Randomised control trial to evaluate the effect of foot trimming before and after first calving on subsequent lameness episodes and productivity in dairy heifers

Sophie A. Mahendran[a*], Jonathan N. Huxley[b], Yu-Mei Chang[a], Mark Burnell[c], David C. Barrett[d], Helen R. Whay[d], Tania Blackmore[a], C.S. Mason[e], and Nicholas J. Bell[a]

[a] *Royal Veterinary College, Hatfield, Herts AL9 7TA. UK*

[b] *University of Nottingham, School of Veterinary Medicine and Science, Sutton Bonington Campus, Loughborough, LE12 5RD. UK.*

[c] *Synergy Farm Health, Evershot, Dorset. DT2 0LD. UK*

[d] *School of Veterinary Sciences, University of Bristol, Langford, Bristol, BS40 5DU*

[e] *Scotland's Rural College (SRUC), Kings Buildings, Edinburgh EH9 3JG, UK*

[*]Corresponding author. Tel.: +44778 4137841

E-mail address: smahendran@rvc.ac.uk

Abstract

The objective of this study was to assess both independent and combined effects of routine foot trimming of heifers at 3 weeks pre-calving and 100 days post calving on the first lactation lameness and lactation productivity. A total of 419 pre-calving dairy heifers were recruited from one heifer rearing operation over a 10-month period. Heifers were randomly allocated into one of four foot trimming regimens; pre-calving foot trim and post-calving lameness score (Group TL), pre-calving lameness score and post-calving foot trim (Group LT), pre-calving foot trim and post-calving foot trim (Group TT), and pre-calving lameness score and post-calving lameness score (Group LL, control group). All heifers were scored for lameness at 24 biweekly time points for 1 year following calving, and first lactation milk production data were collected.

Following calving, 172/419 (41.1%) of heifers became lame during the study (period prevalence), with lameness prevalence at each time-point following calving ranging from 48/392 (12.2%) at 29–42 days post-calving to 4/379 (1.1%) between 295 and 383 days after calving. The effects of the four treatment groups were not significantly different from each other for overall lameness period prevalence, biweekly lameness point prevalence, time to first lameness event, type of foot lesion identified at dry off claw trimming, or the 4% fat corrected 305-day milk yield. However, increased odds lameness was significantly associated with a pre-calving trim alone ($P = 0.044$) compared to the reference group LL. The odds of heifer lameness were highest between 0 and 6 weeks post-partum, and heifer farm destination was significantly associated with lameness (OR 2.24), suggesting that even at high standard facilities, environment and management systems have more effect on heifer foot health than trimming.

Key words

Heifer, lameness, prophylactic foot trimming, productivity

Introduction

Lameness and deterioration in claw health observed during the first lactation (Offer et al., 2000) is likely to contribute to poor longevity, high recurrence of foot lesions between lactations (Hirst et al., 2002), reduced milk yield, poor fertility (Hernandez et al., 2005) and increased likelihood of culling (Sogstad et al., 2007). Claw horn lesion development in dairy heifers can occur pre-calving (Livesey et al., 1998), with concurrent high levels of claw horn pathology present in early lactation (Webster, 2001) and lameness at 50–100 days post-partum is common (Ettema, Ostergaard, 2006 ; Maxwell et al, 2015). Since lameness occurs frequently in heifers, pre-calving foot inspection might reduce subsequent lameness around in the periparturient period.

The main cause of bovine lameness is foot lesions (Murray et al., 1996), and one proposed method of managing foot health is routine foot trimming, aiming to maintain correct weight bearing for optimal function, and to minimise and prevent lesion development (Manske et al., 2001). However, the evidence-base for the regimens used is sparse (Manning et al., 2016).

Locomotion scoring is the main method used to detect lameness, and previous work has demonstrated the low prevalence of proximal limb lameness (Murray et al., 1996). Lesions causing lameness on subsequent foot examination have been reported in lactating dairy cows with a locomotion score of 2 (Groenevelt et al., 2014). These lesions respond best to treatment with non-steroidalanti-inflammatory drugs and the application of a block to a sound claw (Thomas et al., 2014). These reports support the assumption that most lameness detected using mobility scoring is foot lesion-related and potentially manageable using claw trimming methods.

The primary objective of the study was to assess both the independent and combined effects of routine foot trimming in heifers at 3 weeks pre-calving and 100 days post calving on the first lactation lameness and lactation productivity. The hypothesis was that there would be a significant difference between the control group (biweekly lameness score only) and groups containing heifers that received foot trimming either pre-calving and/or post-calving with respect to lameness prevalence, 305-day first lactation milk yield, and/or time to conception.

