Dairy cattle lameness in New Zealand: Defining the problem and investigating preventative and treatment strategies

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Abstract

Lameness is ranked in the top three most important animal health diseases in dairy cattle worldwide, and has significant negative impacts on animal welfare, farm productivity, greenhouse gas emissions and the social license to dairy farm. Despite this, there has been an under-investment in research into lameness in New Zealand over the past three decades.

This thesis aimed to fill some of the gaps in knowledge of dairy cattle lameness in New Zealand by addressing three overarching goals; to define the extent of lameness on New Zealand dairy farms, to improve the treatment of claw-horn lameness and to prevent new cases of lameness. To define the extent of lameness, the prevalence and duration of lameness were assessed. The prevalence of lameness across 120 dairy farms across eight regions was assessed by trained observers collecting lameness scores of the lactating cattle at two time points over a season. The time to soundness following industry-recommended lameness treatment protocols for claw-horn lameness was also reported from five farms in the Waikato. The median farm level prevalence was 2.8% (interquartile range 1.5 – 4.5%) and median time to soundness 18 (interquartile range 14 - 21) days. Both these outcomes provide confidence that the New Zealand dairy industry are world-leaders when it comes to lameness control, and that appropriate lameness treatment strategies can result in rapid cure rates. However, a large range in farm-level lameness prevalence (0 – 17% on any given day) and differences in cure rates between farms were reported, both suggesting strong farm-level risk factors for lameness.

To improve the treatment of lameness, consistent evidence-based advice is required. Non-steroidal anti-inflammatory drugs (NSAIDs) are recommended for painful and inflammatory conditions of dairy cattle. However, the use and advice given for NSAIDs with respect to lame cow treatment is varied. A systematic review of the evidence for NSAID use as part of the treatment of claw-horn lameness was undertaken. Little evidence exists on the benefit of NSAID treatment in isolation at improving lameness cure rates. However, when NSAID are used in conjunction with hoof blocks and early identification of lameness, time to lameness cure can reduce by half. Most farmers (77%) surveyed relied on informal identification of lame cows by farm staff, and few had formal lameness policies implemented on

farm. As response to NSAID, and improved lameness cure rates in general, revolve around early identification of lameness on farm, these are areas of improvement that dairy farmers should focus on.

Preventative measures for lameness were addressed via three objectives; identifying farm-level risk factors for lameness, investigating a practical pre-calving heifer intervention to reduce lameness incidence and exploring the barriers to lameness control and the motivators for lameness control as reported by farmers. From a questionnaire of 119 of the 120 farmers enrolled into the prevalence study, the use of a concrete stand-off pad during periods of inclement weather was a strong determinate of farm-level lameness, with animals on farms implementing this practice associated with a 1.49 (89% uncertainty interval 1.19 – 1.88) times odds of lameness compared to animals from farms that did not use concrete stand-off pads. Animals from farms that reported peak lameness incidence from January-June or all-year-round, had 0.76 times odds of lameness compared to animals from farms that reported peak lameness incidence from July-December (89% uncertainty interval 0.51 – 0.84). Other risk factors that were associated with greater odds of lameness at the univariable level included split-calving herds compared to 100% spring calving herds, no top gate compared to farms that had and used a top-gate, and no backing gate alarm/hose compared to farms that had an alarm or hose on the backing gate when it moved.

Reducing time to first lameness case is one of the keys of lameness control. A randomised clinical interventional study was carried out investigating if a heifer pre-calving intervention involving exercise and time on concrete would result in a reduction in the hazards of lameness. No difference in the time to lameness was noted in heifers exposed to concrete for one hour a day and walked 1km a day on farm tracks for five days a week for five weeks compared to control heifers. The intervention may not have been intense enough to result in the desired response, with evidence for this from the lack of difference in hoof wear between treatment and control heifers. However, as it was possible that a longer or more intense intervention may have resulted in harm, and would have been less practical for a farmer to carry out, it is unlikely that this, or similar interventions will result in meaningful reductions in lameness rates in New Zealand.

Finally, the successful implementation of lameness treatment and prevention strategies requires the buy-in of farmers. From the 120 dairy farms enrolled into the prevalence study, 101 responded to a second questionnaire on the barriers, motivators and perceived impacts of lameness. A farmer's perception of lameness was a poor predictor of true lameness prevalence. The two most important farmer barriers were time and skilled labour, with the most important motivators feeling sorry for lame cows and pride in a healthy herd. Despite the relatively low lameness

prevalence, many New Zealand dairy farmers believe lameness is a problem on their farm, and they rank welfare impacts of lameness of high importance.

Contents

1

Introduction

1. *Introduction*

Dairy cattle lameness is at unacceptably high levels in developed dairy production systems around the world (Afonso *et al.* 2020; Thomsen *et al.* 2023). Lameness not only significantly compromises welfare (Whay and Shearer 2017) and productivity (Huxley 2013), but also negatively impacts greenhouse gas emissions (Mostert *et al.* 2018) and undermines the social licence to dairy farm (Hampton *et al.* 2020).

New Zealand dairy farming has a reputation for high animal welfare standards, in comparison to other international markets. However, the modern consumer is no longer satisfied with mere commentary on these unsubstantiated reports of the New Zealand dairy industry. The New Zealand dairy industry must provide evidence-based data to back up the positive welfare claims of the industry, and pivot from to reducing harm to ensuring cows have a 'good quality of life' (DairyNZ summary of new proposed dairy cattle code of welfare; https://www.dairynz.co.nz/animal/welfare/proposed-new-dairy-cattle-code-of-welfare/, accessed 19 August 2023). To do this, quality research with high external validity is required.

Dairy cattle lameness in New Zealand suffers from limited evidence on the extent of the problem. Lameness prevalence and incidence targets and benchmarking are available but are made up predominantly from expert opinion (Lameness Technical Advisory Group, DairyNZ), or localised studies (Tranter and Morris 1991; Gibbs 2010; Lawrence *et al.* 2011). The recording of lameness is poor from farmers, and relying of farmers to report, or even understand the extent of, lameness is flawed (Fabian *et al.* 2014). Furthermore, relying on the prevalence estimates of other pasture-based lameness systems is perilous, with high lameness prevalence reported in pasture-based systems of Australia and Brazil (Ranjbar *et al.* 2016; Bran *et al.* 2018). Accurate disease incidence or prevalence metrics are also needed to assess the success of lameness control programmes. Thus, there was urgent need to quantity lameness in New Zealand and this was identified as the first step for this project.

Once benchmarks and targets above which would indicate improvements need to be made have been defined, farmers and animal health advisors need the tools to help reduce the extent of lameness on farm. DairyNZ has developed an excellent lameness management programme, the Healthy Hoof Programme (https://www.dairynz.co.nz/animal/cow-health/lameness/healthy-hoof/, accessed 17 August 2023).

However, the control plans provided are based on overseas data (Newsome *et al.* 2016), expert opinion, or scientific evidence that is over 30 years old (Chesterton *et al.* 1989). Whilst these are likely still valid in part, New Zealand dairy farming has changed considerably since 1989, and major factors that contribute to lameness in overseas dairy systems, i.e., housing and hygiene for infectious lameness, are not relevant in New Zealand systems (Oehm *et al.* 2019).

It is essential that New Zealand dairy farmers have scientifically backed effective and practical control strategies to reduce lameness. The calving period has been identified as one, if not the, most critical period for hoof health in dairy cattle (Tarlton *et al.* 2002; Knott *et al.* 2007). Furthermore, as a previous case of lameness has been identified as the single greatest predictor of a future case of lameness (Newsome *et al.* 2016; Randall *et al.* 2018), control efforts should be directed towards dairy heifers, a population that are less likely to have had a previous case of lameness. This approach has never been tried in New Zealand, so a key component of this thesis was to investigate a practical intervention that farmers could instigate as part of a pre-calving management practice for heifers.

Regardless of how effective an intervention may be in a research setting, the successful implementation of control strategies requires the buy-in of farmers (Green *et al.* 2020; Biesheuvel *et al.* 2021). A clinical intervention may have a significant impact but at the same time not be practical or cost effective enough to be implemented at a large scale needed to make population-level differences. To properly manage and improve lameness on dairy farms, farmers need to invest time and money into identifying lame cattle, training their staff, treating cases appropriately and identifying and controlling major risk factors for lameness. However, achieving this level of commitment from farmers is difficult in an environment where the disease has received limited focus from the industry and large gaps in knowledge exist. Farmer engagement is critical, and understanding the barriers and motivators for farmers is essential to controlling lameness (Leach *et al.* 2010a;b). It is one thing identifying a solution for dairy cow disease such as lameness, it is another thing to get widespread farmer uptake of the solution (Green *et al.* 2020). Thus, it is important

to understand what farmers believe is preventing them from controlling lameness, and the motivating factors that encourage them to control lameness.

It is from these discussion points that this project stems from, primarily from the critical lack of knowledge and research on one of the major diseases of New Zealand dairy cattle. There were three over-arching goals of this project: to quantify the extent of the current lameness burden in New Zealand dairy cattle, to improve the treatment of claw-horn lameness and to provide information on ways to prevent new cases of lameness. Whilst acknowledging that these were ambitious goals, it was important to the author that a range of studies were attempted. By addressing three separate components of disease management of lameness, namely defining the scale of the problem, treatment, and prevention, this increased the chances of identifying a finding that may improve lameness control in New Zealand. The results of multiple research projects can also help guide and prioritise the future research direction, if one was needed.

To achieve these goals, the project was broken down into six specific objectives. These are described below and make up the individual chapters and manuscripts for the thesis:

1) Define the prevalence of lameness in New Zealand dairy cattle
2) Define the duration of lameness after best-practice treatment of claw-horn lameness
3) Identify farm-level risk factors for lameness in New Zealand dairy cattle
4) Review the literature on the use of NSAID for cattle lameness treatment
5) Investigate a practical lameness prevention method involving conditioning of heifers' hooves prior to calving
6) Identify farmer barriers and motivators to lameness control

The final chapter summarises the findings of the six objectives and provides commentary on how these findings can be used in the industry and directions for future research.

Publication List

Chapter	Publication	Status
1: Introduction	Introduction of the scope and objectives of the thesis	Not written for publication
2: Prevalence of lameness	**Mason W, Müller K, Huxley J, Laven R.** Prevalence of lameness on pasture-based New Zealand dairy farms; an observational study. *Preventative Veterinary Medicine.* *https://doi.org/10.1016/j.prevetmed.2023.106047* ***Embargoed until November 2024***	Published
3: Duration of lameness	**Mason W, Laven LJ, Cooper M, Laven RA.** Lameness recovery rates following treatment of dairy cattle with claw horn lameness in the Waikato region of New Zealand. *New Zealand Veterinary Journal* 71, 226-35, 2023. https://doi.org/10.1080/00480169.2023.2219227	Published
4: Lameness risk factors	**Mason W, Müller K, Laven LJ, Huxley J, Laven R.** Farm-level risk factors and treatment protocols for lameness in New Zealand dairy cattle, *New Zealand Veterinary Journal*	In Review
5: Systematic review on NSAIDs and lameness	**Mason W, Cuttance E, Müller K, Huxley J, Laven R.** Graduate Student Literature Review: A systematic review on the associations between nonsteroidal anti-inflammatory drug use at the time of diagnosis and treatment of claw horn lameness in dairy cattle and lameness scores, algometer readings, and lying times. *Journal of Dairy Science*, 2022b. https://doi.org/10.3168/jds.2022-22127	Published
6: Clinical intervention on heifers to reduce lameness incidence	**Mason W, Huxley J, Laven R.** Randomized clinical trial investigating the effect of exercise and standing on concrete prior to first calving on time to first lameness event in dairy heifers. *Journal of Dairy Science* 105, 7689-704, 2022a. https://doi.org/10.3168/jds.2021-21640	Published
7: Farmers' barriers and motivators for lameness control	**Mason W, Laven, LJ, Huxley J, Laven R.** Can lameness prevalence in dairy herds be predicted from farmers' reports of their motivation to control lameness, and barriers to doing so? – an observational study from New Zealand. *Journal of Dairy Science.* *https://doi.org/10.3168/jds.2023-23862*	Published
8: Conclusion	Review of lameness in New Zealand and a summary of the preceding thesis chapters	Unpublished

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2

Prevalence of lameness in New Zealand dairy cattle

The first step in fixing a problem is to define a problem. In contrast to the other two major animal health diseases of New Zealand dairy cattle, mastitis and reproductive disorders, farmer recording of lameness is poor. Furthermore, farmer identification of lameness is also poor. Thus, there is little knowledge on the true prevalence of lameness across New Zealand dairy farms. Where prevalence data or benchmarks exists, they are from either localised studies or formed from expert opinion. The first objective of this thesis was to define the prevalence of lameness across New Zealand, by systematically randomly enrolling 120 dairy farms from eight major dairy regions of New Zealand. The link to the publication can be found at https://doi.org/10.1016/j.prevetmed.2023.106047.

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Prevalence of lameness on pasture-based New Zealand dairy farms: An observational study

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ABSTRACT

To understand the current impact of lameness on a system, it is important to define lameness prevalence across a range of dairy farms in that system. Prevalence estimates from dairy systems where cows are permanently managed at pasture are uncommon, although the limited data suggest that they have a lower lameness prevalence than housed cattle. One hundred and 20 farms from eight of the major dairying regions of New Zealand were randomly enrolled into a cross-sectional lameness prevalence study. On each of the farms, trained observers lameness scored cattle on two occasions, between October-December (spring, coinciding with peak lactation for most farms) and between January-March (summer, late lactation for most farms). At each visit, all lactating animals were scored using a four-point 0–3 scoring system, and included animals that had previously been identified as lame by the farmer. Animals with a lameness score (LS) ≥2 were defined as lame. Mixed logistic regression models assessed the interaction between region and season and island and season, respectively, and differences between the lameness prevalence within farm across the two seasons reported descriptively.

A total of 116,317 locomotion scores over two events were conducted across the 120 farms. At the spring scoring event, 2128/60,007 (3.5 %) cows had a LS ≥2 and 1868/56,310 (3.3 %) cows had a LS ≥ 2 at the summer scoring event. At the farm level, across both scoring events, median lameness prevalence was 2.8 (interquartile range 1.5 – 4.5) %, with a range of 0.0–17.0 %. The median farm-level prevalence of LS = 3 was 0.5 % with a range of 0–4.6 %. The effect of timing of scoring was modified by region ($p < 0.001$), and island ($p = 0.006$) and at the individual farm level, differences between spring and summer farm level lameness prevalence were generally small (interquartile range: –1.8 to 1.0 %) but potentially large on individual farms (range from –12.3 % to 7.6 %).

The median farm-level lameness prevalence estimate of 2.8 % across a random representative sample of New Zealand dairy farms give confidence that the overall prevalence of cattle lameness on New Zealand dairy farms is low. This adds to the growing evidence that pasture is a good management system with respect to hoof health. The evidence of strong seasonality of lameness was lacking. Instead of using lameness scoring to identify farms with large lameness problems, lameness scoring should be encouraged to farmers as a tool to improve the identification of lame animals.

1. Introduction

Lameness remains one of the most important diseases impacting dairy cattle worldwide (Algers et al., 2008; Huxley, 2013; Barkema et al., 2015). The impact of lameness on dairy farming extends beyond the often-reported impact on production, and animal welfare (Whay and Shearer, 2017), as with public scrutiny on dairy farms increasing (Barkema et al., 2015; Hampton et al., 2020), lameness is one of the key challenges to the social license to operate a dairy business (Hampton et al., 2020). A recent narrative review on the prevalence of lameness reported that the global median farm-level lameness prevalence was 22 % (Thomsen et al., 2023). This is an unacceptably high prevalence that risks compromising dairy farming's social license.

However, although the global median prevalence is high, lameness prevalence estimates vary considerably depending on country and dairying system (Thomsen et al., 2023). Pasture-based farming systems

Abbreviations: LS, lameness score; IQR, inter-quartile range.

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reportedly have conditions that are beneficial for hoof health, and, compared to housed dairying systems, have been associated with reduced lameness incidence and prevalence (Olmos et al., 2009; Arnott et al., 2017). However, simply grazing dairy cows on pasture is not synonymous with low lameness risk (Hund et al., 2019), with mean prevalences being reported of 18.9 % in pasture-based Australian dairy farms (Ranjbar et al., 2016), and 35.0 % in small-scale grazing Brazilian dairy farms (Bran et al., 2018). Even in New Zealand, individual farm-level prevalences as high as 36.0 % have been reported (Fabian et al., 2014). Thus, to assess the lameness situation and communicate accurate prevalence estimates, we need current and system-specific estimates.

While there has been a recent suite of high-quality lameness prevalence publications from what are referred to as pasture-based dairy cows (O'Connor et al., 2020; Browne et al., 2022), these systems in north-west Europe still house animals over the winter. This practice is rare in New Zealand, with most dairy cows being managed outside for 100 % of the year. Thus, there are few recent lameness estimates from large herd-size, 100 % pasture-based dairy cattle. The last, and only, New Zealand lameness prevalence estimate was made in 2010/11 from a convenience selection of 59 herds, which reported a median farm-level prevalence of 6.7 %, and a range from 1.2 % to 36.0 % (Fabian et al., 2014). This study (combined with expert opinion) is the basis for the herd-level prevalence benchmarking and recommendations present in the industry-led lameness prevention programme in New Zealand, Healthy Hoof (DairyNZ, https://www.dairynz.co.nz/media/5790786/preventing-and-managing-lameness-guide.pdf accessed 20 June 2023). As there is large variability between countries (Thomsen et al., 2023), within countries (Afonso et al., 2020) and even within farms (O'Connor et al., 2020; Browne et al., 2022), it is critical that lameness prevalence estimates are current and appropriate to the population of interest. Thus, there was a desire to gain understanding of the current lameness prevalence in New Zealand via a large randomly-selected population of dairy farms throughout the country.

New Zealand has two major islands, the North Island and South Island, with different climatic conditions varying from warm subtropical regions with high rainfall in the north to cool temperate low-rainfall regions in the south (Overview of New Zealand's climate | NIWA) and farm demographics (average herd size in the South Island is 647 cows compared to 362 cows in the North Island; https://www.dairynz.co.nz/publications/dairy-industry/new-zealand-dairy-statistics-2020–21/; accessed 20 June 2023). There is some evidence of varying peaks of lameness incidence in New Zealand, with case reports of lameness in the Taranaki region of New Zealand reaching peak numbers in the spring (October) from Lawrence et al. (2011), and summer (January) in the Canterbury region of New Zealand (Gibbs, 2010). Confirmation of differences in seasonal and geographical lameness prevalence may point to different risk factors, and thus different critical control points for farms throughout New Zealand. Data on differences between seasons and regions are also important for recommendations of when to lameness score animals and how often.

The objectives of this study were to estimate farm-level lameness prevalence across New Zealand at two time points, coinciding with the a priori greatest risk periods, to assess change in lameness prevalence within a year, and to compare the estimates to previous New Zealand and international lameness prevalence estimates.

2. Methods

The study was designed as a cross-sectional descriptive study, with all procedures approved by Massey University human ethics committee, application number 4000025095 and Massey University animal ethics committee Protocol 21/55 and 22/36.

2.1. Sample size calculations

Sample size calculations were calculated with an expected true prevalence of 8.3 % (from (Fabian et al., 2014)), a precision of 5 % and a 95 % confidence. With these assumptions, a total of 117 farms were required. This was increased to 120 to ensure equal numbers of farms (n = 15) across eight regions were enrolled.

2.2. Farm and animal enrolment

A single-stage cluster sampling method was performed, with a simple random sampling framework used to select farms, and all milking animals within the selected farms enrolled. Farms were enrolled from eight territorial regions of New Zealand, four within the North Island of New Zealand; Northland, Waikato, Taranaki and Manawatu and four within the South Island of New Zealand; West Coast, Canterbury, Southland and Otago. These were selected as they represent eight of the major dairying regions within the 16 New Zealand regions (77.6 % of dairy farms; New Zealand Dairy Statistics 2020–21; https://www.dairynz.co.nz/publications/dairy-industry/new-zealand-dairy-statistics-2020–21/ accessed 20 June 2023). The study was conducted over two dairy seasons, equivalent to two national herd lactation due to the highly seasonal nature of the national production profile (New Zealand dairy seasons typically range from 1 June to 31 May each year), with the North Island farms enrolled in the 2021/22 season, and the South Island farms in the 2022/23 season. A convenience sample of veterinary practices, one within each region, were enrolled to provide lameness scoring and data collection services, based on previous track record of conducting cattle research to a high quality, and willingness to comply with the study protocol. The clients that the veterinary clinic serviced acted as a proxy for dairy farms within the region. Each practice listed their dairy clients in alphabetical order, and excluded farms that were greater than 100 km, or one hour drive away, from the veterinary practice, or that were known to have a parlour design that likely would result in post-milking lameness scoring challenges (e.g., concrete exit race less than 5 m). From the remaining eligible target population, 15 farm clients were then systematically randomly selected for enrolment. A random number was generated in Microsoft Excel between 1 and 10, which was used to select the first farm on the list. Then every N^{th} farm (where N = Total number of eligible farms/15) on the list was selected for enrolment.

