers as well. Possibly cows, with their better constituted digital cushion, are better able to compensate for an insufficient body condition affecting the claws.

When comparing the farms it was noted that both the cows and heifers of farm B had the lowest BFT and the lowest FFA as well as the lowest BHB until 4 weeks *pp*. Low FFA and BHB concentrations suggest a healthy metabolic status, with a low likelihood of fat mobilisation syndrome and ketosis. The finding that the farm with the lowest BFT and FFA/BHB concentrations also had the most SH further supports the results of Espejo et al. (2006), Hoedemaker et al. (2009) and Green et al. (2014), if it is supposed that severe SH are followed by lameness causing claw disorders. However, the different ground surfaces and differences in the feeding rations in the three farms and the high proportion of heifers in farm B should be considered as potential factors contributing to the stronger afflictions observed for farm B animals.

Also, ethological considerations should be discussed. In a herd, newly integrated heifers and animals with low body condition scores have a lower rank. This leads to fewer opportunities for adequate rest, and so the claws are more stressed (Phillips & Rind, 2001; Nordlund & Cook, 2008).

The results of the blood glucose analysis are an indication that *pp* insulin resistance may be contributing to corium changes. Overall, animals with glucose concentrations above the reference value had more SH. There is some evidence that insulin resistance may be connected with laminitis development in horses. For example, Bailey et al. (2008) found an increased incidence of insulin resistance in ponies with laminitis. De Laat et al. (2012) showed an influence of hyperglycaemia and hyperinsulinaemia on the hoof corium of horses. So, it is possible that the claw corium of cows reacts to hyperglycaemia and hyperinsulinaemia in the same way as in horses. However, the occurrence of insulin resistance cannot be concluded on the basis of a high glucose concentration *pp* alone. So, a postulated connection to laminitis has to be verified by further study.

Numerous studies revealed a positive influence of rubber flooring on the health of claws (Platz et al. 2008; Telezhenko et al. 2008; Ouweltjes et al. 2009). For optimal claw health, shock absorption seems to be vital. Thus, internal factors such as fat mobilisation affecting the digital cushion as well as external factors such as flooring surfaces and appropriate claw trimming are important to claw health and seem to be able to compensate each other to a certain extent.

Because there were some crucial differences between the farms regarding flooring conditions, feeding rations and other management factors, the results obtained must be considered as preliminary. Moreover, differences in the routine claw trimming (e.g. claw trimmer, quality of claw trimming, time of last claw trimming) might have influenced the results of this study. Further investigation is required to determine more fully the potential influence of energy metabolism on claw disorders. Also, some strong differences between cows and heifers were revealed. However, to be able to specify the influence of age/lactation number and its connection to energy metabolism on the development of SH, further investigation is needed using animal groups that are closer in size. Thus, the observed results should be considered as a first step towards revealing a potential connection between energy metabolism and development of sole haemorrhages.

The results of this study underline the importance of an optimal body condition at calving on claw health. A too low body condition seems to be worse than one that is too high. The negative sequelae of fat mobilisation syndrome were not detectable in the claws in the first 2 months of lactation. It is surmised that the shock absorbing function of the digital cushion increased with higher body fat content, allowing the higher body weight load to be accommodated by the greater cushioning effect of the claws.

References

ADR. Rinderproduktion in der Bundesrepublik Deutschland 2010 Jahresbericht der Arbeitsgemeinschaft Deutscher Rinderzüchter e.V. [Cattle production in the Federal Republic of Germany 2010. Annual report of the working group of german cattle breeders]. Bonn: Ed. 2011

Andersen PH 2003 Bovine endotoxicosis–some aspects of relevance to production diseases. A review. *Acta Veterinaria Scandinavica Suppl* **98** 141–155

Bailey SR, Habershon-Butcher JL, Ransom KJ, Elliott J & Menzies-Gow NJ 2008 Hypertension and insulin resistance in a mixed-breed population of ponies predisposed to laminitis. *American Journal of Veterinary Research* **69** 122–129

Bergsten C 2003 Laminitis and sole lesions in dairy cows: pathogenesis, risk factors, and precautions. *Acta Veterinaria Scandinavica* **44**(Suppl 1) 58

Bicalho RC & Oikonomou G 2013 Control and prevention of lameness associated with claw lesions in dairy cows. *Lifestock Science* **156** 96–105

Bicalho RC, Machado VS & Caixeta LS 2009 Lameness in dairy cattle: a debilitating disease or a disease of debilitated cattle? A cross-sectional study of lameness prevalence and thickness of the digital cushion. *Journal of Dairy Science* **92** 3175–3184

https://doi.org/10.1017/S0022029916000510 Published online by Cambridge University Press

De Laat MA, Sillence MN, Mcgowan CM & Pollitt CC 2012 Continuous intravenous infusion of glucose induces endogenous hyperinsulinaemia and lamellar histopathology in Standardbred horses. *Veterinary Journal* **191** 317–322

Drackley JK 1999 ADSA Foundation Scholar Award. Biology of dairy cows during the transition period: the final frontier? *Journal of Dairy Science* **82** 2259–2273

Espejo LA, Endres MI & Salfer JA 2006 Prevalence of lameness in high-producing holstein cows housed in freestall barns in Minnesota. *Journal of Dairy Science* **89** 3052–3058

Fischer A 2004 Was steckt hinter der Diagnose Fettmobilisations syndrom [What is behind the diagnosis fat mobilisation syndrom]? *Milchrind* **2** 54–56