Materials and Methods

Study Design

A negatively controlled randomised clinical trial (RCT) was used to compare the effect of pre- and post-calving foot trimming regimens on subsequent lameness events and production during the first lactation. The trial protocol was reviewed and approved by the Ethical Review Committee of the Royal Veterinary College (Approval number, URN 2013 1255; January 2014). Sample size calculations based on detecting a 25% difference in lameness prevalence at 80% power and 5% significance yielded a group size of 43 heifers per group (PS power and sample size calculations, Version 3, 2009).

Herd Selection

One dairy farm business (Dorset, UK), comprising two dairy herds, was used for the study, and Holstein dairy heifers calved between November 2013 and September 2014. A heifer was defined as a female bovine that was due to calve for the first time during the study period; the animal ceased being a heifer at dry off, culling or death during first lactation. Before first calving, heifers were reared at grass during the summer and housed in winter in sand bedded cubicles. At 3 weeks pre-calving, heifers were moved into a transition group at the calving unit, housed in sand bedded cubicles together with multiparous cows, and calved in a loose housed straw yard. Heifers joined one of two milking herds post-partum, located at two different sites. Both dairies operated a continuous housing system for lactating cows with deep sand beds in Super Comfort Sand Stall cow cubicles (IAE, UK). Cows were milked 3 times a day through a rotary parlour, and fed on a total mixed ration. Farm 1 was a high yielding (11,500 L) dairy, with high foot wear due to large walking distances and a lot of concrete flooring, and was where all heifers calved. Farm 2 was a new build, high yielding (10,000 L) dairy, with very high foot wear due to newly laid concrete, and was located approximately 7 km from Farm 1. The destination of heifers was determined at calving by the owner and herd manager who were masked to treatment group allocations and made location selection without animal inspection.

<u>Allocation to treatment group</u>

The study interventions were conducted at the individual animal level, with each heifer treated as an independent unit. Heifers were excluded from enrolment if they had previously been lame or were lame at the time of enrolment (3 weeks pre-calving). Heifers were randomly allocated to one of the four treatment groups using random sequences generated by computer software (Excel 2007, Microsoft). The groups were as follows: pre-calving foot trim and post-calving lameness score (Group TL), pre-calving lameness score and post-calving foot trim (Group LT), pre-calving foot trim and post-calving foot trim (Group TT) and pre-calving lameness score and post-calving lameness score (Group LL, control group; Fig. 1).

Heifers not present in the transition group at the pre-calving foot trimming were randomly re-allocated to either Group LT or Group LL, a modification introduced during the trial. Randomisation was performed using random sequences generated by computer software (Excel 2007, Microsoft). Reasons for heifers not being present in the transition group included overstocking of the shed or a change in the day that heifers were moved into the transition group to a day that the foot trimmer was unavailable.

<u>Foot trimming and lameness scoring</u>

Foot trimming visits were carried out every 2 weeks from 1 November 2013 until 30 November 2014. Heifers in a treatment group that were due to receive a foot trim

(Groups TL, LT, TT) had all four feet examined in a hydraulic upright foot crush (HTL Hydraulic Crush, Hooftrimming). Heifers allocated to Group LL did not have their feet lifted or examined. The foot trimming was carried out by one professional foot trimmer (Dutch Diploma Holder) following the Dutch Five Step method (Toussaint Raven, 1985), with deep and wide dishing out at the sole ulcer site consistent with a modification proposed by Burgi and Cook (2008). A conservative trimming method was used which preserved sole depth and walls, and no trimming was carried out unless detectable overgrowth required correction, thereby avoiding overtrimming.

Any heifers identified as lame before entering the trimming crush was treated using a standardised protocol, irrespective of study group allocation. Any digital dermatitis lesions identified was treated with chlortetracycline spray (Cyclo spray, Dechra Veterinary Products). Claw horn lesions were treated with wooden blocks applied to the sound claw with an adhesive bond to the sole (Mini Moo Gloo, Moogloo), and corrective trimming with loose and under-run horn removed according to Mahendran and Bell (2015). Non-steroidal anti-inflammatory drugs were not administered.

Locomotion was assessed in all heifers at 3 weeks pre-calving, and then biweekly every 14 ± 3 days for 1 year post-calving (producing 24 biweekly locomotion scores). Scoring was conducted using a modified version of the Agriculture and Horticulture Development Board (AHDB) Dairy mobility score (locomotion scores of 0, 1, 2a, 2b, 3a, or 3b; Thomas et al., 2015). Briefly, heifers with score 0 walked with a normal gait; heifers with score 1 had uneven steps but the leg was not immediately identifiable; heifers with score 2a had mild asymmetry with a decreased stride length; heifers with score 2b had moderate asymmetry with a raised back; heifers with score 3a had severe asymmetry with reduced walking velocity so they were unable to keep up with the healthy herd; and heifers with score 3b were minimally weight-bearing and reluctant to walk. Locomotion scoring was carried out by a single trained observer (SAM) who was effectively masked to the treatment group by virtue of the small number of heifers joining large milking groups. When a heifer was identified as lame (locomotion score 2a, 2b, 3a or 3b), the farmer was informed and any further treatments were conducted at the farmer's discretion, while heifers remained in the study.