All milking dairy cattle on enrolled farms were eligible for lameness scoring. Any non-lactating animals on the farm at the time of the visits were excluded. The primary animal-health decision maker on farm was asked to complete a survey consisting of questions on farm management and lameness treatment.

2.3. Lameness scoring

Lameness scoring data were collected by one trained veterinary technician per region. Lameness scoring followed the DairyNZ scoring guidelines with a scoring system 0–3 (Table 1). Lameness scores (LS) were collected between October to December and then again in January-March. All lameness scoring was carried out immediately after milking (either morning or afternoon) with cattle walking on flat concrete in single file. This included animals that had been previously identified as lame by the farmer and had been placed into a separate herd at the time of the lameness scoring visit. As most of these farms milked these lame animals once-a-day, the timing of the visit coincided with when they were being milked (i.e., morning or afternoon) so that they could be lameness scored under the same conditions as the rest of the herd. Individual animal IDs were not recorded, but a tally of each animal with LS = 2 and LS = 3, as well as the total number of animals scored, were collected.

Training and calibration occurred for all personnel involved. A training day was organised in one location for the North Island clinics

Table 1
Lameness scoring descriptors used in a randomized clinical trial investigating the impact of pre-calving exercise and time standing on concrete on time to first postpartum lame event (adapted from DairyNZ Lameness Scoring system).

Lameness Score	Descriptor
0	Walks with even weight bearing on all 4 limbs at a similar walking speed to a person, with regular stride length and rhythm. Straight back line at all times and head held in line or slightly below the backline and steady when walking
1	Walks unevenly but reduced weight-bearing on affected limb not easily obvious. May have uneven stride length and/or rhythm. Backline straight when standing but may be mildly arched when walking.
2	Lame, with decreased stride length on affected limb. Weight bearing reduced on affected limb which can easily be identified. Walking speed slower than normal. Backline often arched when standing and walking and head bobs up and down when walking
3	Severely lame, with minimal or no weight bearing on affected limb. Reluctant to move and cannot keep up with the healthy herd. Backline arched when standing and walking and often large head movements up and down when walking.

and another for the South Island clinics. This consisted of a three-hour morning theory session and video quiz of New Zealand cattle with varying degrees of lameness scores, followed by an afternoon practical lameness scoring session on a farm. At each session, > 300 cows were scored as they returned to pasture after milking, including a proportion of the herd that the farm kept separate as previously identified as lame, which were milked separately. Group discussions took place on the lameness scores of the animals. Then the lead investigator undertook an audit visit individually with each of the technicians on one enrolled farm within their region. The technician and lead investigator lameness scored the animals independently and then compared prevalence at the end of the visit. The eight technicians all scored within 1 % of the prevalence estimate of the lead author, and six technicians scored with 0.5 % of the lead author. Follow-up real-time video conferencing of lameness scoring was carried out at the discretion of the lead author or technician if required by either party.

To minimise bias between lameness scoring events, the results of the lameness prevalence were not communicated to the farmers or veterinary clinic until the completion of the second scoring event and no lameness advice was given to the farmers. The one exception was if an animal welfare concern was noted, which was considered a farm where the number of animals with a LS $\geq$ 2 was greater than 15 % of the herd at the time of the first scoring event. In this instance, the veterinarian who oversaw the farm from the respective veterinary practice was alerted. It was then up to the discretion of the veterinary overseeing the farm how they would like to proceed. If a lameness control intervention was conducted this was reported to the lead author.

2.4. Statistical methods

All raw data were converted to CSV files and imported into R (R Core Team, 2023) to be assessed for completeness, consistency, formatting and logic. The two scoring visits are subsequently referred to as 'spring' (October-December; technically late spring to early summer) or 'summer' (January-March; technically mid-summer to early autumn). Scores for individual cows were collapsed into lame (LS 2 or LS 3) or non-lame (LS < 2) categories. Apart from descriptively reporting the proportion of lame animals and LS = 3 animals (severely lame animals), all other descriptive statistics were reported at the farm-level. The 95 % confidence interval of the median lameness prevalence was calculated from 10,000 bootstrap estimates of the median lameness prevalence.

Summary statistics for prevalence of lameness across region and season were tabulated. The change in farm-level lameness prevalence between the spring and summer scores was calculated by subtracting the prevalence of lameness at the summer score from the spring score. Descriptive statistics for this change were reported in the form of barplots and scatterplots. Farms were assessed for the presence of high lameness prevalence across both scores. The proportion of farms that had both of their LS in the top 25 % of all scores were reported as well as reporting on the lameness prevalence difference for the farms with the top ten prevalence scores.

To assess differences between the eight regions, two island and two scoring occasions, generalised linear mixed models were used. The outcome variable was the presence or absence of lameness at the cow-level, with clustering of animals within farm included as a random intercept. Region and island could not be in the same model together, as region entirely explained the variance in island, thus two respective models were conducted. The initial fixed effects of the first model consisted of region and season, as well as an interaction term for region and season. The initial fixed effects for the second model consisted of island and season, as well as island * season term. For both models, interaction terms remained if the AIC of the model with the interaction term was smaller than the model without the interaction term.

3. Results

3.1. Farm characteristics

In total, 122 farms were approached for enrolment, with two farms excluded due to the race exiting the milking parlour providing limited visibility for individual animal lameness scoring. A total of 120 farms were enrolled, with no farmers refusing to take part in the study. No lameness interventions or control plan changes were reported to the lead author during the study. Overall farm characteristics and characteristics split by Island, are presented in Table 2, with 119 farms responding to the survey; location, season and prevalence data were available for all 120 farms; therefore no missing data were apparent for the variables of interest. Farms in the North Island had a median of 190 fewer cows compared to farms in the South Island (365 vs 555 cows, respectively). Over 90 % of farms were entirely spring-calving, and 100 % of farms had access to grazed pasture all year round. Similar proportions of farms (~40 %) had Holstein-Friesian and Jersey x Friesian (Kiwi-Cross) as

Table 2
Descriptive statistics of 119 of the 120 New Zealand dairy farms enrolled into an observational lameness prevalence study, split by North Island (n = 60) and South Island (n = 59) farms.

Characteristic	Missing	Overall, N = 120[1]	North, N = 60	South, N = 59
Herd size, Median (IQR)	2	440 (330–624)	365 (279–480)	555 (402–693)
Milk solids (kg/cow/year), Median (IQR)	5	430 (400–475)	410 (372–452)	460 (414–481)
Number of full-time staff, Median (IQR)	2	2.50 (2.00–3.00)	2.00 (1.38–3.00)	3.00 (2.00–4.00)
Milking frequency, n (%)	1			
Less than twice-a-day		33 (28)	20 (33)	13 (22)
Twice-a-day all year		86 (72)	40 (67)	46 (78)
Predominant breed, n (%)	1			
Holstein-Friesian		47 (39)	27 (45)	20 (34)
Jersey		18 (15)	13 (22)	5 (8.5)
Holstein/Jersey cross		54 (45)	20 (33)	34 (58)
Milking parlour, n (%)	1			
Herringbone		59 (50)	37 (62)	22 (37)
Rotary		60 (50)	23 (38)	37 (63)
Calving system, n (%)	1			
100% spring calving		108 (91)	49 (82)	59 (100)
Batch-calving spring and autumn		11 (9.2)	11 (18)	0 (0)

[1]Median (IQR); n (%)

their predominant breed, with a greater proportion of North Island farms reporting Jersey as the predominant breed compared to the South Island farms. There was an equal split of herringbone versus rotary parlours, however, the ratio of herringbone to rotary parlours was 2:1 in the North Island and 1:2 in the South Island. Each quarter was reported by >10 % of farmers as being the quarter with their peak lameness incidence, with 75 % reporting peak lameness between June and December (early-mid lactation). However, there were strong island differences, with just 3 % of North Island farmers reporting peak lameness incidence between January to May, compared to 42 % of South Island farmers.

3.2. Lameness prevalence

At the first scoring event in spring, a total of 2128/60,007 (3.5 %) cows had a LS ≥ 2, with 515 (0.8 %) LS = 3. In summer, a total of 1868/56,310 (3.3 %) cows had a LS ≥ 2, with 342 (0.6 %) LS = 3. At the farm level, across both scoring events, median lameness prevalence was 2.8 (95 % CI 2.4 – 3.1 %), with a mean prevalence of 3.6 %. The interquartile range was between 1.5 % and 4.5 %, with a range of 0.0–17.0 % (Fig. 1). Summary statistics of the median farm-level prevalence, interquartile range and range for each region is presented in Fig. 2. Across both scoring events, the median farm-level prevalence of severe lameness was 0.5 (IQR 0.1–1.0) %, with a range of 0.0–4.6 %.

There was a significant interaction between region and season ($p < 0.001$; Table 3), and island and season ($p = 0.006$; Table 4) in the odds of lameness. In the spring, cows from Waikato farms had the greatest odds of lameness, with cows from Canterbury farms with the smallest odds of lameness. In the summer, cows from Northland farms had the greatest odds of lameness, with cows from the West Coast farms with the smallest odds of lameness (Fig. 2). Whilst the odds of lameness were lower in cows from the South Island compared to the North Island, this was less pronounced in the summer scores than the spring scores (Fig. 3).

The difference in lameness prevalence between spring and summer ranged from a 12.3 % reduction in lameness prevalence to a 7.6 % increase (Fig. 4), with a median change in lameness prevalence of a reduction of 0.05 %. In 25 % of farms, there was a reduction in lameness prevalence >1.8 % between spring and summer and in 25 % of farms, there was an increase in lameness prevalence >1.0 % between spring and summer. Of the 48 farms that had at least one prevalence measurement in the top 25 % of all lameness prevalences (i.e. > 4.5 %), 17 (39 %) had >4.5 % scored as lame in both spring and summer. From the farms with the top 10 lameness prevalence at any scoring event (>10.0 %), the median difference between the two scores was 7.1 (IQR 4.7–7.6) %.

4. Discussion

From a total of 120 farms across eight major dairying regions of New Zealand, we report a median farm-level lameness prevalence of 2.8 %, with an interquartile range of 1.5–4.5 %. The effect of timing of scoring

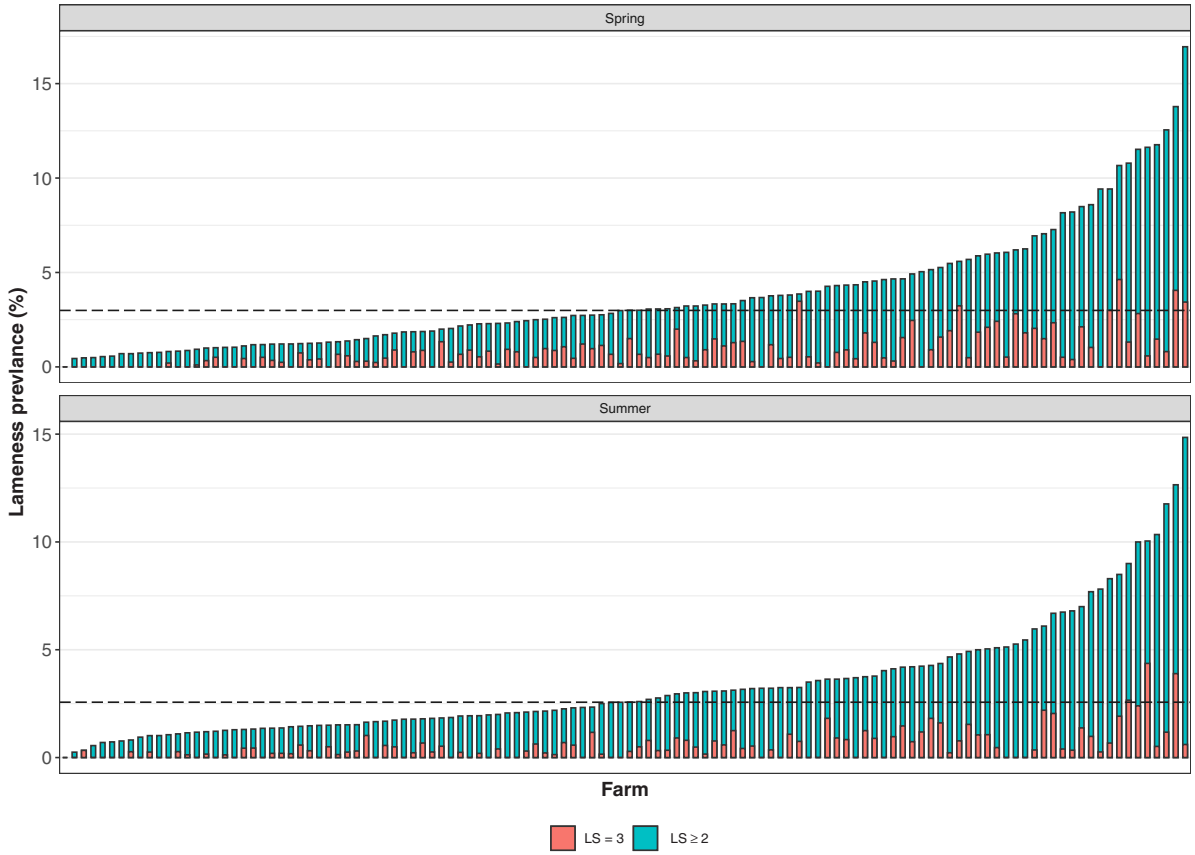

Fig. 1. Barplot of lameness prevalence for 120 farms in New Zealand at two time points – spring and summer. The blue bars represent the percentage of all lame animals (LS ≥ 2) on farm, with the red bars the percentage of severely lame (LS = 3) animals. The horizontal dashed lines represent the median farm-level lameness prevalence at each time point.

2. Prevalence of lameness

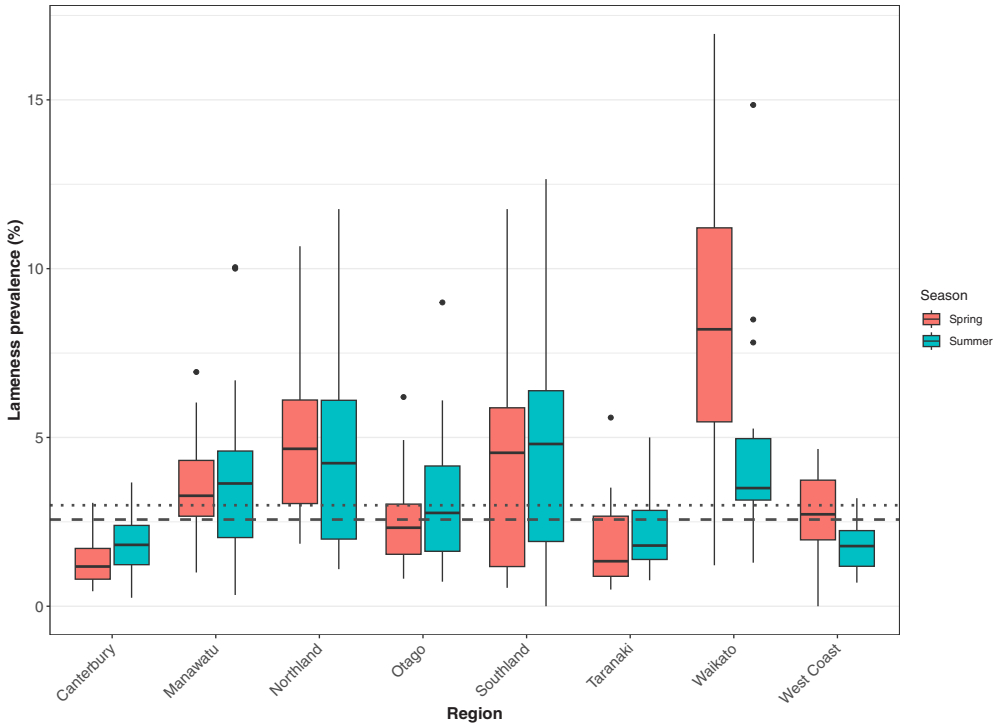

Fig. 2. Boxplot of the farm-level lameness prevalence for 120 farms across eight regions in New Zealand. Each farm had a lameness score in spring (red bars) and summer (blue bars). The dotted line represents the median prevalence for all farms in spring, and the dashed line the median prevalence for all farms in summer.

was modified by region, and at the individual farm level, differences between spring and summer farm level lameness prevalence could be large, with a range from –12.3–7.6 %.

This median prevalence is much lower than that identified in previous international studies which have used lameness (locomotion) scoring to identify lameness prevalence. A narrative review of 53 studies across six continents identified a median lameness prevalence based on lameness scoring of 22.0 % (Thomsen et al., 2023), with a minimum reported study-level prevalence of 5.1 % on Swedish dairy farms (Manske et al., 2002). In addition, a review of lameness prevalence studies in the United Kingdom over the previous 70 years, with a less prescriptive study inclusion criteria than that of Thomsen et al. (2023), reported a minimum study-level prevalence in British dairy cattle of 7.0 % (Afonso et al., 2020). The lameness prevalence estimates from the current study should provide confidence that New Zealand dairy cattle generally have a very low burden of lameness by international standards.

The reasons for this low prevalence were not investigated in this study, however they likely include both a lower burden of lameness-inducing infectious agents in New Zealand and a shorter duration of lameness. Firstly, despite the presence of digital dermatitis lesions in New Zealand dairy cattle, albeit at a low prevalence (Yang et al., 2017), lameness-inducing digital dermatitis disease is very rare in New Zealand (Yang et al., 2018). In contrast, in many other countries, digital dermatitis is one of the most important causes of lameness in dairy cattle (Bicalho and Oikonomou, 2013).

As prevalence is the product of incidence rate and duration of disease, dairy systems with a shorter duration of lameness are likely to have a lower prevalence. In New Zealand, Mason et al. (2023) reported a median time to soundness (LS = 0) from 241 lame cows with claw-horn lesions of 18 days, and a median time to non-lame (LS ≤ 1) of just seven days. Equivalent figures are not available from housed systems but in the UK, cure risks at 35–42 days post treatment have ranged from 15 % to 55 % (Thomas et al., 2015; Thomas et al., 2016) whereas Mason et al. (2023) reported greater than 90 % of enrolled cattle sound by 35 days. Thus, shorter duration of disease is likely at least partially responsible for the low prevalence noted in this study.

This study also provides evidence that the prevalence of lameness may be decreasing in New Zealand, with the upper limit of the 95 % CI for median lameness prevalence well below the 6.7 % median prevalence reported by a New Zealand study conducted a decade earlier (Fabian et al., 2014). This contrasts with the conclusions from two recent reviews describing lameness prevalence over time. Inferences have ranged from no evidence for change in lameness prevalence from 53 international publications from 1989 to 2020 (Thomsen et al., 2023), to evidence for an increase in lameness prevalence from 32 United Kingdom publications (Afonso et al., 2020). However, inferences from both of these reviews need to be interpreted with caution, as substantial descriptive variability (Thomsen et al., 2023) and statistical heterogeneity (Afonso et al., 2020) between lameness prevalence publications were reported. As all three possible trends of lameness prevalence over time, i.e., a reduction, no change and an increase in lameness prevalence, have all been reported in publications within a 12-month period, this should further highlight the challenges with comparing prevalence between publications. Instead, comparisons between lameness prevalence may best be left to studies carried out in similar systems within a country, and those with strong internal validity.

Pasture-based dairy systems provide environmental and management conditions that are beneficial to hoof-health when compared to dairy systems that involve housing (Olmos et al., 2009; Arnott et al., 2017). However, the solution of controlling lameness is not simply to move to grazed pasture systems as even within these systems, a range of prevalences are reported (Hund et al., 2019). Small pasture-grazing herds in tropical locations have been associated with lameness

Table 3
Output from a generalised linear mixed model, with farm as a random intercept, for the odds of cow-level lameness (LS ≥ 2 from a 0–3 scoring system) with a region * season interaction (n = 116,317 lameness scores from 120 farms).

Characteristic	Island	N	Event N	OR (95 % CI)[1]	p-value
Region					<0.001
Canterbury	South	21,084	322	—	
Manawatu	North	14,642	570	2.62 (1.74–3.93)	
Northland	North	14,748	693	3.84 (2.58–5.72)	
Otago	South	19,542	564	1.97 (1.31–2.94)	
Southland	South	14,060	633	3.19 (2.13–4.77)	
Taranaki	North	10,205	203	1.38 (0.89–2.13)	
Waikato	North	10,695	677	6.53 (4.40–9.71)	
West Coast	South	15,337	334	2.08 (1.38–3.13)	
Season					0.001
Spring		62,135	2128	—	
Summer		58,178	1868	1.43 (1.15–1.79)	
Region * Season		120,313	3996		<0.001
*Manawatu * Summer*		6782	280	0.82 (0.62–1.08)	
*Northland * Summer*		6891	317	0.66 (0.50–0.86)	
*Otago * Summer*		9761	310	0.85 (0.64–1.12)	
*Southland * Summer*		6917	303	0.66 (0.50–0.87)	
*Taranaki * Summer*		4978	109	0.85 (0.59–1.21)	
*Waikato * Summer*		5129	233	0.38 (0.29–0.50)	
*West Coast * Summer*		7417	130	0.48 (0.35–0.65)	

[1]OR = Odds Ratio, CI = Confidence Interval

Table 4
Output from a generalised linear mixed model, with farm as a random intercept, for the odds of cow-level lameness (LS ≥ 2 from a 0–3 scoring system) with an island * season interaction (n = 116,317 lameness scores from 120 farms).