Foditsch C, Oikonomou G, Machado VS, Bicalho ML, Ganda EK, Lima SF, Rossi R, Ribeiro BL, Kussler A & Bicalho RC 2016 Lameness prevalence and risk factors in large dairy farms in upstate New York. Model Development for the Prediction of Claw Horn Disruption Lesions. *PLoS ONE* **11**(1) e0146718 doi:10.1371/journal.pone.0146718

Fürll M 2000 Das Fettmobilisationssyndrom [The fat mobilisation syndrom]. *Großtierpraxis* **11** 24–34

Fürll M 2004 Stoffwechselkontrollen und Stoffwechselüberwachung bei Rindern. Teil1: Chancen, Regeln und Risiken [Control of metabolism in cattle. Part 1: chances, rules and risks]. *Nutztierpraxis aktuell* **9** 1–10

Gesellschaft für Ernährungsphysiologie (GfE) (German Society of Nutrition Physiology) 2001 Empfehlung zur Energie- und Nährstoffversorgung der Milchkühe und Aufzuchtrinder [Recommendations of Energy and Nutrient Supply for Dairy Cows and Breeding Cattle]. Frankfurt am Main: DLG-Verlags-GmbH

Green LE, Huxley JN, Banks C & Green MJ 2014 Temporal associations between low body condition, lameness and milk yield in a UK dairy herd. *Preventive Veterinary Medicine* **113** 63–71

Greenough PR & Vermunt JJ 1991 Evaluation of subclinical laminitis in a dairy herd and observations on associated nutritional and management factors. *Veterinary Record* **128** 11–17

Hoedemaker M, Prange D & Gundelach Y 2009 Body condition change ante- and postpartum, health and reproductive performance in German Holstein cows. *Reproduction in Domestic Animals* **44** 167–173

Knott L, Tarlton JF, Craft H & Webster AJF 2007 Effects of housing, parturition and diet change on the biochemistry and biomechanics of the support structures of the hoof of dairy heifers. *Veterinary Journal* **174** 277–287

Lischer C & Ossent P 1994 Klauenrehe beim Rind: eine Literaturübersicht [Laminitis in cattle: a review]. *Tierärztliche Praxis* **22** 424–432

Machado VS, Caixeta LS & Bicalho RC 2011 Use of data collected at cessation of lactation to predict incidence of sole ulcers and white line disease during the subsequent lactation in dairy cows. *American Journal of Veterinary Research* **72** 1338–1343

Mulligan FJ & Doherty ML 2008 Production diseases of the transition cow. *Veterinary Journal* **176** 3–9

Mülling C & Lischer CJ 2002 New aspects on etiology and pathogenesis of laminitis in cattle. In: *Proceedings of the XXII World Buiatric Congress*, pp. 236–247, Hannover, Germany

Nordlund K & Cook N 2008 Dairy cattle behaviour and lameness. In: *Proceedings of the 15th International Symposium & Conference on Lameness in Ruminants*, Kuopio, Finland

Ouweltjes W, Holzhauer M, Van Der Tol PPJ & Van Der Werf J 2009 Effects of two trimming methods of dairy cattle on concrete or rubber-covered slatted floors. *Journal of Dairy Science* **92** 960–971

Phillips CJ & Rind MI 2001 The effects on production and behavior of mixing uniparous and multiparous cows. *Journal of Dairy Science* **84** 2424–2429

Platz S, Ahrens F, Bendel J, Meyer HHD & Erhard MH 2008 What happens with cow behavior when replacing concrete slatted floor by rubber coating: a case study. *Journal of Dairy Science* **91** 999–1004

Räber M, Scheeder MRL, Ossent P, Lischer CJ & Geyer H 2006 The content and composition of lipids in the digital cushion of the bovine claw with respect to age and location – a preliminary report. *Veterinary Journal* **172** 173–177

Schröder UJ 2000 Untersuchungen zur Konditionsbeurteilung mittels ultrasonografischer Messung der Rückenfettdicke als Grundlage zur Anwendung in der Bestandsbetreuung von Milchviehherden [An inquiry into the evaluation of body condition using ultrasonographic measurement of subcutaneous backfat thickness for the use in dairy herd management]. [DISSERTATION]. Berlin, Germany

Schröder UJ & Staufenbiel R 2006 Invited review: methods to determine body fat reserves in the dairy cow with special regard to ultrasonographic measurement of backfat thickness. *Journal of Dairy Sciende* **89** 1–14

Staufenbiel R 1997 Konditionsbeurteilung von Milchkühen mit Hilfe der sonographischen Rückenfettdickenmessung [Evaluation of body condition using ultrasonographic measurement of subcutaneous backfat thickness]. *Der Praktische Tierarzt* **27** 87–92

Telezhenko E, Bergsten C, Magnusson M, Ventorp M & Nilsson C 2008 Effect of different flooring systems on weight and pressure distribution on claws of dairy cows. *Journal of Dairy Science* **91** 1874–1884

Wilhelm K, Wilhelm J & Fürll M 2015 Use of thermography to monitor sole haemorrhages and temperature distribution over the claws of dairy cattle. *Veterinary Record* **176** 146–153

Van Der Tol PPJ, Metz JHM, Noordhuizen-Stassen EN, Back W, Braam CR & Weijs WA 2002 The pressure distribution under the bovine claw during square standing on a flat substrate. *Journal of Dairy Science* **85** 1476–1481

Van Knegsel ATM, De Vries Reilingh G, Meulenberg S, Van Den Brand H, Dijkstra J, Kemp B & Parmentier HK 2007 Natural antibodies related to energy balance in early lactation dairy cows. *Journal of Dairy Science* **90** 5490–5498