Production data

Milk yield and fertility data were extracted from monthly milk recordings collected by a single company (National Milk Records, Chippenham, UK) and by using on-farm management software (Dairy Comp 305, Valley Agricultural Software, USA). A 4% fat corrected 305 day milk yield was calculated using the formula reported by Gaines & Davidson (1923).

Outcome measures of lameness

Never vs. ever lame

The 48-week period prevalence was defined as the proportion of heifers that went lame during the 48-week time period, using the number of heifers present at the beginning of the study period as the denominator.

Proportion of time lame during the study period

This proportion was defined as the number of locomotion scores (>1) during the 24 biweekly locomotion scores following parturition, divided by the total number of locomotion score observations recorded during the study period for each heifer. Heifers exiting the study received biweekly locomotion scoring until their removal from the farm.

Lameness point prevalence at each biweekly period

This was calculated as the total number of heifers that were lame at each specified biweekly time point, divided by the total number of heifers present at that time point.

Statistical analysis

Binary logistic regression was used to assess the effects of treatments and farm on lameness outcome. Binomial logistic regression was used to assess the effects of treatments and farm on the proportion of time lame in the first lactation. Generalised estimating equations with logit link function were used to assess the effects of treatments, farm and time on the outcome of lameness, which accounted for the repeated measures of locomotion scores. Cox regression was used to evaluate effects of treatment and farm on time to first lameness event, and time to conception for heifers that became pregnant. A general linear model was used to assess whether treatment groups and farms had any effect on the 4% fat corrected 305-day yield.

All analyses were conducted using SPSS (SPSS version 21, Lead Technologies, 2012). Type I error rate was set at 5%.

Results

Study inclusions and exclusions

A total of 419 heifers were recruited between 1 November 2013 and 30 September 2014 (Table 1); 188 heifers were milked in Farm 1 and 231 were heifers milked in Farm 2. Nineteen heifers were excluded due to lameness at 3 weeks pre-calving. Fifty-five heifers not in the transition group at the inspection 3 weeks before calving were randomly re-allocated to group LT or LL (27 heifers re-allocated from Group TL, and 28 heifers reallocated from Group TT). Randomisation was performed using random sequences generated by computer software (Excel 2007, Microsoft). Forty-eight heifers (11%) were lost to follow-up (culled or died); 25 were lost from Farm 1 and 23 from Farm 2. Detailed information on why heifers were lost was not available. Locomotion score data were collected for animals present, with no additional missing data, which was achievable because locomotion scoring was conducted during milking on a rotary parlour with a steady exit flow rate, so every heifer could be seen and scored. A total of 259/419 heifers conceived and were identified as pregnant during the first lactation.

Overall period prevalence of heifer lameness

A total of 172 heifers had a locomotion score of >1 after calving. There was an overall 48-week period prevalence of 41.1% across treatment groups; no significant effect of seasonality was detected ($P = 0.471$). The most common locomotion score was 2a, and only one heifer had the most severe locomotion score (3b) during the study period (Table 2).

There was no significant effect of treatment group on development of lameness ($P = 0.669$). Group hazard ratios (HR) are shown in Table 3. Prevalence of lameness was higher at Farm 2 (48.9% vs. 31.4%; $P < 0.001$). There was no significant interaction between farm and treatment group ($P = 0.322$), with the treatment group not significantly affecting the duration of time for which heifers were lame during the 48 week follow-up period ($P = 0.094$), although TL had higher odds of lameness compared to LL (OR = 1.29, 95% CI, 1.01–1.65; $P = 0.044$; Table 3). Of all the lameness events recorded, 76/172 (44.2%) of heifers had only a single lameness event in the entire 48-week follow-up period.

The lameness point prevalence measures differed significantly over the 24 biweekly periods (overall P-value <0.001), and there was a significant effect of farm ($P = 0.005$), but treatment group was not statistically significant ($P = 0.726$). The first 42 days following calving was the time of highest lameness risk (Fig. 2).

The total time at risk for all heifers was 272.6 years; lameness incidence was 0.63 new cases per heifer per year (Table 4). Cox regression analyses demonstrated that farm was significantly associated with time to development of first lameness (HR, 1.797; 95% CI, 1.312–2.462; $P < 0.001$), but treatment group was not (HR, 0.905; 95% CI, 0.792–1.035; $P = 0.527$).