Characteristic	N	Event N	OR (95 % CI)[1]	p-value
Island				<0.001
North	50,290	2143	—	
South	70,023	1853	0.59 (0.46–0.75)	
Season				0.002
Spring	62,135	2128	—	
Summer	58,178	1868	0.87 (0.80–0.95)	
Island * Season	120,313	3996		0.006
*South * Summer*	34,398	929	1.20 (1.05–1.36)	

[1]OR = Odds Ratio, CI = Confidence Interval

prevalence as great as many housed lameness systems, with mean farm-level lameness prevalence of 35 % from 44 small grazing dairy herds in Brazil (Bran et al., 2018), and 33 % from three herds in Tanzania (Werema et al., 2023). Australasian pasture-based dairy farms are not immune to lameness issues too, with a mean prevalence of 18.9 % on Australian dairy farms (Ranjbar et al., 2016), prevalence as high as 36 % on single farms in New Zealand (Fabian et al., 2014) and 17 % in this current study. Conversely, not all prevalence studies on housed cattle reported high prevalence estimates, with mean prevalence of 9.8 % from 191 USA dairy farms, of which only 5 % were managed at pasture (Adams et al., 2017). Thus, the same issues of heterogeneity between studies as discussed above under change over time are apparent with pasture exposure and lameness prevalence (Afonso et al., 2020). Instead, more appropriate inferences of the risk of pasture on lameness can be found from within study comparisons. Cattle at pasture for an entire production cycle had significantly lower odds of lameness for the majority of lactation compared to housed cattle (Olmos et al., 2009). A systematic review into the welfare of dairy cattle in tie-stalls compared to less restrictive housing identified six studies in which lameness prevalence was compared between animals in tie-stalls with and without access to pasture (Beaver et al., 2021). In all six studies, lameness prevalence was either lower or unchanged in the group that had access to pasture. And more recently, a lower lameness prevalence was reported in Irish dairy cattle during the grazing period compared to when housed (Browne et al., 2022). Thus, the findings of this study support the previously published evidence which suggests that keeping dairy cattle on pasture is associated with a reduction in lameness risk.

Prevalence of animal health disease is ever evolving, and the prevalence reported in this current study do not necessarily represent the lameness prevalence across New Zealand now, and particularly not in the future. Instead, the authors desire these data to act as a baseline to compare against in the future. However, at the farm level, the value of such prevalence estimates is less clear. We recently reported that wanting to do better than peers is not a motivator for lameness control for New Zealand dairy farmers (Mason et al., submitted), a similar conclusion to that from a survey of UK dairy farmers (Leach et al., 2010). Thus although benchmarking can be useful for influencing behavior for some dairy cattle diseases (Sumner et al., 2018), measurement of lameness prevalence may not be useful for initiating behavioral change related to lameness control. Furthermore, this study shows that most herds (61 %) with an elevated lameness prevalence (i.e., >4.5 %) in spring or summer did not have a lameness prevalence >4.5 % at the other timepoint; indicating that a single one-off lameness prevalence assessment may not actually produce useful data for benchmarking, as a farm's ranking compared to other farms can change substantially despite no significant changes in lameness management. Instead, benchmarking within farm, as suggested by Archer et al. (2010), may be more useful. In pasture-based herds, rather than focusing on locomotion scoring as a one-off procedure for audit purposes (although this may still be required for farm assurance; (Sapkota et al., 2020), or trying to assess when the 'optimal' time to lameness score is, lameness scoring should be seen more as a tool for early identification and treatment of lame animals, with most efforts directed towards ongoing and real-time lameness monitoring. Manual lameness scoring in pasture-based herds is likely to require significant staff time (Sapkota et al., 2022). However, the advent of precision livestock farming technology that can routinely monitor lameness can potentially solve this problem (Silva et al., 2021), as it can provide real-time evidence of changes in lameness prevalence and response to interventions. However, work is required on the practical implications of these technologies, in particular the less than perfect specificity (O'Leary et al., 2020) which can potentially overwhelm farmers with 'lame' cows that apparently need attention.

Training and formal assessments of each of the technicians were carried out prior to and during the study, however, no formal agreement measurements were reported. The use of agreement and reliability statistics, especially kappa, to assess interobserver reliability is common within lameness research (Barker et al., 2010; Browne et al., 2022; Wilson et al., 2022). Going beyond the well-documented criticisms from the statistical community of reporting kappa for agreement (Gwet, 2002; Wongpakaran et al., 2013; Dettori and Norvell, 2020), kappa are often reported as point estimate values with no discussion on the inference of these to the study. Barker et al. (2010) reported a range of kappa values from 0.67 ('moderate' agreement) to 0.93 ('excellent' agreement) between lameness scorers. Whilst this may sound impressive, the reader is given no information of the variance of these point estimates, and what the true population agreement between the lameness scorers may be. If agreement statistics are to be reported with lameness research, the authors recommend that researchers limit the interpretation based on arbitrary thresholds (Brennan and Silman, 1992), or avoid using these

2. Prevalence of lameness

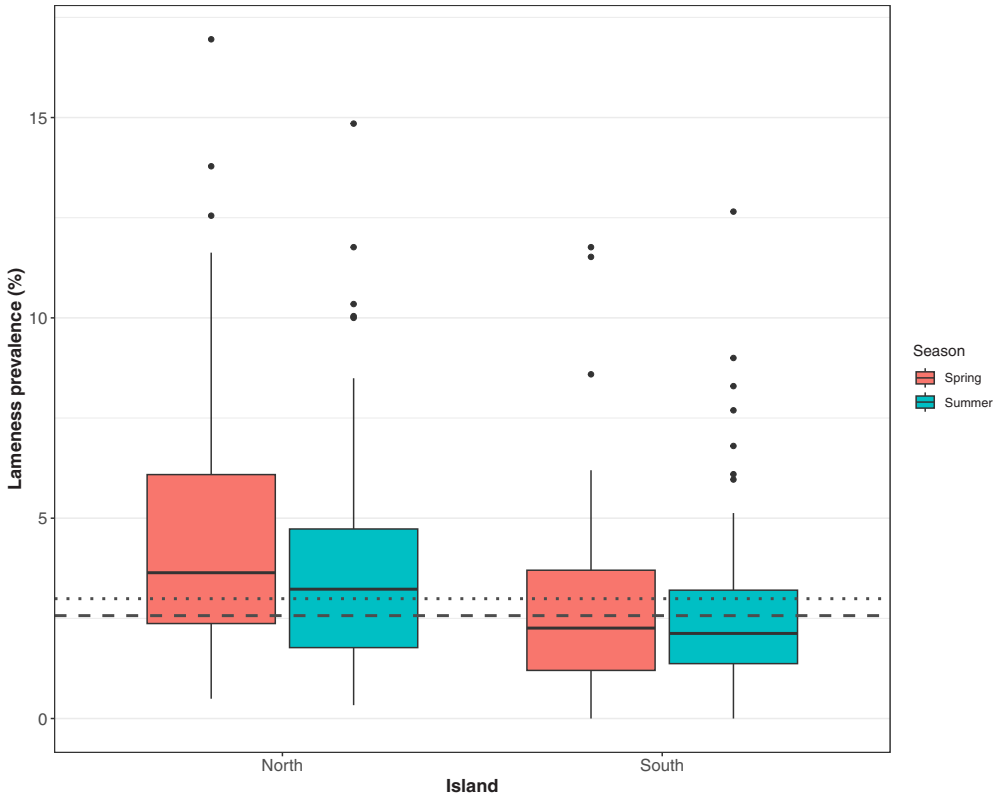

Fig. 3. Boxplot of the farm-level lameness prevalence for 120 farms across North and South Islands of New Zealand. Each farm had a lameness score in spring (red bars) and summer (blue bars). The dotted line represents the median prevalence for all farms in spring, and the dashed line the median prevalence for all farms in summer.

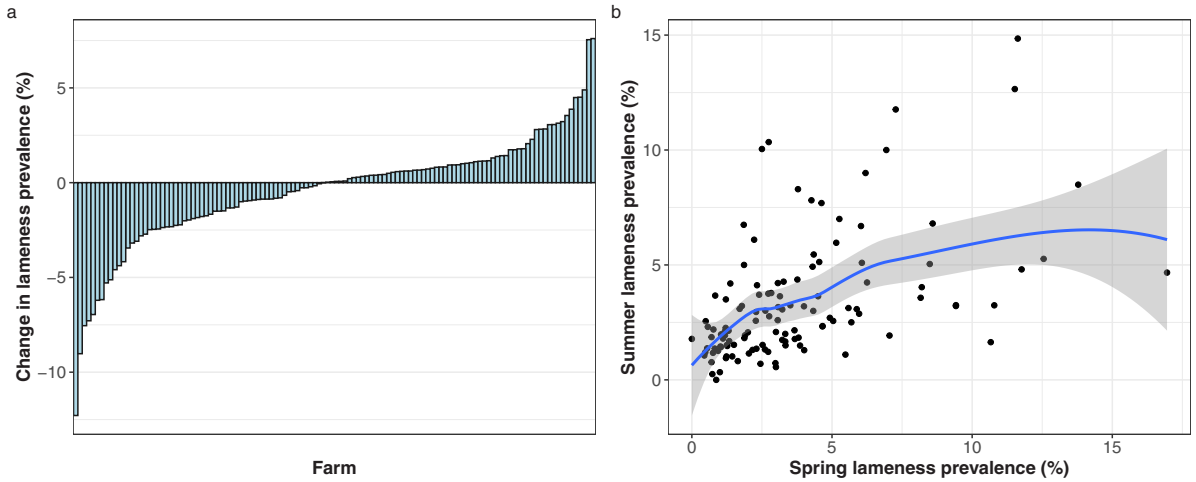

Fig. 4. a) Barplot of the difference in lameness prevalence from the first score in spring and second score in summer; a positive percentage represents a prevalence greater at the summer score than the spring score. b) scatterplot of spring lameness prevalence against summer lameness prevalence, with a locally weighted line of best fit (blue line) and 95 % confidence interval (shaded grey area).

thresholds entirely, and ensure variance measures are supplied for every agreement statistic reported. Furthermore, irrespective of these issues, simply reporting kappa (or more robust measures such as Gwet's AC1; Gwet, 2002) does nothing to account for the less than 100 % agreement uniformly present amongst different lameness scorers. Thus, the authors recommend that researchers measuring lameness prevalence using lameness scoring should acknowledge the limitations of less than perfect agreement and interpret their results in the light of that less than perfect

agreement. For example, in a study such as Fabian et al. (2014) which used a single trained lameness scorer for all LS, it is likely that the errors in identifying truly lame cows will be relatively consistent across farms. This is because a trained individual scorer will generally score either 'harshly' or 'leniently' relative to true status (i.e. their sensitivity and specificity will be relatively consistent). Thus, if Farm B is scored as having more lame cows than Farm A then that conclusion is probably correct, although there is likely to be bias in the estimate of prevalence at both the individual farm and, therefore, at the overall study level. In contrast, in studies which use multiple scorers, such as the current study, there will be less consistency across farms (reducing the reliability of ranking) and there will still be bias in the estimate of prevalence of individual farms. However, at the overall level, the prevalence estimates are likely to more accurately reflect the true prevalence as the biases are spread over more scorers, with some of them with greater sensitivity and others with greater specificity, which means that the overall result is likely to track towards the mean.

The enrolled farmers constitute ~ 1 % of all New Zealand dairy farmers, so they may not represent the true lameness status across all New Zealand dairy farmers. However, as they were enrolled via random sampling within the eight most populist dairying regions in New Zealand, and farm characteristics of enrolled farms including a range of herd sizes and pastoral farming systems. This contrasted with the convenience sampling methods used in (Fabian et al., 2014). As no farmers declined enrolment, minimizing selection biases of farms with lameness issues refusing to be enrolled, we believe that the inferences and conclusions reported here are valid. Another possible limitation of the study was that it was carried out over two different lactation seasons, depending on the island the farm was located on. Therefore, a direct comparison between farms on the two islands is confounded by the year of sampling. Whilst undoubtably there is a seasonal effect of lameness, that in part may be due to varying weather conditions between seasons and years (Ranjbar et al., 2016). However, as we report both an interaction between region and timing of LS, and a small interquartile range for the difference between the lameness scores, we believe the emphasis of the seasonal nature of lameness in New Zealand dairy farms is too simplistic and overstated.

Whilst acknowledging that improvements in lameness on New Zealand dairy farms are still needed, the lameness prevalence reported in the current study are low compared to the rest of the developed dairy world and should provide confidence to advisors, farmers and consumers that New Zealand dairy cattle have a low burden of lameness.

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Declaration of Competing Interest

We disclose the two funding sources for this project: The Ministry of Primary Industries Sustainable Food and Fibres Futures (SFFF19067) and DairyNZ. We declare that we have no conflict of interest as a result of these funding sources and are not affiliated with either source. We have no other conflicts to declare.

We declare that we did not use any Generative AI and AI-assisted technologies in the writing process.

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3

Duration of lameness on five Waikato dairy farms

The previous chapter identified that the median farm-level prevalence of lameness was low across New Zealand, in comparison to international dairy systems. It was speculated that one of the reasons for this was a shorter duration of lameness once identified and treated; fewer chronic and refractory cases of lameness may exist in New Zealand compared to overseas dairy systems. As incidence rate is the quotient of prevalence and duration, defining duration of lameness can also provide valuable information to be able to determine incidence of lameness. Furthermore, duration of lameness can provide information on the effectiveness of a lameness treatment protocol on farm. If the duration of lameness on a farm is longer than on other farms, this suggests either ineffective lameness treatments or chronic lameness cases occurring. Five Waikato dairy farms were enrolled into an observational study where all claw-horn lameness were treated by the same veterinarian, and then lameness scored on average every 4 days until sound. The link to this publication can be found at https://doi.org/10.1080/00480169.2023.2219227.

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Lameness recovery rates following treatment of dairy cattle with claw horn lameness in the Waikato region of New Zealand

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ABSTRACT

Aims: To describe the time in days for lame dairy cows to recover after diagnosis and treatment of claw horn lameness, and to investigate whether cure rates differed between farms.

Methods: Five dairy farms in the Waikato region were conveniently enrolled into a descriptive epidemiological study. Three of these farms had dairy cattle enrolled over two consecutive seasons, while two farms enrolled for one year. Lame cattle diagnosed by the farmers were enrolled into the study if they had a lameness score (LS ≥ 2 on a 0–3 scale) and claw horn lesions. All enrolled animals were treated by a single veterinarian following a consistent methodology, and subsequently assessed for LS at a median frequency of 4 days from enrolment until they were sound (LS = 0). The times (days) taken for animals to become sound and non-lame (LS < 2) were reported for all animals, and Kaplan–Meier survival curves used to present the results. A Cox-proportional hazard model was used to assess if the hazard of soundness was associated with farm, age, breed, lesion, number of limbs involved, and LS at enrolment.

Results: A total of 241 lame cattle with claw horn lesions were enrolled across the five farms. White line disease was the predominant pain-causing lesion in 225 (93%) animals, and blocks were applied to 205 (85%) of enrolled animals. The overall median days from enrolment to becoming sound was 18 (95% CI = 14–21) days, and 7 (95% CI = 7–8) days to become non-lame. A difference in the hazards of lameness cure between farms was identified (p = 0.007), with median days to lameness cure between farms ranging from 11 to 21 days. No associations were identified between age, breed, limb, or LS at enrolment on the lameness cure rates.

Conclusions: Treatment of claw horn lameness following industry-standard guidelines in dairy cattle on five New Zealand dairy farms resulted in rapid cure, although cure rates differed between farms.

Clinical relevance: Following industry best-practice lameness treatment guidelines, including frequent use of blocks, can result in rapid lameness cure rates in New Zealand dairy cows. This study also suggests that management of lame cattle on pasture can positively benefit their welfare and recovery times. The reported cure rates provide veterinarians with benchmarks on the length of time after which a lame animal should be re-examined, and in the investigation of poor treatment response rates at the herd level.

Abbreviations: CHL: Claw horn lameness; HRR: Hazard rate ratio; KM: Kaplan–Meier; LS: Lameness score

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Introduction

Lameness in dairy cattle remains one of the big welfare concerns of dairy farming, with prevalence estimates > 30% at any given time in many dairy systems (Dippel *et al.* 2009; Griffiths *et al.* 2018). However, prevalence is not the only epidemiological measure of lameness impact; incidence and duration of lameness are both important. Duration of lameness has a huge effect on the impact of lameness on the welfare and productivity of dairy cattle (Archer *et al.* 2010; Ekanayake *et al.* 2022). Thus, to understand the true impact of lameness on a farm, knowledge of the expected duration of lameness is essential. Furthermore, understanding variations in lameness duration between farms or systems may also identify treatment and control strategies that are more effective than others, bypassing the need for randomised clinical trials, which are notoriously difficult and expensive to conduct for lameness (Thomas *et al.* 2015). The most clinically relevant causes of lameness in New Zealand are non-infectious lesions that involve damage to the corium with subsequent haemorrhage, collectively known as claw horn disruption lesions. These lesions

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include white line, sole, and axial groove lesions, all of which can lead to claw horn lameness (CHL). Understanding the incidence of lameness is also important, however measuring this requires continued ongoing observation or retrospective analysis of potentially flawed data such as farmer records (e.g. Chawala *et al.* 2013). However, as incidence is dependent on both the prevalence and the duration of disease (Freeman and Hutchison 1980), incidence can be estimated directly from these parameters.

Duration is particularly important for lameness because, among painful diseases of dairy cattle, lameness is unique in its prolonged duration of effect. It has been demonstrated in New Zealand that dairy cows start to lose liveweight 3 weeks prior to being diagnosed and treated for lameness (Alawneh *et al.* 2012b). Following treatment for CHL there is a period of at least 28 days where animals have an exaggerated response to painful stimuli (Laven *et al.* 2008). However, there is very little information on expected clinical recovery rates, with the majority of previous research focused on time to cure describing lameness scoring at fixed time periods (Whay *et al.* 2005; Laven *et al.* 2008; Thomas *et al.* 2015). While these fixed time periods facilitate communication of results and comparisons between studies and systems, they do not give accurate information on the time taken for cattle to become sound. Fixed time points of 35 days (Thomas *et al.* 2015) and 42 days (Thomas *et al.* 2016) have been used in the UK to assess recovery risk. The use of these fixed time points means that a cow enrolled in the Thomas *et al.* (2016) study that became sound 3 days after treatment would have the same weighting as one that became sound at 41 days. Clearly, these different durations of lameness would have resulted in profound differences in the welfare and productivity of the lame animals. A more powerful method of analysis of duration data is time-to-event (survival) analysis, which identifies the time to cure for *x*% of animals (usually 50%, i.e. median). This analysis can take account of both when cows become sound during the study period, and cows that are lost to follow-up. In addition to time to cure, this analysis also calculates the hazard rate of soundness (i.e. the frequency at which cows become sound per unit of time). Cure rates can be converted without difficulty to cure risks when descriptive time-to-event data are provided, but converting cure risks to cure rates is usually not possible. Thus, comparisons between the studies reporting cure risks are challenging. However, the use of time-to-event analysis for CHL cure is rare, and often incomplete. For example, Klawitter *et al.* (2019) reported the hazard ratio of cure in cows with sole ulcers treated with and without bandages, but their measure of duration was the proportion healed on day 28 (rather than time to cure for *x*%). With respect to New Zealand data, Tranter and Morris (1991) analysed time to recovery of lame cows at pasture (principally white line disease, sole bruising and footrot), but did not use time-to-event analysis, and their outcome measure was mean time to recovery. Thus, there is still a gap in the literature on the recovery rate of dairy cattle, especially for claw horn lesions.

Knowledge on lameness recovery times is important both to judge the welfare impact of lameness, and to gauge whether a treatment is successful. More detailed knowledge around expected recovery times will empower animal health advisors and farmers to assess farm performance of lameness treatment, and to give more scientifically backed advice around when re-examination of an animal is required. With the increasing use of precision livestock farming, this may enable advisors to track the recovery rates of lame animals across various farms. The aims of this study were therefore to describe the clinical lameness recovery rate in pasture-based dairy cattle diagnosed with CHL and treated with best-practice treatment protocols, and to assess whether the recovery rate varied between farms.

Materials and methods

This was a descriptive observational epidemiological study. All manipulations of animals were approved by AgResearch (Ruakura) Animal Ethics Committee application number 15097.

Five dairy farms from the Waipā and Otorohanga districts (Waikato region) of New Zealand were enrolled, based on a convenience sample, in the spring of 2020, and three of those farms were enrolled again in the spring of 2021. The farms were enrolled based on a proven track record of involvement in research trials, with a location within 50 km of the veterinary clinic that author WM was affiliated with, and with the necessary willingness and lame cow treatment facilities to conduct and participate in the study. The start and end dates were dependent on the farm enrolled and were based on the historical time frame at which peak lameness incidence typically occurred (either pre-mating or during mating). Across both years, the median enrolment time period on the farms was 70 (min 45, max 141) days.

The target population for this study was cows with CHL. The eligible population consisted of all non-lame lactating dairy animals present on enrolled farms at the initial enrolment date. From the start date until the end date for enrolment on each farm, animals that were identified as lame by the farmer, and then examined by the study veterinarian (MC), were eligible to be enrolled in the study. Lame cattle were identified as per normal on-farm practices, with no formal training given to the farmers.

Following the identification of a lame animal by the farmer, the animal was examined within 24–48 hours

by the primary veterinarian. As a first step, all animals had a lameness score (LS) event recorded by a technician while the cows were on a concrete collecting yard. Scoring was based on the DairyNZ 0–3 grading system (DairyNZ 2023) (Table 1), a method adapted from the Agriculture and Horticulture Development Board in the UK. Cows that were given a LS $\geq$ 2 by the technician were eligible for inclusion in the study.

For the trial, all cows were scored by the same technician who was trained to LS by author WM, and who was re-assessed four times within the first month of the study by the same author. Formal training consisted of LS theory and watching pre-recorded videos, which the technician was quizzed on until 100% agreement was reached with author WM. A practical session was then conducted with > 200 animals scored while walking back to grazing following milking. Assessment of drift was not carried out during the observation period, and reliability measures were not assessed. For all LS events, both the score and the limb were recorded; however, the animal was the unit of interest for the study.

After scoring, eligible cows were placed into a purpose-built lame cow crush on the farm. Non-lame animals were not examined in the crush. Examination and treatment of the lame foot followed the guidelines set out in the DairyNZ Lameness Field Guide (DairyNZ 2017), with the primary pain-inducing claw and lesion identified using hoof testers. After therapeutic trimming, wooden blocks (Demotec blocks with Hoof-Tite adhesive; Veehof, Ashburton, NZ) were applied to the non-lame claw provided there was an absence of marked pain detectable by hoof testers. The presence of visible lesions on that claw, the LS, and lesion severity did not affect the decision making for block application. The application of wooden blocks was ultimately done at the veterinarian's discretion; however, the use of blocks was actively encouraged, and a reason recorded if one was not applied. Farmers were incentivised to participate in the study by having their lame cattle treated without charge. The same veterinarian carried out all examinations and therapeutic hoof trimming on the five farms across both study years to ensure consistency.

In addition to exclusion from the study if they had a LS of $\leq$ 1 at the time of the veterinary visit, cows presented by the farmer to the veterinarian as lame were excluded if they had non-CHL (e.g. footrot, digital dermatitis, upper limb injury); lameness that required claw amputation; bilateral LS = 3 lameness; marked pain response on medial and lateral claw of the same limb upon hoof-testing; or non-compliance (i.e. difficult to handle/treat). After exclusions, the CHL identified as causing lameness were defined as either primarily white line lesions, sole lesions, or axial wall lesions. An animal could only be enrolled once; any subsequent or repeat case of lameness was not eligible for inclusion in the study.

After enrolment, an animal was removed from further involvement in the study in the event of any health or welfare reason(s) that might bias the study or cause unnecessary suffering of the animal. Specifically, they were re-examined if they had a LS = 3 on more than one occasion after enrolment, or if they became lame (LS $\geq$ 2) on another limb and were then removed from any further participation in the study. Animals were also excluded if they were treated for lameness by the farmer at any stage during the study period. Animals were included within the analysis up to the date of any subsequent exclusion, so that LS data prior to exclusion was still analysed; all animals that had at least one LS following initial lameness examination were included in the analysis.

Once enrolled, animals had a LS event recorded a median of 2 (min 1, max 3) times per week; the greatest length of time between scoring events on a farm was 8 days, with a median of 4 days. All enrolled animals were managed in a separate lame herd close to the milking parlour and milked once per day, with the dietary allocation decided and managed by the farmer. Lame animals remained in this herd until the study technician had defined them as sound (LS = 0), at which point the study concluded for that animal. Blocks were assessed for retention up to 14 days; if they fell off, the animal was bought back into the crush and a block re-applied. No data were collected on block retention after 14 days, and no attempt was made to remove blocks from sound animals.

Table 1. Lameness scoring descriptors used in a study of lameness recovery rates following treatment of dairy cattle with claw horn lesions on 5 farms from the Waikato region of New Zealand (adapted from DairyNZ lameness scoring system; DairyNZ 2023).

Lameness score	Descriptor
0	Walks with even weight bearing on all four limbs at a similar walking speed to a person, with regular stride length and rhythm. Straight back line at all times and head held in line or slightly below the backline and steady when walking
1	Walks unevenly but reduced weight-bearing on affected limb not easily obvious. May have uneven stride length and/or rhythm. Backline straight when standing but may be mildly arched when walking
2	Lame, with decreased stride length on affected limb. Weight-bearing reduced on affected limb, which can easily be identified. Walking speed slower than normal. Backline often arched when standing and walking and head bobs up and down when walking
3	Severely lame, with minimal or no weight-bearing on affected limb. Reluctant to move and cannot keep up with the healthy herd. Backline arched when standing and walking and often large head movements up and down when walking

Statistical analysis

Descriptive statistics were tabulated and presented for the number of animals examined and enrolled into the

study based on farm, age, breed, year, LS at enrolment and lesion. Age was categorised into 2, 3, 4–8 and > 8 years of age. Breed was defined as one specific type if an animal had > 12/16 of one breed as defined by Livestock Improvement Corporation (Hamilton, NZ); all others were defined as cross-bred. All analyses were carried out at the cow level and were undertaken using R Version 4.2.0 (R Core Team, 2022; R Foundation for Statistical Computing, Vienna, Austria).

Survival analysis techniques were used to analyse the days from enrolment to being diagnosed as sound. Kaplan–Meier (KM) survival curves, with risk tables, were produced for each farm, and overall. Animals were right-censored at the time they were removed from the study due to post-inclusion removal, or at the last LS event if they did not have a LS = 0. The time-to-event for 10%, 25%, 50%, 75% and 90% of enrolled lame cows to become sound was reported, and the probability of lameness cure, with 95% CI of the KM estimate using the log–log method, at 7, 14, 21, 28 and 35 days presented.

Table 2. Descriptive statistics (number (n) and percentage) of the population of enrolled dairy cattle with claw horn lameness across two dairy seasons (n = 241) recorded as part of a study of lameness recovery rates following treatment on 5 farms from the Waikato region of New Zealand.

		Year	
Variable	Overall (n = 241)	2020 (n = 151)	2021 (n = 90)
Farm			
Farm 1	33 (14%)	33 (22%)	0 (0%)
Farm 2	78 (32%)	31 (21%)	47 (52%)
Farm 3	33 (14%)	21 (14%)	12 (13%)
Farm 4	60 (25%)	29 (19%)	31 (34%)
Farm 5	37 (15%)	37 (25%)	0 (0%)
Claw-horn lesion			
Sole	16 (6.6%)	10 (6.6%)	6 (6.7%)
White line	225 (93%)	141 (93%)	84 (93%)
Two limbs involved			
No	226 (94%)	140 (93%)	86 (96%)
Yes	15 (6.2%)	11 (7.3%)	4 (4.4%)
Age (years)			
2	18 (7.5%)	12 (7.9%)	6 (6.7%)
3	22 (9.1%)	14 (9.3%)	8 (8.9%)
4–8	161 (67%)	99 (66%)	62 (69%)
> 8	40 (17%)	26 (17%)	14 (16%)
Breed			
Friesian	61 (25%)	41 (27%)	20 (22%)
Jersey	47 (20%)	24 (16%)	23 (26%)
Cross-breed	133 (55%)	86 (57%)	47 (52%)
Block applied			
No	34 (14%)	25 (17%)	9 (10%)
Yes	207 (86%)	126 (83%)	81 (90%)
LS[a] at enrolment			
2	218 (90%)	138 (91%)	80 (89%)
3	23 (9.5%)	13 (8.6%)	10 (11%)
Limb			
Back left	124 (51%)	82 (54%)	42 (47%)
Back right	99 (41%)	61 (40%)	38 (42%)
Front left	10 (4.1%)	5 (3.3%)	5 (5.6%)
Front right	8 (3.3%)	3 (2.0%)	5 (5.6%)
Claw			
Lateral	189 (78%)	131 (87%)	58 (64%)
Medial	52 (22%)	20 (13%)	32 (36%)

[a]Lameness score (LS) system adapted from DairyNZ (2023).

To assess statistical associations between potential risk factors and the hazard rate of soundness, Cox proportional-hazard models were generated. Potential risk factor variables and confounders included farm, age, breed, block application, loss of block, lesion, year of enrolment, LS at enrolment, and multiple limb involvement. Each of these potential risk factors were initially screened with respective unconditional Cox proportional-hazards models and any that had a likelihood ratio test $p < 0.20$ were included in an initial multivariable Cox proportional-hazards model; no interactions were assessed due to the low power to assess interactions and lack of biological plausibility. Backwards elimination of variables was carried out until the likelihood ratio test between two nested Cox proportional-hazard models had a $p < 0.05$. Those variables that were removed from the model were then placed back in one by one, in order of the smallest p-value from the likelihood ratio test to the greatest to assess for confounding. If the variable altered the coefficients or standard errors of the included risk factors by > 20%, then it was considered a confounder and retained in the model. Results from the model were reported as hazard rate ratios (HRR) with associated 95% CI and p-values. The HRR and 95% CI for all unconditional associations were also reported. The proportional hazards assumption was assessed using a global statistic based on Schoenfeld residuals. Deviance residuals and Cook's distances were investigated to assess for outliers and influential observations, respectively.

The KM descriptive statistics as described above were then replicated for the number of days taken for an animal to become non-lame (LS $\leq$ 1) as the outcome.

Results

A total of 284 animals were examined for lameness from five farms, with 241 animals enrolled. Those not enrolled were excluded due to either footrot (n = 26), upper-limb lameness (n = 5), or no identifiable lesion despite a LS $\geq$ 2 (n = 12). The majority of lameness identified in the enrolled cows on the five farms was diagnosed as being due to white line disease (225/241; 93%), with only 16/241 (7%) of animals diagnosed with a primary sole-based lameness-causing lesion (Table 2). There were no animals diagnosed and enrolled with axial wall lesions. In total, 16/241 (7%) enrolled animals had lameness in the front claws. Fifteen animals (6%) had clinical lesions on two limbs; all of these were in hind feet. In total, 207/241 (86%) enrolled animals received a wooden block on the sound claw. Eleven of the 207 (5.3%) blocks fell off within 14 days of treatment and were replaced. Monthly CHL incidence rates on the farms during the study periods ranged from 2.0 to 9.2 cases per 100 cow months, with a median of 3.5 cases per 100 cow months (Supplementary Table 1).

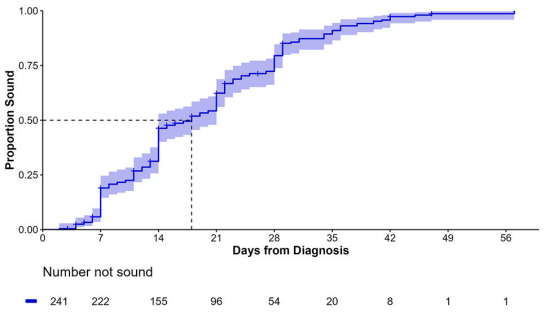

Figure 1. Kaplan–Meier estimate of cumulative survival curve and risk table for the days to become sound (lameness score = 0, adapted from DairyNZ 2023) following treatment for dairy cattle (n = 241) with claw horn lesions on five farms in the Waikato region of New Zealand. The shaded area represents 95% log-log CI, and the + are right-censored animals.

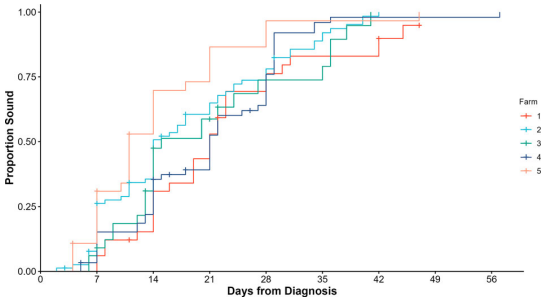

Figure 2. Cumulative survival curve from a Cox proportional-hazard model for the days to become sound (lameness score = 0, adapted from DairyNZ 2023) following treatment for dairy cattle (n = 241) with claw horn lesions on each of five farms in the Waikato region of New Zealand.

Time to soundness (LS = 0)

The overall median days taken from enrolment to becoming sound was 18 days, i.e. 50% of lame cows were sound and back with the main milking herds within 18 (95% CI = 14–21) days of treatment (Figure 1 and Table 3). The cumulative unadjusted KM survival curve, and associated risk table, highlights a relatively consistent pattern in the time taken for animals to become sound up to approximately 35 days following enrolment. It took 7 days for at least 10% of animals to become sound, 11 days for 25%, 28 days for 75% and 35 days for 90%.

There were 25/241 (10.4%) animals right censored (median 14 (min 3, max 47) days) that never achieved a recorded LS = 0 event after treatment. Six of those became lame on a different limb, 13 were re-treated because lameness did not improve or became worse, three were treated by the farmer after enrolment, and three were the result of unrelated death or culling. If it was assumed that all 25 censored animals would have been LS > 0 at 60 days following treatment, then the only major difference noted would have been an overall cure rate of 90%, compared to 99%. The time for 50% and 75% of animals to become sound would have increased by 1 day, to 19 and 29 days, respectively, while there would have been no difference in the time taken for 10% and 25% of animals to cure.

The only variable that was included in the final Cox proportional-hazard model was farm, with differences noted between farms in the hazard rates of becoming sound following lameness treatment (Figure 2, Table 4). The predicted median survival times by the KM analysis ranged from 11 days to 21 days, and HRR from the Cox proportional-hazard model were significantly different between farms (p = 0.007). From the unconditional Cox proportional-hazard models, no associations were identified between any of the other potential risk factor variables and time to soundness (Table 5). No deviation from the proportional hazards assumption was identified, and no influential observations or outliers were identified. There was also no association between application of a block compared to no application of a block (HRR = 1.26; 95% CI = 0.8–1.9), although the proportional hazard assumption was violated, so this inference may be invalid.

With non-lame as the outcome (number of days to first LS ≤ 1), the median number of days predicted by the KM analysis to become non-lame was 7 (95% CI = 7–8) days (Figure 3 and Table 3). It took 4 days for at least 10% of animals to become non-lame, 7 days for 25%, 14 days for 75% and 21 days for 90%. The median number of days to non-lame event per farm ranged from 7 to 9 days, but there was a greater range between farms for when 75% of the animals became non-lame (11–21 days).

Table 3. Kaplan–Meier non-parametric cumulative survival probability (with 95% CI) for probability of soundness (lameness score[a] (LS) = 0) and probability of non-lame (LS ≤ 1) at 7, 14, 21, 28 and 35 days after enrolment in a study of lameness recovery rates following treatment of dairy cattle with claw horn lesions on 5 farms from the Waikato region of New Zealand.

	Probability of lameness cure	
Days since enrolment	LS = 0	LS ≤ 1
7	0.19 (0.25–0.15)	0.54 (0.61–0.48)
14	0.46 (0.53–0.4)	0.81 (0.86–0.76)
21	0.62 (0.69–0.56)	0.94 (0.97–0.9)
28	0.8 (0.85–0.74)	0.97 (0.99–0.94)
35	0.91 (0.94–0.86)	1.00

[a]LS adapted from DairyNZ (2023).

Discussion

This observational study reports the cure rates of lactating dairy cattle with LS ≥ 2 diagnosed with CHL on five New Zealand dairy farms undergoing best-practice hoof trimming treatment. Median cure rates to soundness of 18 days and to non-lame in 7 days were reported, highlighting that excellent recovery rates

Table 4. Results of final Cox proportional-hazards semi-parametric regression model predicting hazard rate ratio (HRR) for return to soundness following treatment of dairy cattle (n = 241) with claw horn lesions on five farms in the Waikato region of New Zealand.

Variable/category	Coefficient	SE	HRR (95% CI)	P-value
Farm				0.007
1	Reference			
2	0.43	0.22	1.54 (1.00–2.39)	
3	0.26	0.27	1.29 (0.76–2.21)	
4	0.26	0.23	1.30 (0.82–2.06)	
5	0.92	0.26	2.51 (1.50–4.18)	

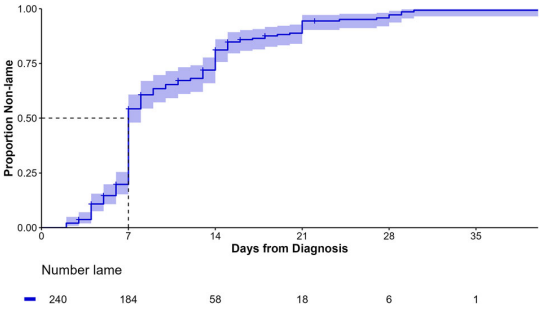

Figure 3. Kaplan–Meier estimate of cumulative survival curve and risk table for the days to become non-lame (lameness score ≤ 1, adapted from DairyNZ 2023) following treatment for dairy cattle (n = 241) with claw horn lesions on five farms in the Waikato region of New Zealand. The shaded area represents 95% log-log CI, and the + are right-censored animals.

can be achieved in lame New Zealand dairy cattle, even when the animals are identified as lame by farm staff without routine measurement of LS. Differences in cure rates between farms were also identified.

A range of values for risk of cure of CHL have been previously reported, with the majority of these considerably poorer than those reported in the current study. Studies from the UK had non-lame cure risks ranging from 78.6% 2 weeks after treatment (Miguel-Pacheco *et al.* 2017) to 15% at 42 days (Thomas *et al.* 2016). At 35 days after treatment in a randomised clinical trial on acutely lame animals in the UK, soundness cure risks of 24–55% were reported (Thomas *et al.* 2015); for comparison purposes, 90% of lame animals had returned to sound in the current study by 35 days. The cure risk has also varied in studies conducted on cattle managed at pasture. An early New Zealand study of pasture-based cattle reported mean recovery times of 27 days from 73 animals with white line lesions and 30 days from 78 animals with bruising (Tranter and Morris 1991). More recently, Laven *et al.* (2008) reported between 54% and 79% cure risk 28 days after treatment for soundness (LS = 1/5), or 62–91% 28 days after treatment with non-lame as the outcome (LS < 3/5). The cure rates reported for the current study are most similar to the recovery rates reported by Australian farmers from a study three decades ago (Pyman 1997). Almost 50% of animals treated with a wooden block had an improved LS by 3 days and 65.8% by 7 days; however, these cure rates were reported by the farmer and a more subjective and unvalidated LS method was used in that study, thus the quality of the information is uncertain. To the authors' knowledge, the cure rates reported in the current study are both the most sensitive ever reported for CHL due to the frequent nature of the LS events and are among the shortest time-to-soundness estimates reported.

In order to assess the true lameness cure risks/rates, it is important to consider animals that were either removed from the study after enrolment (Thomas *et al.* 2015, 2016), or those that were re-treated but remained in the study (Laven *et al.* 2008). In some studies, this is no trivial matter. For example, 33 out of the initial 189 enrolled lame cattle (17.5%) in the study by Thomas *et al.* (2016) were lost to follow up and not analysed, with 13/33 of these due to re-treatment of lameness. From a total of 3,967 individually treated lame animals in Taranaki, New Zealand, 521 had a re-treatment event recorded, although no further data were provided on the time frame from first to second case of lameness (Chesterton *et al.* 2008). In all studies reporting cure risk, an *a priori* decision has to be made on whether those animals are included or removed from the analysis. Regardless of the decision, this biases the cure risks such that the true cure risks are likely poorer than reported. One of the major advantages of using survival analysis techniques is that all enrolled animals can make up part of the denominator at some stage prior to censoring. The current study had 25 censored animals, 19 of which were either re-treated for lameness in the

Table 5. Results of univariable Cox proportional-hazards semi-parametric regression models predicting hazard rate ratio (HRR) for return to soundness following treatment of dairy cattle (n = 241) with claw horn lesions on five farms in the Waikato region of New Zealand.

Variables	HRR (95% CI)	P-value
Age (years)		
>8	Ref	0.48
2	0.89 (0.49–1.63)	
3	0.69 (0.40–1.20)	
>3–8	0.77 (0.54–1.11)	
Lame limbs		
1	Ref	0.72
2	0.91 (0.53–1.56)	
Lameness score at enrolment (0–3 scale[a])		
2		0.50
3	0.85 (0.52–1.38)	
Breed		
Friesian	Ref	0.72
Jersey	1.1 (0.74–1.65)	
Cross-breed	0.95 (0.69–1.32)	
Year		
2020	Ref	0.11
2021	0.8 (0.60–1.06)	

[a]Adapted from DairyNZ (2023)
Ref = the reference category for each categorical variable.

same limb or became lame in a different limb. Using sensitivity analysis, we could confirm that these censored observations did not influence the median time to cure, and only made a 9% difference to the final cure risk at 60 days if it were assumed that none of these would have cured.