Type of lesions detected at the dry-off trim

Of 371 heifers, 287 (77.4%) had no lesions detected at trimming. A total of 50/371 heifers (13.5%) had detectable sole haemorrhage or thin soles, and 70% (35/50) of those were located at Farm 2.

Milk production

Treatment did not affect the 4% fat corrected 305-day yield ($P = 0.104$), although farm ($P < 0.001$) and the days in milk at conception ($P < 0.001$) were significantly associated with this outcome measure. The mean difference in 4% fat corrected 305-day yield was 925 ± 238L between farms.

Time to conception

There was no effect of farm (HR, 0.651; 95% CI, 0.403–1.295; $P = 0.121$) or treatment (HR, 0.545; 95% CI, 0.084–3.547; $P = 0.559$) on time to conception. Among the 259 pregnant heifers, median time to conception was 85 days and 70 days for those 'never' and 'ever' lame during the study period, respectively.

Discussion

Preventing lameness in heifers is a critical control point due to the high prevalence of lesions (Bell et al., 2009), the deterioration in foot health that occurs during first lactation (Offer et al., 2000), increased risk of recurrence of lameness in subsequent lactations (Hirst et al., 2002), and premature culling (Sogstad et al., 2007) that occurs in lame heifers. Routine foot trimming of dairy cows and heifers is now a widespread practice, although the evidence base for their effective use is minimal (Potterton et al, 2012; Manning et al, 2016).

Our study evaluated the effect of foot trimming heifers in a high claw wear environment at 3 weeks pre-calving and 100 days post-calving (both independently and in combination) to assess the impact of foot trimming on subsequent lameness occurrence and productivity. There was no significant difference in lameness period prevalence ($P = 0.669$), lameness point prevalence ($P = 0.726$), or time to first lameness event between treatment groups ($P = 0.527$). However, a pre-calving trim alone significantly increased ($P = 0.044$) the proportion of lame heifers during the first lactation compared to the control group, and this increase occurred consistently across the follow-up period. Consequently, we concluded that the prophylactic trimming interventions used in this study did not have beneficial effects on post-calving heifers when compared to the control group (lameness scoring only). Since this deleterious effect was not seen in Group TT (pre-calving foot trim and post-calving foot trim), we suggest interpreting this finding cautiously, especially given the confidence interval calculated (Table 3; OR, 1.29; 95% CI, 1.01–1.65; $P = 0.044$). The Dutch Five Step claw trimming method used aimed to conserved sole depth, but this may not have been sufficient to prevent thin soles and bruising exacerbated by new concrete and sand on Farm 2; the relationship between concrete flooring and thin soles has previously been reported in the literature (van Amstel et al., 2004). This suggests that on farms where the prevalence of thin soles is high, preventative trimming techniques might not be suitable, but reducing the excessive rate of wear might be beneficial. Abrasive concrete causes increased sole wear, leading to sole thinning and predisposing to contusions due to a lack of protection of the sensitive corium by the thin sole. However, these contusions can be responsive to appropriate trimming treatments (Groenevelt et al, 2014; Thomas et al, 2015). It is important that the timing and technique of trimming is appropriate to individual farm conditions, and the term 'foot inspection' is preferred to 'foot trimming' to encourage sole depth conservation rather than following routine trim protocols or seeking to achieve an aesthetically pleasing finish.

The maximum point prevalence detected in this study was 12.2% (standard error of the mean [SEM], 1.7%) between 29 and 42 days post-partum (Fig. 2), which agrees with previously reported data for UK dairy heifers (6–37%; Maxwell et al., 2015). This pattern of increased prevalence of lameness over the first 6 weeks post-partum suggests a severe deterioration in foot health through the post-calving transition period until the time of peak lactation. Changes in the suspensory apparatus in the periparturient period challenge foot health (Tarlton, et al., 2002) and the loss of the digital cushion could also be involved in the development of claw lesion.

The 48-week period prevalence for lameness in our study was 41.1%. This is the first report detailing the extent to which heifer populations are affected by lameness; lameness was also more prevalent than previously described in multiparous cows. However, 76/172 (44.2%) of the affected heifers had a single lameness event, in agreement with others who have reported transient and fluctuating lameness (Groenevelt et al., 2014). Apparent self-cure in the absence of treatment is common in the early stages of lameness before clinically recognisable foot lesions appear. This has been previously explained by the resolution of sole bruising through rest, or by resolution of digital dermatitis through footbathing (Relun et al., 2012). This suggests that the proportion of lameness scores 2 and 3 was the simplest and most appropriate outcome measure for this study, particularly on a farm where problems with sole haemorrhage and thin soles were more prevalent than sole ulcers or white line lesions in primiparous heifers, a pattern typical on well managed units with good lameness detection.