Another challenge of lameness research measuring cure risk/rate as the outcome is that of recurrent lameness *vs.* a new case of lameness. If only single LS time points are reported, it may be near-impossible to differentiate an ongoing case of lameness from an animal becoming sound and then lame again, especially in systems with high prevalence of lameness. Animals in the study by Groenevelt *et al.* (2014) had a more than 30% lower cure risk at 18 weeks post-treatment compared to 2 weeks post-treatment, highlighting how substantial this issue can be. The current study focused on time to first soundness event with frequent assessments and, as such, the issue of recurrent *vs.* new cases was not an issue. However, the animals were not followed beyond the point at which they became sound, so no information was available on whether those animals then became lame again. Cure rates also depend on whether the analysis is at the limb level or cow level. Despite the very poor cure rates at the cow level reported in Thomas *et al.* (2016), when the apparent leg-cure was used as the outcome, rather than the whole animal, cure rates between 52% and 58% for each of the treatment groups were reported. Although cure rates were assessed at the cow level in the current study, there was a low incidence of contra-lateral limb lameness reported, so we do not believe this to be a large issue.

There is a consensus that time to lameness diagnosis and lameness treatment protocols are strongly associated with lameness cure risk (Groenevelt *et al.* 2014; Thomas *et al.* 2015; Pedersen and Wilson 2021). Although it is hypothesised that the adherence to best-practice treatment protocols and prompt identification of the lame cattle were at least partly responsible for the rapid cure times noted in this study, no control group was present to assess this. Farmers were incentivised by having the lame animals treated and managed for them at no cost and this undoubtedly increased their motivation to identify lame animals early. However, this was similar to the study protocol of Laven *et al.* (2008). Alawneh *et al.* (2012b) also offered to treat lame animals at no cost, yet there was still a median period of 3 weeks of weight loss before lameness was identified. Furthermore, although all cows identified with LS > 3 (1–5 scale) were eventually presented for lameness treatment by the farmer in the study by Alawneh *et al.* (2012a), > 40% of these were treated > 3 weeks after being identified as lame. Therefore, it is unlikely that a large proportion of the cure rates in the current study can be attributed to rapid identification of lameness.

The use of blocks on the sound claws was encouraged in all animals, regardless of size and severity of lesions. Whilst the study design did not enable direct inferences to be assessed, the authors propose that the high frequency of blocks may be at least partially responsible for the rapid cure rates identified. Blocks were applied to 85% of all enrolled cattle, with 50% of animals non-lame within 1 week of treatment. Laven *et al.* (2008) reported that 45% of all lame animals enrolled required a plastic shoe based on lesion severity and size, and that usage below this proportion likely indicates underuse of this treatment. The present authors would go one step further and state that, based on the results from the current study, there should be a good reason provided not to apply a block, rather than requiring reasons to administer a block, and we should aim for targets close to 100% of animals with CHL receiving some form of block.

The authors speculate that the other likely reason for the relatively rapid cure rates reported in this study is the post-treatment management of the lame animals, an area that has received little attention in the lameness literature compared to rapid detection and prompt treatment. There has been concern for the welfare of lame cattle post-treatment in pasture-based dairy cattle due to the perceived distances that they need to walk (Pinheiro Machado Filho and Gregorini 2022). In this study, as is common practice in New Zealand, to minimise the impact of walking on lameness recovery, all of the lame cows were managed in a separate herd close to the milking parlour and milked once per day until they recovered. This management approach probably reduced time to soundness by maximising time spent on pasture and minimising the contact with hard-wearing surfaces such as tracks and collecting yards (an approach that has been shown to have benefits in lame cows that are normally housed; Hernandez-Mendo *et al.* (2007); Black *et al.* (2017)). The differences in cure risk apparent when the lameness studies are collapsed into housed or pasture-based systems support this suggestion, with the poorest cure risk/rates associated with housed cows (Thomas *et al.* 2015, 2016; McLellan *et al.* 2022), and all of the best cure risk/rates reported on pasture-managed cattle (Pyman 1997; Laven *et al.* 2008). The comparisons between these studies strongly suggest that management system has the biggest impact on the cure risk of CHL (even greater than the speed of recognition of lameness), and that post-treatment management must always be considered as part of the optimal treatment strategy for lame cows. Nevertheless, it is important to identify that there is an absence of evidence that the strategy of managing lame cows in close proximity to the milking parlour does improve lameness cure risk, and, if it does, what the optimal regime is, particularly in regard to how long cows should be kept in the lame

group. Having a separate group of lame cows is not without costs or potential welfare impact (grass availability is often lower and re-introduction to the main herd may result in increased experience of agonistic behaviour).

Appropriate post-treatment management also includes defining when an animal should be re-examined and re-treated in the face of poor treatment response. NZ dairy industry advice is that animals should be re-examined if lameness worsens or does not improve within 7 days (DairyNZ 2017), although this was based on expert opinion rather than published evidence. This study does provide some evidence to corroborate the advice that lame animals that have not improved within 7 days should be re-examined. Farmers and veterinarians should have systems in place to monitor and manage the re-treatment of lame animals.

Differences were identified in lameness cure rates between farms, despite the animals undergoing the same treatment protocols by the same veterinarian and similar management post-treatment (within 200 m of milking parlour, regular monitoring for treatment failure and milked once per day). Thus, much of the variation in the treatment itself was removed. We do not know why the differences between farms occurred, but HRR on the farm with the most rapid lameness cure rates was two times higher than on the farm with the slowest cure rates. Further investigation into the reasons between farm differences may provide some insight into lameness risk factors and possible improvements in lameness treatment, particularly with respect to after care. Validating and using continuous precision livestock farming systems for LS in the future may highlight these farms, allowing benchmarking and investigations into why cure rates were different between farms.

It is important to note that the current findings may not be extended to all New Zealand dairy farms. All five farms were located within the Waikato region and carried out at a similar time of year (late spring, early summer). There have been reported differences in month of peak lameness incidence between North and South Islands (Chesterton *et al.* 2008; Gibbs 2010), and it is not known whether cure rates of lameness identified later in lactation would be different to those identified earlier in lactation. Furthermore, these farms were conveniently selected due to historical study compliance of the farm owners and managers, and these farmer behavioural traits may also flow on to how they handle stock. Finally, the lesion type was predominantly white line, with little primary sole lesions and no axial wall lesions. While the proportion of lameness attributable to white line disease is increasing in New Zealand (Gibbs 2010; Lawrence *et al.* 2011), the proportion noted in this report is greater than those previous reports.

There were some limitations with the internal validity of the data. One potential source of bias with this study design was the farmer-reporting of lameness cases, as described previously in this discussion. Whilst the specificity and positive predictive value of included lameness cases was increased in this study as both farmers and trained technicians had to record the animal as lame, the low sensitivity of lameness detection in New Zealand (Fabian *et al.* 2014) suggests that there would have been unidentified lame cows present within the enrolled herds. Cows identified lame by New Zealand farmers have both a greater LS at diagnosis, and a greater duration of lameness compared to those identified by trained dedicated observers (Alawneh *et al.* 2012a). Therefore, while the lame animals identified in this current study represent lame animals typically identified and treated by NZ farmers, they likely represent lame animals on the more severe and chronic spectrum of the disease. Chronicity of lameness is an important predictor of cure risk (Thomas *et al.* 2015, 2016) with shorter time to lameness identification being associated with improved cure risks (Groenevelt *et al.* 2014). There was also a potential bias with the non-parametric KM estimate used to report time to cure. As is common with most medical time-to-event data, the data were interval-censored with LS occurring at a median of every 4 days. The KM estimate assumes that the moment of the event (in this case lameness cure) occurs at the time of observation. In reality, the animal may have become sound at any stage between two LS events. Other estimates, such as the Turnbull estimate, provide methods to account for interval-censoring. The KM estimate was used here despite this limitation for several reasons. Firstly, the interval length between LS events was biologically small (median of 4 days). Thus, the impact of this bias is likely to be very small and not biologically relevant. Secondly, and consequently, the communication of KM methods is well used and understood in the veterinary profession. The methods defining KM estimates and their variance are more straightforward than those for interval censored data, and reporting of KM outcomes enables more ready comparisons between studies, including for different disease processes if desired. The implication of both farmer diagnosis and interval-censored data is that the estimates presented may be conservative, and that the true lameness cure rates on these farms may be even more rapid. Finally, as the technician and veterinarian were both employed by the same company, it was possible that unconscious bias was occurring from the technician with LS. While this is highly unlikely from a trained research technician, this bias cannot be completely ignored.

Despite these limitations, this descriptive study provides evidence that rapid times to non-lameness and

soundness are possible on New Zealand dairy farms, and that cure rates can differ between farms. Knowledge on expected recovery rates can be used at the farm level, by identifying animals that should be re-examined if still lame after *x* days, and also at the industry level, by identifying and investigating why certain farms have more rapid lameness cure rates than other farms. Importantly, these data provide further evidence that the management of lame cattle on pasture can positively benefit their welfare and recovery times.

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4

Farm-level risk factors for dairy cattle lameness

Whilst Chapter 2 reported on the low lameness prevalence in New Zealand dairy cattle, it was apparent that there was a large range between farms (0.0 to 17.0%). This suggests that there are certain farm-level risk factors for lameness on certain farms. Farmers enrolled into the prevalence study were all provided with a questionnaire on potential farm-level risk factors, as well as the treatment protocols used on farm. I report here on the questionnaire results from the 119 responders, with the goal of identifying farm-level variables that could be controlled or promoted to reduce the impact of lameness on farms. Descriptive statistics on lameness treatment and recovery protocols used across these farms are also reported. This manuscript has been submitted to the New Zealand Veterinary Journal.

Farm-level risk factors and treatment protocols for lameness in New Zealand dairy cattle

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ABSTRACT

AIMS: The aim of this study was to identify farm-level risk factors for dairy cow lameness, and to describe lameness treatment protocols used on New Zealand dairy farms.

METHODS: One hundred and nineteen farms from eight major dairying regions of New Zealand were randomly enrolled into a cross-sectional lameness prevalence study. Each farmer completed a questionnaire on lameness risk factors and lameness treatment and management. Trained observers lameness scored cattle on two occasions, between October-December (spring, coinciding with peak lactation for most farms) and between January-March (summer, late lactation for most farms). A four-point 0-3 scoring system was used to assess lameness, with animals with a lameness score (LS) ≥ 2 defined as lame. At each visit, all lactating animals were scored including animals that had previously been identified as lame by the farmer. Associations between the farmer-reported risk factors and lameness were determined using mixed logistic regression models in a Bayesian framework, with farm and score event as a random effect.

4. Farm-level risk factors

RESULTS: A lameness prevalence of 3.5% (2,113/59,631) was reported at the first LS event, and 3.3% (1,861/55,929) at the second LS event. There was a median prevalence of 2.8% from the 119 farms, with a range of 0.0 to 17.0%. Most farmers relied on informal identification by farm staff to identify lame animals (90/117; 77%). On 65% (75/116) of farms, there was no external provider of lame cow treatments, with the farmer carrying out all lame cow treatments. Most farmers had no formal training (69/112; 62%). Animals from farms that used concrete stand-off pads during periods of inclement weather had 1.49 times the odds of lameness compared to animals on farms that did not use concrete stand-off pads (89% uncertainty interval 1.19 – 1.88; posterior probability 100%). Animals from farms that reported peak lameness incidence from January-June or all-year-round, had 0.76 times odds of lameness compared to animals from farms that reported peak lameness incidence from July-December (89% uncertainty interval 0.51 – 0.84; posterior probability 100%).

CONCLUSIONS: Lameness prevalence was low amongst the enrolled farms. Use of concrete stand-off pads and timing of peak lameness incidence were associated with odds of lameness.

CLINICAL RELEVANCE: Veterinarians should be encouraging farmers to have formal lameness identification protocols and lameness management plans in place. There is ample opportunity to provide training to farmers for lame cow treatment. Management of cows on stand-off pads should consider the likely impact on lameness.

KEY WORDS:

Lameness, Risk factors, Treatment, Concrete, Dairy Cattle

ABBREVIATIONS:
LS – Lameness score

MICE - Multiple imputation chained equation

OR – Odds ratio

UI - Uncertainty interval

INTRODUCTION

Worldwide, lameness is one of the most important dairy cattle diseases impacting animal welfare (Whay and Shearer 2017), productivity (Huxley 2013), the environment (Mostert *et al.* 2018) and the social license to dairy farm (Hampton *et al.* 2020). We thus need effective evidence-based prevention strategies to reduce the burden of lameness.

For lameness, most of our evidence base is derived from large-scale observational studies (Bran *et al.* 2018; O'Connor *et al.* 2020; Browne *et al.* 2022a). Whilst such studies do not allow temporal causation to be assessed, the complexities and cost of conducting interventional studies for claw-horn lameness (Thomas *et al.* 2015; Wilson *et al.* 2022), compared to the relative ease of collecting data on a large number of farms/cows, means that observational studies have been key to our understanding of the epidemiology of disease.

These observational studies have identified a wide range of risk factors including animal-level risk factors such as age (Mason 2017), previous lameness (Randall *et al.* 2018), and body condition score (Lim *et al.* 2015) as well as farm-level risk factors such as housing system (Haskell *et al.* 2006), routine hoof-trimming (Griffiths *et al.* 2018), patience of farm staff (Chesterton *et al.* 1989) and rainfall (Ranjbar *et al.* 2016). However, the multifactorial nature of lameness involving, as it does, animal, environment and management components means that we need system-specific studies that identify risk factors for that system (Ranjbar *et al.* 2016). For example, Barker *et al.* (2010) identified the use of automatic floor scrapers as a key risk factor, while (Chesterton *et al.* 1989) identified track maintenance as an influential factor. The first of these is not relevant to cows kept permanently at pasture, while the second is irrelevant in zero-grazed cows.

4. Farm-level risk factors

In New Zealand, dairy cows on the vast majority of farms are kept permanently at pasture. This means that they are not regularly exposed to hard surfaces outside of milking time and, on an increasing number of farms (Milet *et al.* 2015), when they are fed supplementary feed (usually for a short period of time before or after milking). This system is markedly different from many of the systems used in North America and Europe where much of the research on lameness risk factors has been undertaken (Olechnowicz and Jaśkowski 2010; Oehm *et al.* 2019). Thus, in order to develop evidence-based lameness control programmes for dairy cattle in New Zealand we need research that is relevant to the New Zealand system. However, there is a lack of such data (Ranjbar *et al.* 2016).

This means that the current industry-led lameness programme, Healthy Hoof (DairyNZ, Hamilton, New Zealand) has based its guidelines for lameness prevention on a mix of recommendations supported by published evidence and recommendations from expert opinion. Indeed, recommendations are often a mix of the two. For example, maintaining farm tracks immediately around the milking parlour is emphasised as a crucial risk-reduction strategy. This is consistent with the findings of Chesterton *et al.* (1989) that "average maintenance state of the main track" accounted for 13.7% in the variation in lameness prevalence between farms. However, the focus on tracks near the milking parlour is based on expert opinion that these tracks will be responsible for most of the impact on lameness of poorly maintained tracks. Furthermore, expert opinion is used to decide where there is conflicting published evidence. For example, Healthy Hoof recommends that, for Friesian cows, the size of the collecting yard should be at least 1.5 m^2 per cow. This focus on collecting yard size (though not the specific minimum) is consistent with Ranjbar *et al.* (2016) who reported that an increase in the available space was associated with a reduction in the odds of lameness. However, Chesterton *et al.* (1989) reported that increased space per cow in the collecting yard was associated with an *increase* in the odds of the farm having a high lameness prevalence. This combination of evidence-base and expert opinion stands in stark contrast to the New Zealand-developed SmartSAMM mastitis and milk quality programme (https://www.dairynz.co.nz/animal/cow-

health/mastitis/tools-and-resources/about-smartsamm/) which is backed up by 23 evidence-based technotes (https://www.dairynz.co.nz/animal/cow-health/mastitis/tools-and-resources/guidelines-and-technotes/).

We clearly need more data and analysis of the risk factors for lameness in pasture-based cattle in New Zealand, so that we can better guide lameness control programmes. Furthermore, to develop such programmes, we need a better understanding of what is currently happening in regard to lameness treatment and management of New Zealand dairy farms. Thus, the aims of this study are to describe the lameness treatment and management practices carried out on New Zealand pasture-grazing dairy farms and to investigate farm-level risk factors for lameness on those farms.

METHODS

The study was designed as a cross-sectional descriptive study, with all procedures approved by Massey University human ethics committee, application number 4000025095 and Massey University animal ethics committee application number Protocol 21/55 and 22/36.

Details on farm enrolment and lameness score methods are described in full in Mason et al (submitted). In brief, a total of 120 dairy farms across New Zealand were enrolled into a lameness prevalence and risk factor cross-sectional study. Veterinary clinics from eight territorial regions of New Zealand, four within the North Island of New Zealand (Northland, Waikato, Taranaki and Manawatu) and four within the South Island of New Zealand (West Coast, Canterbury, Southland and Otago), were contracted to each randomly enrol fifteen farms. On each farm, the locomotion of all lactating cows was scored on two occasions during one dairy season (New Zealand dairy seasons are from 1 June to 31 May), using a 0 – 3 scale, where lameness score (LS) ≥ 2 was considered clinically lame (DairyNZ lameness score; Table 1). Animals were scored by trained and calibrated observers (one observer for each region) immediately after milking whilst walking on a flat concrete surface. This included animals that had been previously identified as lame by the farmer and had been placed into a separate herd at the time of the lameness scoring visit. Animals with LS

≥ 2 and the total number of animals scored on each farm were tallied. This data is the subject of a separate publication (Mason et. al, under review) and further information on the results of the lameness scores can be found in that publication. The power of the study, and thus the number of farms enrolled, was selected based on being able to detect lameness prevalence to within 5%, if the true prevalence estimate was 8.3%. It was not powered to detect differences between farm-level risk factors. However, the power calculation of 100 cows from 100 farms used in Browne *et al.* (2022a) would infer that the current study was powered to detect a risk factor with a relative risk of 1.3, with an 80% power.

Table 1. Lameness scoring descriptors used in a cross-sectional observational study investigating farm-level risk factors for lameness (adapted from DairyNZ Lameness Scoring system)

Lameness Score	Descriptor
0	Walks with even weight bearing on all 4 limbs at a similar walking speed to a person, with regular stride length and rhythm. Straight back line at all times and head held in line or slightly below the backline and steady when walking
1	Walks unevenly but reduced weight-bearing on affected limb not easily obvious. May have uneven stride length and/or rhythm. Backline straight when standing but may be mildly arched when walking.
2	Lame, with decreased stride length on affected limb. Weight bearing reduced on affected limb which can easily be identified. Walking speed slower than normal. Backline often arched when standing and walking and head bobs up and down when walking
3	Severely lame, with minimal or no weight bearing on affected limb. Reluctant to move and cannot keep up with the healthy herd. Backline arched when standing and walking and often large head movements up and down when walking.

On each of the farms, the primary decision maker for animal health was asked to respond to a survey after the completion of the first farm visit. The farmers were blind to the results of the lameness score until the completion of the study, and no lameness advice was provided to the farmers by study personnel.

Farmer questionnaire

A questionnaire consisting of four sections was sent to all enrolled farmers. The first section consisted of farm demographics and descriptive information and included responses on herd size, breed proportion, collecting yard shape and size, milking parlour design, milking frequency, farmer-defined lameness

incidence risk for the lactation and month of peak lameness incidence. The second and third sections were on lameness diagnosis and treatment, respectively. This included how lame cows were identified, whether all lame cows had their hooves lifted and examined, if lame cows were treated in a purpose-built lame-cow crush, whether lame cows were treated by an external operator (veterinarian and/or hoof-trimmer), if the farmer had had any formal lameness treatment training, the predominant lameness lesion identified, the proportion of lame cows that received NSAIDs or a block, and whether any culling decisions were based on lameness or if the farmer prioritized culling based on lameness. Data were also collected on whether lame cows were milked once-a-day, and if lame cows were always managed in a separate herd near the milking parlour. The final section was on lameness and animal handling management on farm, and included the use of a top-gate, whether the backing-gate or top-gate was alarmed or electrified, whether dogs were used to move cows, whether the farm had a permanent foot-bath or in-shed feeding, or whether they used a concrete 'stand-off' pad (i.e., cows were held on either a feed pad or on the collecting yard during periods of inclement weather to protect pasture from pugging damage). Farmers were also asked to report the maximum one-way distance a cow would walk and the average distance walked per day across the season, and what percentage of the farm tracks underwent maintenance every year. Questionnaires were completed by the primary decision maker on farm either in person at the completion of the first LS visit, or within two weeks following the first LS via phone consultation, with farmer responses transcribed by the technician. Study technicians were responsible for transcribing all questionnaire responses into a Microsoft Excel spreadsheet. All responses were from the farmer, with no on-farm validation of farmer responses by study personnel (Supplementary Table 1).