The most common lesions at drying off were sole haemorrhage and thin soles, and 70% of these reported lesions occurred on Farm 2. These lesions could have been under-recorded in other studies, which might explain the apparent lack of lameness prevention in our study compared to previous reports, due to the high prevalence of thin sole lesions.

In our study, there was no significant difference in the 4% fat corrected 305-day milk yield or calving to conception interval between treatment groups. However, lame heifers had a mean increase in calving to conception interval of 15 days, which confirms the study by Hernandez et al. (2007), who reported 3.5 increased odds of delayed ovarian cyclicity compared to non-lame animals.

The absence of 55 heifers from the transition group at 3 weeks pre-calving and their subsequent random re-allocation to treatment groups LT and LL was a limitation of the study design. While this was not intended, we have no reason to suspect that this reallocation unbalanced the groups with respect to potential confounders, as it was simply a consequence of maintaining suitable stocking densities in the transition group. Further work is needed to investigate which heifer foot trimming regimen, if any, would be most suitable in different claw wear scenarios, the effect of trimming style on lameness prevention, and whether foot trimming can provide long-term protection against pathology such as new bone formation on the third phalanx (Newsome et al., 2015).

A modified AHDB locomotion score was used in our study (Thomas et al., 2015), with scores of 2 and 3 being defined as clinically lame. Scoring can inform the therapeutic management of lameness (Groenevelt et al., 2014), and with appropriate training, high within-observer agreement of scoring is possible (Garcia et al., 2015). Using repeated scoring at 2-week intervals, it is possible to standardise lameness detection for the calculation of robust incidence rates, rather than relying on detection by farmers, which is inherently variable between farms and people (Groenevelt et al., 2014). Our study used biweekly scoring rather than monthly scoring as described by Green et al. (2002), partly in an effort to improve accuracy, but also because delays in treatment initiation associated with monthly scoring has been shown to reduce recovery rates (Thomas et al., 2015). Further work is required to explore variations in the accuracy and precision of lameness and lesion detection using biweekly screening, but most studies, including ours, are primarily limited by lesion diagnosis, since lesions such as sole ulcers can take several weeks to manifest.

While no routine foot trimming regimen was protective in our study, trimming did not have a significant deleterious effect on the prevalence of lameness, apart from in Group TL (pre-calving foot trim and post-calving locomotion score), and there was no effect on production performance compared to the control group. Therefore, despite our findings, if lameness and severe claw lesion prevalence is high and lameness scoring is not feasible, routine claw inspection could remain a viable alternative to general observation for lameness or fortnightly lameness scoring.

Conclusions

No beneficial effect of a pre-calving or post-calving foot trimming regimen was detected in this controlled study, which used various lameness outcome measures including period prevalence, point prevalence, or time to index lameness event during the first lactation. The proportion of lameness in the pre-calving foot trimming group (Group TL) was significantly higher than in the control group. This indicates that routine lameness screening using locomotion scoring could be preferable to routine trimming in some units for the management of heifer lameness. The protocol used should be appropriate to individual farm conditions, taking into account the availability of trained staff to carry out foot trimming or lameness scoring, cow comfort level, level of foot exposure to concrete, and heifer group sizes. The greatest risk period for heifer lameness was 0–6 weeks post-partum, suggesting potential for more targeted intervention and monitoring of health status during this period. Further work is required to investigate whether there are significant benefits of foot trimming in more traditional dairy housing systems.

Acknowledgments

Thanks go to the Dartington Cattle Breeding Trust for funding the project, to Synergy Farm Health and their foot trimmer Dave Phillips for the on-farm support and trimming, to the

Dairy Group used in the project, to the farm owner and his staff, and to Karl Burgi for his technical advice.

Table legend:

Table 1: Distribution and performance of heifers in each of the four treatment groups in the trial designed to investigate foot trimming interventions before and after first calving in dairy heifers.

Variable	TL	LT	TT	LL
Number of heifers enrolled in each group	79	132	77	131
Number of heifers lost to follow-up and excluded from analysis	10	15	7	17
Proportion of heifers in each group at Farm 1 (%)	41.8	49.2	37.7	46.6
Lameness 48-week period prevalence (%)	46.8	40.2	42.9	37.4
4% fat corrected 305-day milk yield ± SEM (L)	8491 ± 272	8759 ± 203	9035 ± 290	9308 ± 245
Days to conception ±SEM	95.5 ± 7.4	105.4 ± 7.2	86.3 ± 6.8	98.6 ± 6.7

TL, pre-calving foot trim and post-calving locomotion score; LT, pre-calving locomotion score and post-calving foot trim; TT, pre-calving foot trim and post-calving foot trim; LL, pre-calving locomotion score and post-calving locomotion score (control); SEM, standard error of the mean.