Statistical methods

At the completion of the collection period, the raw questionnaire data in a .csv file was imported into R (R Core Team 2023), where all data analysis was conducted. Farmer survey data were tabulated and reported descriptively, split by whether they were on the North or South Island.

4. Farm-level risk factors

Scores for individual cows were collapsed into lame (LS 2 or LS 3) or non-lame (LS < 2) categories and the unit of interest for all lameness score data was at the cow level. All continuous variables were categorised into two or three categories each containing an equal number of farms, based on discussions between the researchers on the biological relevance and granular reporting of the answers. The proportion of each breed was recategorised as the single breed that made up the greatest amount of the herd. The month of greatest number of lameness cases was categorized into July-December, or January-June, with the latter category including all responses where "all months' were reported as the greatest number of lameness cases. As farmers could select more than one option for lameness detection methods, this variable was collapsed into whether farmers only identified lame animals informally when cow were walking to and from the milking parlour, or if they selected any of the formal lameness identification methods (LS from external providers, farm staff or on-farm technology). Farmers that entered more than one primary lameness lesion were recategorised as reporting multiple lesions.

Missing predictor data was handled using different methods, depending on the analysis. At the univariable level, all missing values were removed from the respective models. At the multivariable level, missing data was handled via two methods, depending on the proportion of data missing for each variable. If a variable had greater than 10% missing, it was not included in the multivariable model, regardless of its significance at the univariable level. If a variable had less than 10% missing, it was included in the initial multivariate model, and multiple imputation chained equations (MICE; n=10 chains) were used to simulate and replace missing predictor values, all of which were coded as factors.

The final data set consisted of a total of 34 farm-level risk factors (described in Tables 2-4). These variables were individually assessed at a univariable level initially using mixed logistic regression techniques. There were two areas of lack of independence with cows having two repeated scores, and cows nested with farm. This was accounted for by including score nested within farm as a random intercept in all models. The odds ratio (OR), with 95% confidence interval and p value based on the log-likelihood ratio test, was then reported individually for each risk factor. These ORs can be interpreted as the odds of a

cow being lame in the average farm with the presence of the risk factor, without accounting for any potential confounders. Any variable with a log-likelihood ratio test (between a model with the variable included and an intercept only model) with a $p < 0.20$ was then included into an initial multivariable mixed logistic regression model. These variables were first assessed for collinearity, with variables with variance inflation factors > 4 from a multivariable generalised linear regression model deemed to have high collinearity with other predictors, and not included further in the analysis.

For the subsequent multivariable analyses, Bayesian generalised linear regression models were used, using default non-informative priors. These were implemented within the brms package in R (Bürkner 2017), using no-u-turn Markov chain Monte Carlo sampling methods. For each of the 10 MICE chains, five chains of 4000 iterations each, with 500 warm-up iterations, were run (a total of 50 chains). Starting with a full model, variable selection was carried out using leave-one-out cross-validation with Pareto smoothed importance sampling algorithms, the model with the combination of fixed effects with the smallest expected log predictive density defined as the best fit for the data (Vehtari *et al.* 2017). No interactions were investigated. After fitting the model, posterior predictions of the odds ratio were made for each remaining variable. Uncertainty around the odds ratios of these variables is reported as 89% equal-tailed uncertainty intervals. Trace plots of each chain and the rhat statistic (>1.05 was defined as poor convergence) were used to assess convergence of posterior samples.

RESULTS

Farm descriptive statistics

A total of 119 of the 120 enrolled farms responded to the farm survey, 14 farms from the West Coast, and 15 from the other seven regions. Farm characteristics, split by island, are presented in Table 2. From the 119 farms, a total of 2,113/59,631 (3.5%) cows had a LS ≥ 2 at the first LS event. During the second LS event, a total of 1,861/55,929 (3.3%) cows had a LS ≥ 2. At the farm level, across both scoring events,

median lameness prevalence was 2.8%, with a range of 0.0 to 17.0%, (more detail available in Mason et al. (submitted)).

Table 2. Farm characteristics of those enrolled into the study, split by North and South Island of New Zealand

Characteristic	**Overall**, N = 119	**North**, N = 60	**South**, N = 59	**p-value**[1]
Herd size, n (%)				<0.001
110-359	40 (34)	30 (50)	10 (17)	
360-560	39 (33)	19 (32)	20 (34)	
561-1,850	39 (33)	11 (18)	28 (48)	
Missing	1	0	1	
Milk solids (kg/cow/year), n (%)				0.023
240-399	39 (34)	26 (44)	13 (23)	
400-460	39 (34)	20 (34)	19 (34)	
461-600	37 (32)	13 (22)	24 (43)	
Missing	4	1	3	
Number of full-time staff, n (%)				0.006
<2.5	66 (56)	41 (68)	25 (43)	
≥2.5	52 (44)	19 (32)	33 (57)	
Missing	1	0	1	
Milking frequency, n (%)				0.17
Less than twice-a-day	33 (28)	20 (33)	13 (22)	
Twice-a-day all year	86 (72)	40 (67)	46 (78)	
Yard size (m^2), n (%)				<0.001
<300	21 (36)	16 (53)	5 (17)	
300-600	18 (31)	11 (37)	7 (24)	
>600	20 (34)	3 (10)	17 (59)	
Missing	60	30	30	
Predominant breed, n (%)				0.016
Holstein-Friesian	47 (39)	27 (45)	20 (34)	
Jersey	18 (15)	13 (22)	5 (8.5)	
Holstein/Jersey cross	54 (45)	20 (33)	34 (58)	
Milking parlour, n (%)				0.008
Herringbone	59 (50)	37 (62)	22 (37)	
Rotary	60 (50)	23 (38)	37 (63)	
Calving system, n (%)				<0.001
100% spring calving	108 (91)	49 (82)	59 (100)	
Split calving	11 (9.2)	11 (18)	0 (0)	
Yard shape, n (%)				0.052
Circular	81 (70)	46 (78)	35 (61)	
Rectangular	35 (30)	13 (22)	22 (39)	
Missing	3	1	2	
Farmer-reported % lame, n (%)				0.12
< 7%	40 (40)	21 (38)	19 (42)	
7-15%	35 (35)	16 (29)	19 (42)	
>15%	25 (25)	18 (33)	7 (16)	
Missing	19	5	14	
Peak lameness, n (%)				<0.001
No peak	4 (3.4)	3 (5.1)	1 (1.8)	
January-March	15 (13)	0 (0)	15 (26)	
April-June	11 (9.5)	2 (3.4)	9 (16)	
July-September	32 (28)	22 (37)	10 (18)	
October-December	54 (47)	32 (54)	22 (39)	
Missing	3	1	2	

[1]Pearson's Chi-squared test

Lameness identification and treatment methods

Descriptive statistics of the methods reported by farmers for lameness identification, treatment and recovery management are presented in Table 3, grouped by island. Due to errors entering survey data, data were missing from farmers from Northland and West Coast for two questions on treatment methods. The majority of farmers relied on informal identification by farm staff to identify lame animals (77%), although this was more pronounced in the North Island (87%) than the South Island (67%). Of those that reported formal lameness identification methods, 16 (14%) of farmers carried out lameness scoring of the herd, 13 (11%) used on-farm technology to assist with lameness identification, and two (2%) utilised external providers to conduct lameness scoring. White line disease was reported as the predominant lameness-inducing lesion (43% of farmers), this was consistent across the two islands. The majority of farmers reportedly undertook all the lame cow treatments themselves with no assistance from external providers (65%), with the other 35% of farmers using professional hoof trimmers or veterinarians for at least some of the lame cow treatment. Most had no formal training (62%). Lame cow crushes were present and used on approximately half of the farms. Fifty percent of responding farmers reported using blocks for at least 22% of lame animals, and NSAIDs for at least 30%. Once-a-day milking of the identified lame animals was common (73% of all farmers always milked lame animals once-a-day), with the practice more common in the South Island compared to the North Island (80% vs 63%). Lame animals were always managed in a separate herd near the milking parlour on 83% of farms. Most farmers considered lameness when making culling decisions (65%), however, this decreased to 42% when they were asked if they prioritised culling decisions based on lameness.

Table 3. Descriptive statistics of lameness treatment and recovery management as reported by 119 farmers enrolled into a lameness prevalence and risk factors study, from the North (n=60) and South (n=59) Islands of New Zealand, with Chi-squared

Characteristic	**Overall**, N = 119	**North**, N = 60	**South**, N = 59	**p-value**[3]
Identify lame cows, n (%)				0.010
Dedicated LS or technology	27 (23)	8 (13)	19 (33)	
Informal, non-dedicated task	90 (77)	52 (87)	38 (67)	
Missing	2	0	2	
Primary lameness, n (%)				0.047
Footrot	18 (15)	13 (22)	5 (8.6)	
Multiple lesions	18 (15)	4 (6.7)	14 (24)	
Other	6 (5.1)	3 (5.0)	3 (5.2)	
Sole lesions	25 (21)	14 (23)	11 (19)	
White line	51 (43)	26 (43)	25 (43)	
Missing	1	0	1	
Lift hoof, n (%)				0.70
Always	75 (91)	40 (93)	35 (90)	
Never or sometimes	7 (8.5)	3 (7.0)	4 (10)	
Missing	37	17[1]	20[2]	
% treated with a block, n (%)				0.68
≤22	49 (50)	26 (48)	23 (52)	
>22	49 (50)	28 (52)	21 (48)	
Missing	21	6	15[2]	
Where lame cows are treated, n (%)				0.001
Lame cow crush	59 (52)	20 (36)	39 (67)	
Other	54 (48)	35 (64)	19 (33)	
Missing	6	5	1	
External trimmer, n (%)				0.11
No	75 (65)	34 (58)	41 (72)	
Yes	41 (35)	25 (42)	16 (28)	
Missing	3	1	2	
Formal trimming training, n (%)				0.56
No	69 (62)	36 (64)	33 (59)	
Yes	43 (38)	20 (36)	23 (41)	
Missing	7	4	3	
% treated with NSAID, n (%)				>0.99
≤30	55 (53)	27 (53)	28 (53)	
>30	49 (47)	24 (47)	25 (47)	
Missing	15	9	6	
Lame milked once-a-day, n (%)				0.051
No	12 (12)	9 (21)	3 (5.4)	
Sometimes	15 (15)	7 (16)	8 (14)	
Yes	72 (73)	27 (63)	45 (80)	
Missing	20	17	3	
Cull based on lameness, n (%)				0.050
Maybe	13 (12)	5 (8.9)	8 (15)	
No	25 (23)	18 (32)	7 (13)	
Yes	72 (65)	33 (59)	39 (72)	
Missing	9	4	5	
Prioritise culling based on lameness, n (%)				0.062
Maybe	34 (30)	12 (21)	22 (39)	
No	31 (27)	20 (36)	11 (19)	
Yes	48 (42)	24 (43)	24 (42)	
Missing	6	4	2	
Manage lame, n (%)				0.031
Always in separate herd near shed	85 (83)	33 (73)	52 (90)	
Other	18 (17)	12 (27)	6 (10)	
Missing	16	15[1]	1	

[1] Farmers from Northland did not answer this question
[2] Farmers from West Coast did not answer this question
[3]Pearson's Chi-squared test
test of proportions comparing responses from farms from the two islands.

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Farm descriptors of lameness management factors

A small percent of farmers used dogs to move cows (16%), although this practice was almost entirely associated with North Island farmers (Table 4). One third of farmers (32%) used the practice of a concrete stand-off pad, including 48% of North Island farmers and 16% of South Island farmers. There was a difference between the islands in the use of top-gates to move cattle in the collecting yard, with use on 67% of South Island farms compared to 23% on North Island farms. The majority of farms (71%) had a backing gate with an alarm or hose that turned on when the gate moved. Permanent footbaths were an uncommon finding (8% of farms). Undertaking track maintenance on more than 20% of the farm tracks over the preceding 12 months was reported on 35% of all sampled farms, but was more common on South Island farms than North Island farms (53% vs 17%, respectively).

Table 4. Descriptive data of lameness management strategies for lameness from enrolled farmers, split into the North and South Islands of New Zealand, with Chi-squared test of proportions comparing responses from farms from the two islands.

Characteristic	**Overall**, N = 119	**North**, N = 60	**South**, N = 59	**p-value**[1]
Top gate, n (%)				<0.001
N	63 (55)	44 (77)	19 (33)	
Y	52 (45)	13 (23)	39 (67)	
Unknown	4	3	1	
Electrified backing/top gate, n (%)				0.12
N	89 (77)	48 (83)	41 (71)	
Y	27 (23)	10 (17)	17 (29)	
Unknown	3	2	1	
Backing gate alarm/hose, n (%)				<0.001
N	34 (29)	26 (45)	8 (14)	
Y	82 (71)	32 (55)	50 (86)	
Unknown	3	2	1	
Use dogs to move cows, n (%)				0.010
N	98 (84)	44 (76)	54 (93)	
Y	18 (16)	14 (24)	4 (6.9)	
Unknown	3	2	1	
Concrete stand-off pad, n (%)				<0.001
N	79 (68)	30 (52)	49 (84)	
Y	37 (32)	28 (48)	9 (16)	
Unknown	3	2	1	
In-shed feeding, n (%)				<0.001
N	41 (40)	34 (59)	7 (16)	
Y	62 (60)	24 (41)	38 (84)	
Unknown	16	2	14	
Permanent footbath, n (%)				0.49
N	106 (92)	54 (95)	52 (90)	
Y	9 (7.8)	3 (5.3)	6 (10)	
Unknown	4	3	1	
Farm policy for managing lameness, n (%)				<0.001
N	25 (22)	21 (36)	4 (7.1)	
Y	89 (78)	37 (64)	52 (93)	
Unknown	5	2	3	
Maximum one-way distance, n (%)				0.26
<= 1.5km	68 (60)	32 (55)	36 (65)	
> 1.5km	45 (40)	26 (45)	19 (35)	
Unknown	6	2	4	
Track maintenance over past 12 months (%), n (%)				<0.001
<= 20%	75 (65)	48 (83)	27 (47)	
> 20%	40 (35)	10 (17)	30 (53)	
Unknown	4	2	2	
Average distance walked per day, n (%)				0.77
<= 2km	55 (50)	28 (49)	27 (52)	
> 2km	54 (50)	29 (51)	25 (48)	
Unknown	10	3	7	

[1]Pearson's Chi-squared test

Farm risk factors for lameness

Univariable associations between the 34 reported predictor variables identified 11 variables that could be included in the initial multivariable models (Table 5). However, region and island were both highly collinear (variance inflation factors > 10) with other predictors and thus were not included in any multivariable models. The nine remaining variables were farmer-reported lameness incidence risk, calving system, farmer-reported peak lameness incidence period, primary lameness lesion, use of an external trimmer, use of a top-gate to move cattle in the collecting yard, electrified backing gate, backing gate alarm/hose, use of a concrete stand-off pad and track maintenance. All of these nine variables had < 10% missing data, and were thus included in the initial multivariable model, using MICE.

Two farm-level predictors were selected for the final multivariable generalised linear mixed model on the association with the odds of lameness (Table 6). After accounting for herd and repeated LS between cow, animals from farms that used concrete stand-off pads during inclement weather were associated with 49% times greater odds of lameness compared to animals on farms that did not use concrete stand-off pads, with an 89% probability that the true odds were between 19-88% greater. One hundred percent of the posterior samples identified an increased odds of lameness in animals on farms with concrete stand-off pads compared to without concrete stand-off pads. Animals from farms that reported peak lameness incidence from January-June or all-year-round, had 24% times lower odds of lameness than cows from farms that reported peak lameness incidence from July-December, with an 89% probability that the true odds were between 16 and 49% lower. There was a 100% probability that the OR comparing peak lameness from January-June was < 1 compared to July-December. No issues with model convergence were identified.

Table 5. Univariable association for 34 predictor variables on their odds of lameness in dairy cows. Each model was a mixed logistic regression model containing score timing nested within farm as random intercepts. For each risk factor category, the number of cows and number of lame events are reported, along with odds ratio and confidence interval compared to the reference category. $P < 0.20$ are in bold, indicating variables that were considered for multivariable analysis.

Characteristic	N	Event N	OR (95% CI)[1]	p-value
Region				**<0.001**
Canterbury	20,762	322	—	
Manawatu	14,072	570	2.42 (1.63 to 3.59)	
Northland	14,055	693	3.13 (2.12 to 4.62)	
Otago	18,978	564	1.83 (1.24 to 2.70)	
Southland	13,427	633	2.66 (1.80 to 3.93)	
Taranaki	10,002	203	1.27 (0.84 to 1.90)	
Waikato	10,018	677	4.27 (2.90 to 6.30)	
West Coast	14,228	312	1.43 (0.95 to 2.13)	
Island				**<0.001**
North	48,147	2,143	—	
South	67,395	1,831	0.63 (0.49 to 0.81)	
Herd size				0.96
110-359	21,099	785	—	
360-560	34,498	1,221	0.96 (0.69 to 1.32)	
561-1,850	58,630	1,944	0.98 (0.71 to 1.35)	
Milk solids (kg/cow/year)				0.70
240-399	34,810	1,249	—	
400-460	38,601	1,253	0.88 (0.64 to 1.21)	
461-600	38,856	1,372	0.97 (0.70 to 1.34)	
Full time equivalent				0.22
<2.5	45,258	1,782	—	
≥2.5	68,969	2,168	0.85 (0.66 to 1.10)	
Milking frequency				0.70
Less than twice-a-day	28,323	952	—	
Twice-a-day all year	87,219	3,022	0.94 (0.71 to 1.26)	
Yard size				0.21
<300	14,981	589	—	
300-600	19,953	595	0.75 (0.51 to 1.09)	
>600	23,426	668	0.74 (0.51 to 1.08)	
Breed				0.21
HF	46,071	1,736	—	
Jersey	12,040	405	0.91 (0.61 to 1.34)	
Kiwi Cross	57,431	1,833	0.78 (0.59 to 1.03)	
Milking parlour				0.28
Herringbone	41,762	1,584	—	
Rotary	73,780	2,390	0.87 (0.67 to 1.12)	
Calving				**0.036**
100% spring calving	103,192	3,379	—	
Split calving	12,350	595	1.59 (1.03 to 2.45)	
Yard shape				0.81
Circular	73,754	2,513	—	
Rectangular	39,366	1,406	0.97 (0.72 to 1.29)	
Farmer-reported lameness incidence				**0.023**
< 7%	34,021	962	—	
7-15%	33,532	1,084	1.04 (0.75 to 1.45)	
>15%	28,595	1,285	1.60 (1.12 to 2.28)	
Farmer-reported peak lameness				**0.008**
All	3,171	110	—	
January-March	12,400	303	0.65 (0.29 to 1.44)	
April-June	18,886	401	0.58 (0.27 to 1.25)	
July-September	31,422	1,178	0.99 (0.48 to 2.05)	
October-December	47,176	1,875	1.11 (0.55 to 2.26)	
Id lame cows				0.50
Dedicated LS or technology	32,355	952	—	
Informal farmer only	81,814	2,973	1.11 (0.82 to 1.52)	
Primary lameness				**0.17**
Footrot	16,550	475	—	
Multiple lesions	20,251	532	1.01 (0.63 to 1.60)	
Other	4,480	248	1.95 (1.01 to 3.76)	
Sole lesions	18,884	677	1.25 (0.81 to 1.92)	
White line	54,627	2,015	1.35 (0.92 to 1.98)	
Lift hoof				0.92

Characteristic	N	Event N	OR (95% CI)[1]	p-value
Always	73,067	2,565	—	
Never or sometimes	5,367	217	1.03 (0.57 to 1.86)	
% treated with a block				0.88
≤22	45,703	1,565	—	
>22	49,110	1,804	0.98 (0.73 to 1.31)	
Where lame cows are treated				0.54
Lame cow crush	66,858	2,314	—	
Other	44,139	1,434	0.92 (0.70 to 1.20)	
External trimmer				**0.15**
N	72,148	2,235	—	
Y	40,405	1,600	1.22 (0.93 to 1.61)	
Formal training				0.31
N	66,718	2,125	—	
Y	43,744	1,615	1.16 (0.88 to 1.53)	
% treated with NSAID				0.81
≤30	53,912	1,776	—	
>30	49,279	1,684	1.04 (0.78 to 1.37)	
Lame milked once-a-day				0.56
N	9,840	245	—	
Sometimes	12,284	523	1.35 (0.77 to 2.36)	
Y	76,832	2,380	1.23 (0.79 to 1.93)	
Cull based on lameness				0.41
Maybe	11,742	366	—	
N	18,119	497	0.85 (0.53 to 1.38)	
Y	77,450	2,726	1.07 (0.70 to 1.63)	
Prioritise culling based on lameness				0.28
Maybe	33,350	1,022	—	
N	26,338	759	0.89 (0.63 to 1.26)	
Y	50,724	1,984	1.15 (0.84 to 1.58)	
Manage lame				0.69
Always in separate herd near shed	88,445	2,817	—	
Other	12,830	399	0.93 (0.64 to 1.35)	
Top gate				**0.011**
N	47,890	2,032	—	
Y	64,606	1,813	0.71 (0.55 to 0.93)	
Electrified backing gate				**0.15**
N	81,234	2,991	—	
Y	32,051	873	0.80 (0.58 to 1.09)	
Backing date alarm/hose				**0.031**
N	26,080	1,080	—	
Y	87,205	2,784	0.73 (0.55 to 0.97)	
Use of dogs to move cows				0.30
N	98,425	3,287	—	
Y	14,860	577	1.21 (0.84 to 1.75)	
Concrete stand-off pad				**0.003**
N	81,568	2,504	—	
Y	31,717	1,360	1.51 (1.15 to 1.99)	
In-shed feeding				0.42
N	33,945	1,350	—	
Y	66,148	2,242	0.89 (0.66 to 1.19)	
Permanent footbath				0.79
N	100,715	3,342	—	
Y	10,592	385	1.07 (0.66 to 1.74)	
Farm policy for managing lameness				0.32
N	17,647	676	—	
Y	94,229	3,170	0.85 (0.61 to 1.17)	
Maximum one-way distance				0.34
<= 1.5km	59,664	1,861	—	
> 1.5km	50,134	1,915	1.14 (0.87 to 1.51)	
Track maintenance over past 12 months (%)				**0.19**
<= 20%	66,927	2,407	—	
> 20%	44,645	1,389	0.83 (0.63 to 1.09)	
Average distance walked per day				0.50
<= 2km	47,842	1,500	—	
> 2km	56,681	2,024	1.10 (0.84 to 1.43)	

[1]OR = Odds Ratio, CI = Confidence Interval

Table 6. Final Bayesian multivariable logistic mixed regression model output with odds ratio and 89% equal-tailed uncertainty intervals. Data from cows across 119 farms, using multiple imputed chained equation (n=10) for missing data.

Characteristic	Estimate	Std. error	**OR (89% UI)**[1]
Peak lameness incidence			
July-December	*Reference*		—
January-June[2]	-0.43	0.14	0.76 (0.51 to 0.84)
Concrete stand-off pad			
No	*Reference*		—
Yes	0.40	0.16	1.49 (1.19 to 1.88)[3]

[1] Odds ratio and 89% equal-tailed uncertainty interval

[2] January-June also includes four farms that stated all months of the year had equal incidence of lameness

[3] The odds of lameness in cows on farms that used a concrete stand-off pad was 1.49 (uncertainty interval 1.19 – 1.88) times that compared to cows on farms that did not use a concrete stand-off pad.

DISCUSSION

This cross-sectional survey of 119 dairy farms across eight regions of New Zealand revealed associations between lameness prevalence and using a concrete stand-off pad and of timing of peak lameness. A range of lameness treatment procedures and lameness management practices were reported, with potential areas for improvements identified, such as considering lameness identification as a dedicated job on farm.

Lameness identification and treatment methods

Lameness identification was not treated as a formal dedicated task on most farms. This is in agreement with the situation in Ireland, where only one of 99 Irish dairy farms carried out lameness scoring and used technology to identify lame animals, respectively (Browne *et al.* 2022b). Early identification of lameness is a critical component of lameness management (Groenevelt *et al.* 2014; Pedersen and Wilson 2021). As the low detection of lameness by farmers is as apparent in New Zealand (Alawneh *et al.* 2012; Fabian *et al.* 2014) as it is worldwide (summarized by Sadiq *et al.* (2019)), improving lameness detection is one major area that could see improvement across New Zealand dairy farms. (Leach *et al.* 2010)

4. Farm-level risk factors

The use of formal lameness identification, whether via on-farm technology or via lameness scoring, is greater in the South Island, possibly due to larger herd sizes (Gargiulo *et al.* 2018) and greater frequency of rotary milking parlours (Dela Rue *et al.* 2020) on these farms. Automated lameness detection methods, such as cameras with machine-learning technology, have the potential to offer a range of lameness identification benefits, from real-time lameness prevalence and incidence monitoring, through early identification of lame cows along with automated identification and drafting and, even, assessing the decision making for the recovery of lame animals. All of these are difficult to achieve using manual lameness scoring, However, before widespread adoptions and recommendations of these systems occurs, optimising sensitivity and specificity, and addressing farmer barriers and needs must be addressed (Alsaaod *et al.* 2019; O'Leary *et al.* 2020).

All lame cows were managed in a separate herd near the milking parlour on 83% of farms, and 87% of farms milked lame cows once-a-day at least some of the time. Provided the nutritional needs of the convalescing lame cows can be met (Lim *et al.* 2015), the recovery of treated lame cows on pasture provides an ideal surface to encourage recovery (Mason *et al.* 2023). The practice of cattle recovering on pasture close to the milking parlour and milking them once-a-day was speculated in part to be responsible for the rapid time to recovery noted in 241 cattle lame with claw-horn lameness (median time of 19 days for animals to become sound and just seven days to become non-lame) (Mason *et al.* 2023). Although the recovery of lame cows once identified and treated remains an under-researched area of lameness management, the authors believe this should be considered an integral part of all on-farm lameness management plans globally.

Very few South Island farms used dogs to move cattle (7%), in contrast to almost a quarter of North Island farmers (24%). The use of biting dogs has been strongly associated with the risk of high lameness prevalence on New Zealand dairy farms (Chesterton *et al.* 1989). However, in that same study, whether dogs were used at all was not associated with lameness in the final path analysis, and the current study did not reveal a negative association between the use of dogs and the odds of lameness. A well-behaved dog is

likely to be better than a human with poor patience when moving cattle (Chesterton *et al.* 1989), and thus the authors suggest that a blanket recommendation to avoid dogs on dairy farms to minimise lameness is not appropriate. Instead, concentrating on educating farm staff and owners on the importance of cattle handling should be the priority, regardless of the methods used to achieve this.

Risk Factors

The use of a concrete stand-off pad was identified as an important risk factor for lameness. As this practice was reported by one-third of farmers, there is substantial room for improvement in this space. The negative impact that concrete has on hoof-health is well documented in housed dairy systems (Adams *et al.* 2017; McLellan *et al.* 2022). Factors associated with concrete surfaces have also been reported previously in pasture-based systems, with the smoothness of the concrete surface associated with the risk of lameness (Ranjbar *et al.* 2016). Although information was not collected on when farmers were using stand-off pads in this current study, anecdotally, this practice is most common around the time of parturition, a period where the hoof is most vulnerable to damage (Tarlton *et al.* 2002; Knott *et al.* 2007). The issue with the concrete feedpad is likely not just due to the concrete surface *per se*, but also the lack of choice the cow has for standing surface. Cattle prefer to stand and ambulate on comfortable softer surfaces when given the choice (Telezhenko and Bergsten 2005; Boyle *et al.* 2007; McLellan *et al.* 2022), and this choice of surfaces has resulted in less time standing on concrete, with an associated reduction in the risk of lameness (Boyle *et al.* 2007; McLellan *et al.* 2022). The practice of using a stand-off pad removes this choice for the cow, thus the surface likely becomes more critical. Collecting data on the timing, frequency, surface and space available would be of interest in future studies, as would data on feedpad use. It is possible that farms with a feedpad are more inclined to use concrete stand-off pads, thus this association may be confounded by the total daily time on concrete. However, this study provides enough evidence that the practice of standing cows off on concrete surfaces during times of inclement weather greatly increases the risk of lameness and should be discouraged, and other methods (e.g., dedicated sand area) need to be

investigated on these farms if the practice is to continue. Furthermore, it is likely that any practice that results in prolonged exposure to concrete in pasture-grazing cattle is harmful. On Irish dairy farms, retaining cattle on the concrete collecting yard until all cows were milked, rather than being able to freely walk back to pasture, was associated with a 2.26 times odds of lameness (O'Connor *et al.* 2020).

Peak lameness incidence, as defined by farmers, was associated with the odds of lameness. Farms where lameness peaked between January to June, or which had no defined peak, were associated with a reduction in the odds of lameness compared to farms that had peak lameness between July to December. As 108 of the 119 (91%) of farms were 100% spring-calving, this can be extrapolated out to farms that reported peak lameness in the second half of lactation were associated with a reduced odds of lameness. A criticism of this association is that it is relying on farmer recall. However, all farmers should have similar recall bias pressure and if anything, this bias should have shifted the result towards no association. As the posterior probabilities reported suggest a large effect (an 89% probability that the true odds of lameness were between 16 and 49% lower on farms that reported a peak lameness prevalence in the second half of lactation), we believe this to be a true association. Whilst we do not know why this is the case, one theory is that farms that are reporting a later lameness peak may have a lower overall annual incidence of lameness. If more animals are lame later in lactation compared to earlier in lactation, then this may indicate a delayed time to first-lameness. As lameness risk increases with age (Newsome *et al.* 2016; Mason 2017) and with previous cases of lameness (Randall *et al.* 2018), this delayed time to first lameness may have prolonged and profound effects on the lameness prevalence. However, the evidence isn't clear on this point, with both reduced risk of lameness (Oehm *et al.* 2019), and increased risk of lameness (Thomas *et al.* 2023) reported in animals that are lame later in lactation compared to earlier in lactation. Thus, more research is needed into this area.

Whilst it must be stressed that unconditional associations may be biased, some unadjusted associations identified in this current study warrant further discussion. The presence of an alarm or hose that turned on when the backing gate moved was associated with a 27% reduction in the odds of lameness. This

unconditional finding was also reported by Chesterton *et al.* (1989). From a Bayesian perspective, reporting a similar finding across more than one study increases the probability that the effect is real. Thus, these unconditional associations add evidence that placing alarms on backing gates to alert cows and farm staff to the presence of the moving gate assists in reducing lameness risk. This is presumably due to reduced pressure placed on cattle in the collecting yard (Ranjbar *et al.* 2016).

The use of a top-gate was also associated with a reduction in the odds of lameness. We do not know why this is the case, but speculate that the use of a top-gate improves cow flow within the collecting yard (Chesterton *et al.* 1989; Ranjbar *et al.* 2016). Milking order and cow behaviours can impact lameness risk (Sauter-Louis *et al.* 2004). Those authors hypothesised that the use of the backing gate mostly affects those cows at the rear of the collecting yard, and also identified that these cows positioned at the rear of the collecting yard had greater risk of lameness compared to those positioned towards the front of the collecting yard. A top-gate likely improves cow flow within the yard, ensuring that the animals placed towards the back of the collecting yard are less likely to have backing gate pressure placed on them, thus lowering the risk of lameness.

The lack of associations with some variables are also of interest. Conflicting associations between herd size and risk of lameness have been reported in studies investigating housed or partly-housed cattle. An increased risk of lameness with increasing herd size has been reported in some studies (Sjöström *et al.* 2018; Oehm *et al.* 2019; Browne *et al.* 2022a). In contrast, other studies in housed cattle have reported that increased herd size was associated with a reduced risk of lameness (Chapinal *et al.* 2013; Chapinal *et al.* 2014; Solano *et al.* 2015). Such evidence for associations between herd size and lameness in either direction is lacking in pasture-based studies. In this current study, no association between herd size and lameness was identified ($p = 0.70$), consistent with the findings of other pasture-based lameness risk factor studies (Chesterton *et al.* 1989; O'Connor *et al.* 2020). These findings all suggest that herd size *per se* is not a useful predictor of lameness risk across any dairy system, and placing emphasis on this factor is unfounded.

Limitations

Regional and island differences in lameness prevalence were reported at the univariable level. Region and island were intrinsically linked to certain risk factors, and as a consequence, substantial collinearity and convergence issues arose when region or island were placed into multivariate models. For example, only 2 of the 45 farms from the three most southern regions (Southland, Otago and Canterbury) used dogs, compared to 16 out of 75 from the other regions. Therefore, region can be considered a case of an extreme confounder in this dataset, and it was not possible to separate out the latent effect of region from the reported risk factors. Furthermore, whilst region and island were strongly associated with the odds of lameness, these variables are just proxies for certain latent farm variables, and further investigations should be conducted to identify particular farm factors that may occur in those regions with greater or lower levels of lameness. This is the challenge of interpreting region-specific data on lameness risk factors (Chesterton et al., 1989). It is possible that the risk factors reported from Taranaki are not valid to a population of farms outside of Taranaki. The other potential bias was that different trained observers were used for each region; this is covered at length in Mason et al. (submitted).

A major limitation of this study design was that all farm-level variables were reported by the farmer; no on-farm validation or recording of potential risk factors were conducted by study personnel. We attempted to minimise this limitation by asking closed-ended questions, and splitting the data into two or three categories for analysis. The implications of this likely reduced the power of the analysis for certain variables (e.g., walking distance). We encountered issues with the data when open-ended answers were requested and the question could be skipped; collecting yard size, for example, had a large proportion of missing or improbable entries. The number of biologically relevant associations reported in this current study was far fewer than that reported by Chesterton *et al.* (1989) (although different analytical methods were used), and part of this may be due to these survey data limitations. One positive for this study design,

however, is that it removes any potential bias that a technician may have if they are conducting both the lameness scoring and farm data collection (Chesterton *et al.* 1989; Ranjbar *et al*. 2016).

Despite these limitations, due to the random farm enrolment, stratified by region, we believe that the enrolled farms are representative of the greater New Zealand dairy farming population. Whilst we have identified a few areas that could be improved upon, such as reducing concrete stand-off pads and improving lameness identification, there is still a lot of unexplained variation for between and within farm lameness prevalences that urgently need investigating.

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Systematic review of non-steroidal anti-inflammatory drugs for the treatment of claw horn lameness

The second goal of the thesis was to improve the treatment of lame cattle in New Zealand. One way for this to occur is for animal health advisors to sing from the same song sheet. There is currently a large range of treatment regimes and varying treatment recommendations from veterinarians, and this has the effect of confusing farmers and resulting in less-than-ideal treatment outcomes. This chapter reports a systematic review on the use of non-steroidal anti-inflammatory drugs (NSAIDs) on the outcomes of claw-horn lameness in dairy cattle, with the goal for veterinarians to provide consistent, evidence-based messaging to farmers with respect to NSAID use for lame cow treatment. The link to this publication can be found at https://doi.org/10.3168/jds.2022-22127.

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Graduate Student Literature Review: A systematic review on the associations between nonsteroidal anti-inflammatory drug use at the time of diagnosis and treatment of claw horn lameness in dairy cattle and lameness scores, algometer readings, and lying times*

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ABSTRACT

The objectives of this systematic review were to investigate the association between nonsteroidal anti-inflammatory drug (NSAID) use during the treatment of claw horn lameness in dairy cattle and locomotion score (LS), nociceptive threshold, and lying times. A total of 229 studies were initially identified and had their title and abstract screened. From this, we screened the full text of 23 articles, identifying 6 articles for inclusion in the systematic review. Of these 6, 5 reported LS, 2 reported nociceptor thresholds, and 1 reported lying times. The quality of evidence was assessed using a Cochrane risk-of-bias tool and CONSORT items reported for each included study. Due to heterogeneity between the studies, data were reported following Cochrane's Synthesis without meta-analysis guidelines. Identified heterogeneity between the studies included differences in LS systems and statistical analyses, length of time from enrollment to outcome reported, the NSAID used, concomitant treatments administered, and severity and chronicity of lameness. Recommendations are made with respect to consistency of LS reporting and analysis, along with improvements that may be noted with compulsory reporting guidelines. There were at least some concerns over the risk of bias in 4 of the studies, with risks of bias present in missing outcome data between the study groups. Within the 5 studies included with LS outcomes, there were 22 different pairwise comparisons with either NSAID or NSAID + block as the intervention, with measures of association with presence or absence of lameness as the outcome available for 20 of these comparisons. Animals in the NSAID intervention groups had a lower point estimate lameness risk than animals in the comparison groups in 3 of 8 and 9 of 14 analyses for LS outcomes <10 and ≥10 d post-treatment, respectively. However, there was no difference identified between animals in the NSAID intervention groups compared with the animals in the control group in any of these pairwise comparisons with lameness as the outcome. Twelve pairwise comparisons were reported in the 2 studies with nociceptor threshold as an outcome. Animals in the NSAID intervention groups had a greater nociceptor threshold point estimate compared with animals in the comparison groups in 6 of 6 and 1 of 6 analyses for outcomes <10 and ≥10 d post-treatment, respectively. However, no differences were identified between animals in the NSAID intervention groups and those in the comparison groups. All 4 pairwise comparisons reported in the study with lying times as an outcome found no differences between animals in the NSAID groups and those in the comparison groups. Despite the widespread use of NSAID in the treatment of claw horn lameness, there is a lack of studies of NSAID association with LS, nociceptive thresholds, or lying times. The limited evidence is consistent with no association with NSAID use and those parameters, but comparability across studies was limited by heterogeneity.

Key words: locomotion score, systematic review, claw horn lameness, nonsteroidal anti-inflammatory drug

INTRODUCTION

The pronounced and prolonged pain response to claw horn (**CH**) lesions (consisting principally of white-line, sole hemorrhage, sole ulcer, or a combination of these 3 symptoms) in dairy cattle (Laven et al., 2008; Coetzee et al., 2017) requires science-based solutions to mitigate that pain. Treatment with nonsteroidal anti-inflammatory drugs (**NSAID**) potentially provides one route to achieve this objective (Laven, 2020). These compounds

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have an increasing importance in the maintenance of the health and welfare of dairy cattle (Laven, 2020), demonstrated by an increase in NSAID research in cattle over the past decade. From 2010 to 2021, there have been 209 articles published with the search terms "NSAID" and "cattle" (Web of Science search engine, accessed January 19, 2022; https://www.webofscience.com/wos/woscc/basic-search). From 1985 to 2010, there were just 107 articles published with the same search terms. From this crude scientometric approach, it can be concluded that approximately two-thirds of all published NSAID research in the English language in cattle has been carried out over the past 11 yr.

However, it is unclear how much of this recent NSAID research in cattle has focused on the effect of NSAID on CH lameness outcomes, as there are few recent reviews. Review articles on the treatment of lameness have previously been conducted (Hirst et al., 2002; Potterton et al., 2012; Huxley et al., 2014), but these were either not specific for NSAID use or did not follow a systematic review process, and thus may be prone to bias. Nevertheless, those reviews have identified a problematic, historical lack of scientific articles on the effect of NSAID on CH lameness. In a scoping review of lameness treatment and prevention of foot lameness in cattle from 2000 to 2012, only 3 papers were identified on the topic of treatment of CH lameness, and none of these related to NSAID use (Potterton et al., 2012). Given the recent increase in NSAID publications, and the comparative lack of NSAID reviews in lame cattle, there is a need for a systematic review of the current literature on the use of NSAIDs for treating lame dairy cattle.

Another motivating factor for conducting this systematic review was that it appeared that there was positive confirmation bias (where individuals search for evidence to confirm their beliefs; Jones and Sugden, 2001) in the cattle lameness field relative to the use of NSAID. This is particularly clear in the citation of 2 papers from the Dairy Herd Health Group based at Nottingham University, United Kingdom. The first paper, Thomas et al. (2015), reported a positive NSAID response in regard to locomotion score (**LS**), whereas the second paper (Thomas et al., 2016) reported no such benefit. The former paper has been cited more frequently than the latter (48 vs. 31 citations in Web of Science, respectively), despite it being published only 11 mo earlier and, in the authors' experience, is much more commonly referred to in the on-farm setting (e.g., Healthy Hoof lameness advisory service, DairyNZ, New Zealand). This discrepancy in citation count is despite the principal difference between the 2 studies being that, compared with cows in the original study, cows in Thomas et al. (2016) were treated slightly later and when lameness was judged to be slightly more severe, a situation that probably reflects on-farm reality more than the situation in Thomas et al. (2015). The question of whether confirmation bias exists, or if there are outlier study results, is best addressed using a systematic review.

Lameness can induce a vast array of changes in cattle, ranging from alterations in trace elements and inflammatory markers (Sun et al., 2015), systemic nociceptive thresholds (Laven et al., 2008), and clinical behavioral changes in gait and behavior (Mainau et al., 2022), to production-limiting effects such as reduced longevity (Huxley, 2013). Although these outcomes are important, it was beyond the scope of this manuscript to review all potential lameness-related changes. Instead, the following 3 outcome measures were selected that the authors believed to have the greatest clinical relevance to lameness response to NSAID treatment: LS, nociceptive threshold, and lying times. The most obvious of these outcome measures is LS, as the definition of lameness involves some alteration in LS (Mainau et al., 2022). If NSAID use had an effect on lameness, the most clinically important effect would be on LS. However, LS is a subjective measure, with low sensitivity for detecting early changes and hoof pain (Dyer et al., 2007). To counter this, a more objective measure was desired. Lame cattle often develop hyperalgesia, an exaggerated sensitivity and perception of pain (Laven et al., 2008). A method for indirectly quantitatively assessing this has been developed for use in lame ruminants (Chambers et al., 1994) by measuring nociceptive threshold in response to a stimulus. Nonsteroidal anti-inflammatory drugs have been widely used in humans and other species for their anti-nociceptive effect (Burian and Geisslinger, 2005); therefore, it is logical to test their efficacy in cattle too. Finally, lameness is known to induce changes in the activity and state of an animal, with respect to lying times (reviewed by Mainau et al., 2022). Thus, lying time may be a useful nongait-related behavioral measure for identifying recovery from lameness.