Table 2: Proportion of lameness scores within each of the lameness scoring classes (Thomas et al., 2015) as a percentage of the total number of lameness observations in that group, presented for the four treatment groups and the two farms in a trial designed to investigate foot trimming interventions before and after first calving in dairy heifers.

	Lameness score 0 (%)	Lameness score 1 (%)	Lameness score 2a (%)	Lameness score 2b (%)	Lameness score 3a (%)	Lameness score 3b (%)
Group TL	91.1	2.1	3.8	2.3	0.7	0.1
Group LT	93.5	1.6	3	1.8	0.2	0
Group TT	91.9	1.8	3.5	2.4	0.3	0
Group LL	93	1.7	3.6	1.3	0.3	0
Farm 1	95.1	1.5	2	1.2	0.2	0
Farm 2	90.5	2	4.5	2.3	0.6	0.1
Overall	92.8	1.8	3.3	1.8	0.4	0.1

TL, pre-calving foot trim and post-calving locomotion score; LT, pre-calving locomotion score and post-calving foot trim; TT, pre-calving foot trim and post-calving foot trim; LL, pre-calving locomotion score and post-calving locomotion score (control).

Table 3: Association between treatments and lameness assessment based on different lameness measurements. All analyses have adjusted for farm effect. Binary logistic regression, binomial logistic regression, generalised estimating equations for repeated binary measures and Cox regression were employed for these four analyses.

	Binary logistic regression: lameness period prevalence over 48-week period	Generalised estimating equation: proportion of time being lame over 48-week period	Binomial logistic regression: presence or absence of lameness at each biweekly period	Cox regression: time to first lameness event
	OR (95% CI)	OR (95% CI)	OR (95% CI)	HR (95% CI)
LL	Reference	Reference	Reference	Reference
TL	1.44 (0.81–2.56)	1.29 (1.01–1.65)	1.38 (0.74–2.57)	1.38 (0.90–2.12)
LT	1.15 (0.69–1.90)	0.96 (0.76–1.22)	1.26 (0.73–2.18)	1.14 (0.77–1.68)
TT	1.18 (0.66–2.12)	1.14 (0.88–1.47)	1.36 (0.72- 2.56)	1.18 (0.76–1.83)

TL, pre-calving foot trim and post-calving locomotion score; LT, pre-calving locomotion score and post-calving foot trim; TT, pre-calving foot trim and post-calving foot trim; LL, pre-calving locomotion score and post-calving locomotion score (control); OR, odds ratio; 95% CI, 95% confidence intervals; HR, hazard ratio.

Table 4: Overall heifer lameness incidence rate (new lameness cases per heifer per year) for the four treatment groups and the two farms.

Treatment group	Denominator time at risk (years)	Index lameness events	Incidence (new lameness cases per heifer per year)
Group TL	46.3	37	0.8
Group LT	89.4	53	0.59
Group TT	48.1	33	0.68
Group LL	88.8	49	0.55
Farm 1	130.5	59	0.45
Farm 2	142.1	113	0.8

TL, pre-calving foot trim and post-calving locomotion score; LT, pre-calving locomotion score and post-calving foot trim; TT, pre-calving foot trim and post-calving foot trim; LL, pre-calving locomotion score and post-calving locomotion score (control).

Figure legends:

Figure 1: Flow chart representing events for each treatment groups at specified intervention times. LS, locomotion score; Tr, foot trim; TL, pre-calving foot trim and post-calving locomotion score; LT, pre-calving locomotion score and post-calving foot trim; TT, pre-calving foot trim and post-calving foot trim; LL, pre-calving locomotion score and post-calving locomotion score (control).

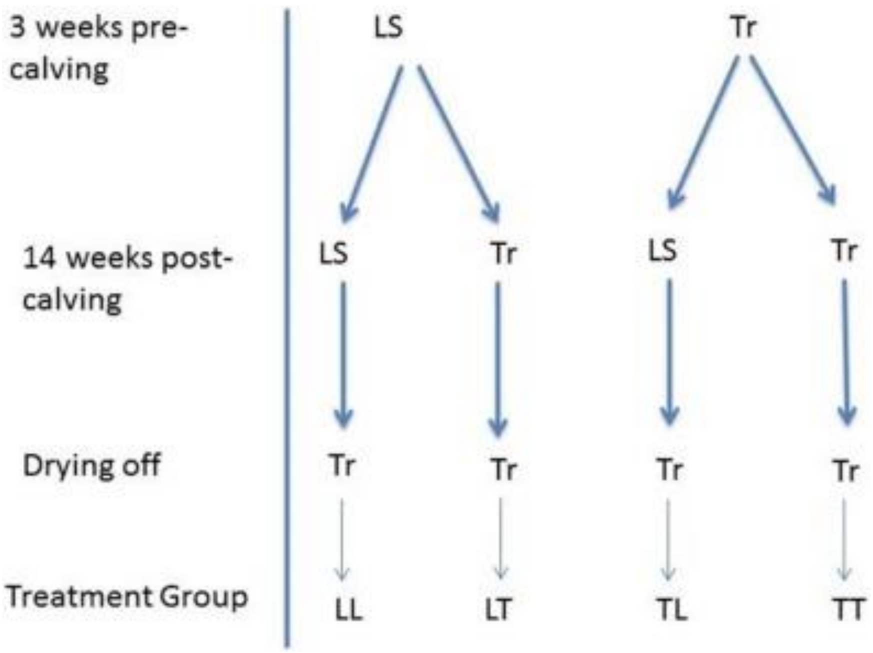
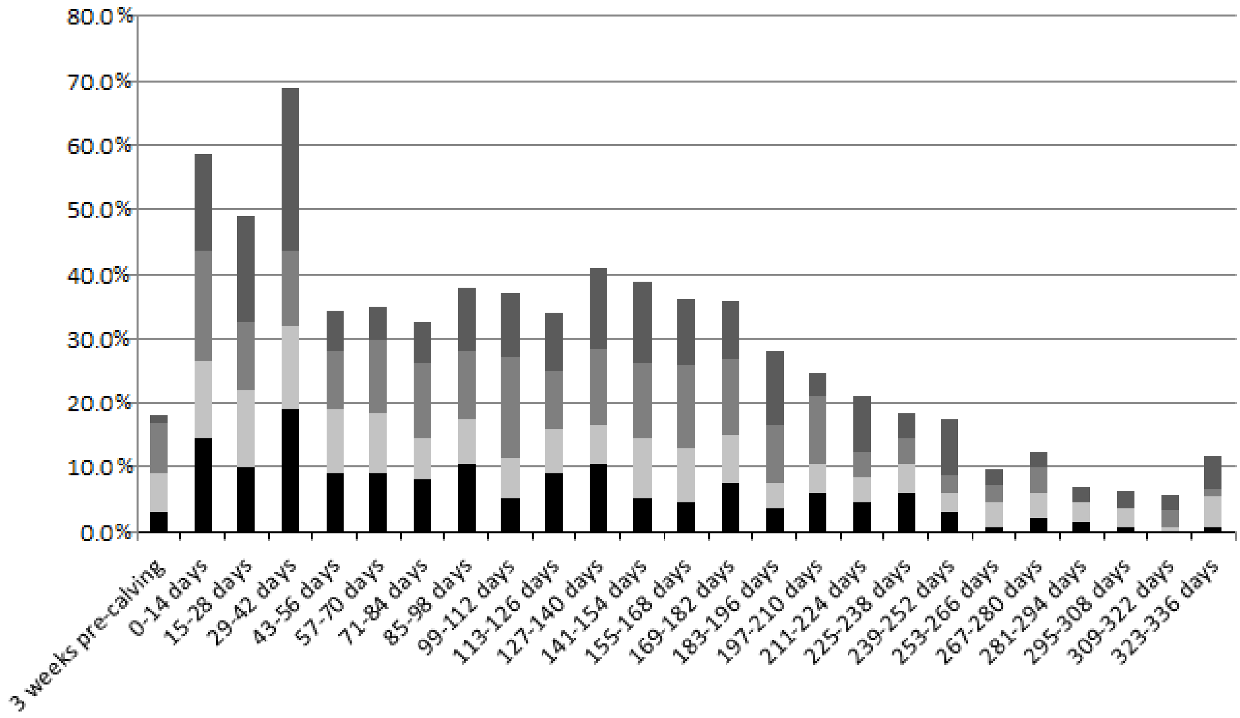


Figure 2: Lameness point prevalence (%) throughout the first lactation recorded at each of the 24 biweekly lameness scores.



References

Bell, N. J. et al., 2009. The development, implementation and testing of a lameness control programme based on HACCP principles and designed for heifers on dairy farms. *The Veterinary Journal,* Volume 180, pp. 178-188.

Burgi, K. & Cook, N. B., 2008. *Three adaptions to the functional trimming method.* Kuopio, Finland, Proceedings 7th conference of lameness in ruminants.

Ettema, J. F. & Ostergaard, S., 2006. Economic decision making on prevention and control of clinical lameness in Danish dairy herds. *Livestock Science*, Volume 102, pp. 92-106.

Gaines, W. L. & Davidson, F. A., 1923. Relation between percentage fat content and yield of milk: Correction of milk yield for fat content. *Bulletin* No. 245, The University of Illinois, USA, pp. 594.

Garcia, E. et al., 2015. Experienced and inexperienced observers achieved relatively high within-observer agreement on video mobility scoring of dairy cows. *Journal of Dairy Science,* Volume 98, pp. 4560-4571.

Green, L. E. et al., 2002. The impact of clinical lameness on the milk yield of dairy cows. *Journal of Dairy Science,* Volume 85, pp. 2250-2256.

Green, L. E., Huxley, J. N., Banks, C. & Green, M. J., 2014. Temporal associations between low body condition, lameness and milk yield in a UK dairy herd. *Preventive Veterinary Medicine,* Volume 113, pp. 63-71.

Groenevelt, M. et al., 2014. Measuring the response to therapeutic foot trimming in dairy cows with fortnightly lameness scoring. *The Veterinary Journal,* Volume 201, pp. 283-288.

Hernandez, J. A. et al., 2005. Comparison of milk yield in dairy cows with different degrees of lameness. *Journal of the American Veterinary Medical Association.*

Hernandez, J. A. et al., 2007. Evaluation of the efficacy of prophylactic hoof health examination and trimming during midlactation in reducing the incidence of lameness during late lactation in dairy cows. *Journal of the American Veterinary Medical Association,* Volume 230, pp. 89-93.

Hirst, W. M., Murray, R. D., Ward, W. R. & French, N. P., 2002. A mixed-effect time-to-event analysis of the relationship between first-lactation lameness and subsequent lameness in dairy cows in the UK. *Preventive Veterainry Medicine,* Volume 54, pp. 191-201.

Livesey, C. T. et al., 1998. The effect of diet and housing on the development of sole haemorrhages, white line haemorrhages and heel erosions in Holstein heifers. *Animal Science,* Volume 67, pp. 9-16.

Mahendran, S. A. & Bell, N. J. Managing claw health in dairy cows and heifers through appropriate trimming techniques. *In Practice*, Volume 37, pp. 231-242.

Manning, A., Mahendran, S. A. & Bell, N. J., 2015. Evidence base behind foot trimming in UK dairy cattle. *Livestock,* 21(1), pp. 6-14.

Manning, A., Mahendran, S. A. & Bell, N. J., 2016. Evidence base behind foot trimming in UK dairy cattle. *Cattle Practice.*

Manske, T., Hultgren, J. & Bergsten, C., 2001. The effect of claw trimming on the hoof health of Swedish dairy cattle. *Preventative Veterinary Medicine.*

Maxwell, O. J., Hudson, C. D. & Huxley, J. N., 2015. Effect of early lactation foot trimming in lame and non-lame dairy heifers: a randomised controlled trial. *Veterinary Record,* Volume 177.

Murray, R. D. et al., 1996. Epidemiology of lameness in dairy cattle: Description and analysis of foot lesions. *Veterinary Record*, Volume 138, pp.586-591.

Newsome, R. et al., 2015. Linking bone development on the caudal aspect of the distal phalanx with lameness during life. *Journal of Dairy Science*, Volume 99, pp. 4512-4525.

Offer, J. E., MvNulty, D. & Logue, D. N., 2000. Observations of lameness, hoof conformation and devlopement of lesions in dairy cattle over four lactations. *Veterinary Record,* Volume 147, pp. 105-109.

Potterton, S. L. et al., 2012. A descriptive review of the peer and non-peer reviewed literature on the treatment and prevention of foot lameness in cattle published between 2000 and 2011. *The Veterinary Journal,* Volume 193, pp. 612-616.

Relun, A., Lehebel, A., Bareille, N. & Guatteo, R., 2012. Effectiveness of different regimens of a collective topical treatment using a solution of copper and zinc chelates in the cure of digital dermatitis in dairy farms under field conditions. *Journal of Dairy Science*, Volume 95, pp. 3722-3735.

Sogstad, A. M., Osteras, O., Fjeldass, T. & Nafstad, O., 2007. Bovine claw and limb disorders related to culling and carcass characteristics. *Livestock Science,* Volume 106, pp. 87-95.

Tarlton, J. F. et al., 2002. Biomechanical and histopathological changes in the support structures of bovine hooves around the time of first calving. *The Veterinary Journal,* Volume 163, pp. 196-204.

Thomas, H. J. et al., 2014. Evaluation of treatments for claw horn lesions in dairy cows in a randomized controlled trial. *Journal of Dairy Science,* Volume 98, pp. 4477-4486.

Toussaint Raven, E., 1985. The principles of calw trimming. *Veterinary Clinics of North America Food Animal Practice,* Volume 1, pp. 93-107.

van Amstel, S. R., Shearer, J. K. & Palin, F. L., 2004. Moisture Content, Thickness, and Lesions of Sole Horn associated with thin soles in dairy cattle. *Journal of Dairy Science,* Volume 87, pp. 757-763.

Webster, A. J., 2001. effects of housing and two forage diets on the development of claw horn lesions in dairy cows at first calving and first lactation. *Veterinary Journal,* pp. 56-65.