The aim of this systematic review was to review the literature on NSAID use and its association with 3 key targets of clinical lameness treatment (i.e., LS, nociceptor thresholds, and lying times). Thus, in effect, this systematic review will investigate if these outcome variables can predict whether NSAID treatment has been effective. The systematic review question that the authors were investigating was "Does NSAID use at the time of treatment and diagnosis of CH lameness improve LS, nociceptor thresholds, and lying times in dairy cattle?"

METHODS

The systematic review was designed and conducted according to PRISMA 2020 reporting guidelines for systematic reviews (Page et al., 2021), with veterinary adaptations as recommended by Sargeant and O'Connor (2020). As the PRISMA 2020 statement does not fully cover synthesis of data in the absence of meta-analysis, the reporting of the results was conducted according to synthesis without meta-analysis (**SWiM**) reporting guidelines (Campbell et al., 2020). The protocol was not independently registered.

Search Terms and Databases

The systematic review question was translated into population, intervention, control group, and outcomes (Sargeant and O'Connor, 2020; Table 1). The search terms used were as follows: (Cattle OR Cow*) AND (Lame* OR mobility OR locomotion) AND (NSAID* OR steroidal OR analgesi*). A search of the full Web of Science database (which consists of CAB Abstracts, Medline, Biological Abstracts and Web of Science Core Collection), and the Scopus database (https://www.scopus.com/) was carried out by WM on October 23, 2021, with the search timelines not restricted. Screening of the reference list of review articles (Hirst et al., 2002; Potterton et al., 2012; Huxley et al., 2014; Coetzee et al., 2017) was carried out by WM after databases had been searched and were included at the eligibility phase in Figure 1 to ensure no key references were missed.

Article Selection

De-duplication was conducted in EndNote (Version X9.2, Thomson Reuters) following the methodology proposed by Bramer et al. (2016), and then manually during the screening process.

After duplicate removal, the remaining citations were exported from EndNote to the systematic review software, Rayyan (Rayyan) and screened on titles and abstract by WM and EC. Both reviewers were blinded to the decision of the other reviewer until both had made a decision (include, exclude, or maybe) on 100% of the articles. The screening criteria for titles and abstract were as follows:

1. The title and abstract were written in English or German.
2. The study involved adult dairy cattle.
3. The predominant lameness lesions were described as CH (white-line, sole hemorrhage, sole ulcer, or a combination of these 3 symptoms).
4. The study was an observational or experimental original research paper.
5. Outcome measures included at least 1 of lameness, locomotion, or mobility scores; algometer or nociceptor threshold; or lying or standing time.
6. The NSAID or response to analgesia was mentioned.

Any conflicts between the reviewers for screening decisions were discussed together, with a collective final decision reached. If any doubt existed for any of the screening criteria based on title and abstract alone, or if an agreed decision could not be reached, then the article was not excluded at the screening stage. All articles that had not been excluded underwent full text recovery. For final inclusion, the studies needed to meet all the following criteria:

1. Full text could be obtained.
2. The full text was in English or German.
3. The study was an observational or experimental original research paper.
4. The population of interest contained dairy cattle with CH lameness.
5. Outcome measures included at least 1 of lameness, locomotion, or mobility scores; algometer or nociceptor threshold; or lying or standing time.
6. NSAID were used as a treatment intervention or cohort group.
7. The control group consisted of dairy cattle with CH lameness and did not receive NSAID. Control group could receive concomitant treatments.

Table 1. Population, intervention, control group, and outcome descriptions for the aim and scope of the systematic review

Criterion	Description
Population	Clinically lame dairy cattle suffering from claw horn lameness
Intervention	Nonsteroidal anti-inflammatory drug (NSAID) use at the time of treatment and diagnosis of lame cow, could receive concomitant treatments
Control group	Did not receive NSAID, but could receive other concurrent treatments
Outcome	Locomotion score, nociceptive threshold, and lying times

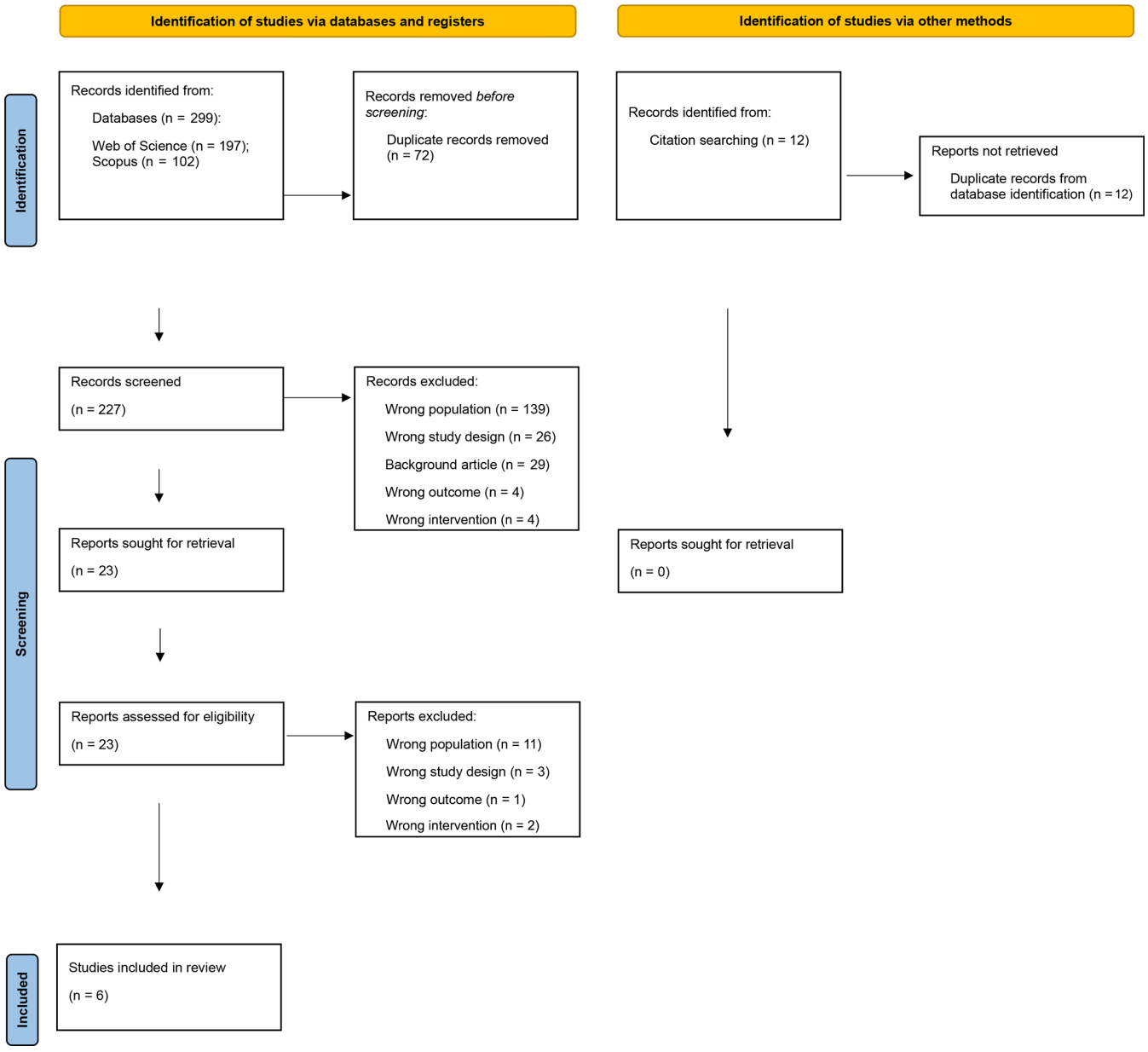

Figure 1. PRISMA 2020 (Page et al., 2021) flow diagram for systematic review for nonsteroidal anti-inflammatory drug use and its association with locomotion score, nociceptive threshold, and lying times in dairy cattle with claw horn lameness.

These articles were then reviewed by 3 reviewers (WM, EC, and KM), with the exception of German full text articles that were screened by KM only (a native German speaker). Each reviewer was blinded to the other reviewers' selections until all articles had been scored. Any conflicts between the 3 reviewers were discussed together, with a final tie-breaker decision carried out by WM where necessary.

Data Extraction, Synthesis, and Reporting

It was decided a priori that the included articles would not be amenable to meta-analysis, due to distinct heterogeneity between studies with respect to study outcomes. For example, LS reported on different scales (0–3, 1–5, lame vs. not lame, sound vs. not-sound), different time frames (from hours after NSAID treat-

ment to 100 d post-NSAID treatment), varying study population (chronic vs. acute), difference between types and proportion of CH lameness, and varying interventions (e.g., types of NSAID used and concomitant treatments in both treatment and control groups). As a result, synthesis of data from included articles were reported following the methods proposed by Campbell et al. (2020). The 9 SWiM reporting categories are detailed in Table 2, with the approaches used in this study reported.

Along with study primary author, year of publication, country, and whether or not the article was peer reviewed, we extracted data on the intervention and comparison group, the NSAID used, and outcomes measured. Data were grouped into the outcome measurement and length of time from NSAID administration to outcome measurement, and the raw data and statistical outcomes extracted from the text. For articles with LS as an outcome, an attempt was made to synthesize the results as lame or nonlame. If sufficient data were not present in the text to categorize LS, then the corresponding authors were contacted and a request was made for the raw data, or in one instance, data were obtained from a PhD thesis (O'Callaghan, 2003). If the raw data were obtained, the primary author transformed the LS into lame or not (based on the LS system used), and the proportion lame at each period was reported. Contrast analyses were carried out on each combination of intervention versus comparison group in each study. For example, Thomas et al. (2015) contained 4 treatment groups (NSAID, NSAID + block, block, and no treatment). The contrast analyses for this included NSAID versus block, NSAID versus no treatment, NSAID + block versus block, and NSAID + block versus no treatment. If the contrast analyses could not be obtained directly from the manuscript, then Monte-Carlo random simulation was carried out using the normally disturbed characteristics of regression coefficient and standard errors. In the case of Laven et al. (2008), the raw data were reanalyzed following the methodology proposed in Laven et al. (2008). No adjustments for multiple comparisons were used. Further detail on the data extraction for each study is presented in Table 2.

In addition to the above SWiM guidelines, each included article was assessed for risk of bias and for reproducibility and adherence to protocol reporting guidelines for clinical trials. Risk of bias was assessed by WM for each outcome of the included articles according to the methods proposed by Cochrane Risk of Bias tool V2.0 (Sterne et al., 2019). Although these were conducted for each outcome, as recommended by Sterne et al. (2019), the risk of bias for studies that reported more than 1 relevant outcome was the same across all of their outcomes. Thus, an overall risk of bias for each study was presented, rather than for each outcome. A Microsoft Excel macro tool was used to collate the responses for each of the 5 potential bias domains (recovered October 5, 2021, from https://www.riskofbias.info/welcome/rob-2-0-tool/current-version-of-rob-2).

We reviewed all of the included studies for the presence or absence of the 25 items in the CONSORT reporting guidelines checklist (Moher et al., 2010). These were reported for each article, and an overall proportion of articles that included the CONSORT items were also reported.

RESULTS

The PRISMA 2020 flow diagram for the systematic review is presented in Figure 1. A total of 299 articles were identified by the search terms in the databases, 72 of which were identified as duplicates. Thus, 227 articles had their titles and abstracts screened, with 204 excluded at this stage as they did not meet the title and abstract screening criteria. Full text screening was carried out on the remaining 23 articles, with 6 articles identified as meeting all inclusion criteria and included in the systematic review. All 6 articles included in the systematic review were in the English language.

Of the 6 studies, 5 were carried out in the United Kingdom, and 1 was conducted in New Zealand. They were all published after 2000. In all of the studies, the control animals received, at a minimum, a therapeutic trim of the lameness-causing CH lesion. Substantial heterogeneity existed between the included studies, and included duration of lameness (<2 wk duration or ≥2 wk or unknown duration), NSAID investigated (ketoprofen or tolfenamic acid), concomitant treatments administered in animals in both the intervention and control groups (the addition of a hoof block or no further treatments), severity of lameness or lesion, and time from treatment to when outcome was measured (for LS, this ranged from several hours after NSAID administration to 100 d after NSAID administration). Further details of the studies are presented in Table 3.

Lameness Outcomes

A total of 5 of the 6 articles that met the inclusion criteria reported LS outcomes, and these consisted of 22 different contrast analyses with either NSAID or NSAID + block as the intervention. Measures of association with lame or not lame as the outcome were available for 20 of these analyses. None of these analyses identified a difference between groups, with the 95% confidence interval for odds ratio overlapping 1 in all analyses

Table 2. Synthesis without meta-analysis (SWiM) reporting items and descriptions of the methodology of how each item was addressed; SWiM is intended to complement and be used as an extension to PRISMA (Campbell et al., 2020)

SWiM reporting item	Description
Methods	
1. Grouping studies for synthesis	The studies were first grouped according to their outcome variable, either locomotion scores (LS), nociceptive threshold measurements, or lying times. Studies were then grouped into intervention comparison groups for subgroup synthesis. For example, if a study reported the findings of nonsteroidal anti-inflammatory drug (NSAID) and non-NSAID groups with and without foot block, then each pairwise comparison was reported and grouped separately. Finally, studies were grouped from subgroup synthesis based on the length of time after NSAID treatment for which the outcome variable was reported (<10 or ≥10 d).
2. Describe the standardized metric and transformation methods used	The LS were reported using different systems and scales (i.e., 4 different scales in the 5 articles that reported LS). Due to this, an attempt was made to transform them from the ordinal score to a lame versus not lame binary variable, as defined by each of the outcome scales. If this was not possible, then the data were reported as was in the article. Nociceptive threshold measurements were reported in different units, kPa or N. These were not transformed to a consistent measure (N), as doing this depended on external factors that could not be controlled. Nociceptive threshold data were reported in the original units used in the respective articles.
3. Describe the synthesis methods	An effect size with 95% CI and a direction of association was reported for each pairwise comparison from each included study. Whether the 95% CI overlapped with 1 for binary outcomes, or 0 for continuous outcomes, for each analysis was reported. The direction of the association between the intervention and the comparison group was also reported, regardless of 95% CI.
4. Criteria used to prioritize results for summary and synthesis	As it was expected that there would not be many included articles, all were reported equally. However, those with some concern or high risk of bias were explicitly commented upon.
5. Investigation of heterogeneity in reported effects	There were many sources of heterogeneity and likely too few studies to investigate further. Rather, the important sources of heterogeneity identified were discussed.
6. Certainty of evidence	An overall risk measure, with confidence intervals, was not reported. The proportion of analyses in a given direction of association was reported, with a greater proportion of associations in a given direction likely to be more certain of an association. However, no certainty measurement (confidence interval or probability statistic) could be assigned to this value. The overall risk of bias and the proportion of the studies that reported each of the CONSORT items were discussed, as they had bearing on the certainty of the evidence.
7. Data presentation methods	All results were reported in tabular format, apart from risk of bias, which was presented in graphical format for each domain, and overall risk. The tables included a column for the citation, study type, NSAID and dosing regimen, intervention group, control group, outcome measurement, time period, results, significance of association, direction of association, overall risk of bias, and comments.
Results	
8. Reporting results	As it was expected that outcomes would be in various forms, results were reported in a table with commentary, rather than a forest plot. A PRISMA diagram of the exclusion reasons were presented, as was a description of all the included studies in tabular format.
Discussion	
9. Limitations of the synthesis	Limitations included, but were not limited to, variation in the methods used for LS, the study population, concomitant treatments, and follow-up or losses to the study. These could be addressed in the methods and results, but could not be accounted for (e.g., in a meta-analysis); therefore, an overall metric was not produced.

Table 3. Descriptions of the 6 studies included for the systematic review, including whether the article was peer reviewed or not, country where the work was conducted, study population investigated, the various intervention groups for pairwise comparisons, outcomes and time frames of outcomes, nonsteroidal anti-inflammatory drug (NSAID) used, and the total number enrolled and analyzed

Reference	Number	Peer reviewed	Country	Study population	Interventions	Outcomes	NSAID	Total number enrolled (number analyzed if reported)
Laven et al. (2008)	1	Yes	New Zealand	Lame dairy cattle identified by farmer; included if claw horn lameness only, could be lame in more than 1 limb	Six treatment groups, split depending on whether animal required plastic shoe; did not require plastic shoe: (1) NSAID, (2) NSAID + plastic shoe, (3) plastic shoe, (4) no additional treatment; required plastic shoe: (5) NSAID + plastic shoe, (6) plastic shoe	Locomotion score (LS): repeated at d 3, 8, 28, and 100; Nociceptive threshold: repeated at d 3, 8, 28, and 100	Tolfenamic acid (2 mg/kg BW) single treatment immediately after corrective trim	149
Miguel-Pacheco et al. (2016)	2	Yes	UK	Dairy cattle with acute (<2 wk duration) lameness identified by trained LS observers; claw horn lameness only included, lame in only 1 limb	Four treatment groups: (1) no additional treatment, (2) foot block, (3) NSAID, (4) NSAID + foot block	Lying times for 5 days post-treatment	Ketoprofen (3 mg/kg BW) SID[1] for 3 d, immediately after corrective trim	44 (40)
O'Callaghan-Lowe et al. (2004)	3	No	UK	Dairy cattle with acute (<2 wk duration) lameness identified by trained LS observers; non-claw horn lameness and claw horn lameness included, exclusion criteria not stated	Three treatment groups for claw horn lameness group: (1) NSAID, (2) foot block, (3) no additional treatment	LS: repeated between 3 and 7 d, 16–20 d and 26–30 d	Ketoprofen (3 mg/kg BW) SID for 3 d, immediately after corrective trim	118
Thomas et al. (2015)	4	Yes	UK	Dairy cattle with acute (<2 wk duration) lameness identified by trained LS observers; claw horn lameness only included, lame in only 1 limb	Four treatment groups: (1) no additional treatment, (2) foot block, (3) NSAID, (4) NSAID + foot block	LS at 35 d post-treatment	Ketoprofen (3 mg/kg BW) SID for 3 d, immediately after corrective trim	183 (167)
Thomas et al. (2016)	5	Yes	UK	Dairy cattle with chronic (>2 wk duration) lameness identified by trained LS observers; claw horn lameness only included, lame in only 1 limb	Three treatment groups: (1) no additional treatment, (2) foot block, (3) NSAID + foot block	LS at 42 d post-treatment	Ketoprofen (3 mg/kg BW) SID for 3 d, immediately after corrective trim	189 (154)
Whay et al. (2005)	6	Yes	UK	Dairy cattle with lameness of unknown duration as identified by trained LS observers; infectious and claw horn lameness included, lame in only 1 limb	Two treatment groups: (1) NSAID, (2) sterile saline placebo	LS: repeated at d 1, 3, 8, and 28; nociceptive threshold: repeated at d 1, 3, 8, and 28	Ketoprofen (3 mg/kg BW) SID for 3 d, first dose 1 h before corrective trim	28 claw horn lameness; 40 total enrolled

[1]SID = once daily.

(Table 4). The length of time from treatment to LS measurement varied between studies, with 3 reporting LS outcomes <10 d post-treatment, and all 5 reporting LS ≥10 d post-treatment. Of those LS outcomes ≥10 d post-treatment, animals in the intervention groups had a lower point estimate lameness risk than animals in the comparison groups in 9 of 14 analyses. For the LS outcomes <10 d, only 3 of 8 analyses of contrasts had a lower point estimate lameness risk in favor of animals in the intervention groups compared with the comparison groups.

Nociceptor Threshold and Lying Times

Two of the 6 articles that met the inclusion criteria reported nociceptive threshold outcomes (Table 5). No differences were identified in the 12 contrast analyses (either NSAID or NSAID + block as the intervention) from the 2 articles, with the 95% confidence intervals overlapping 0 in all of them. For nociceptive threshold <10 d post-treatment, animals in the intervention groups had a greater nociceptor threshold point estimate in 6 of 6 analyses compared with animals in the comparison groups. For nociceptor thresholds collected ≥10 post-treatment, only 1 of 6 analyses had a greater nociceptor threshold for animals in the intervention group compared with the comparison group.

Only 1 article that met the inclusion criteria reported lying times. All 4 lying time contrast analyses in Miguel-Pacheco et al. (2016) had a point estimate with NSAID-treated animals lying for a longer time per day than animals in the comparison groups, although all of the 95% confidence intervals between intervention groups and comparison groups included 0. The largest increase in lying times was noted in animals treated with NSAID + block compared with block.

Bias and Reporting Guidelines

The overall risk of bias varied between studies from low risk to high risk (Figure 2). At least a moderate risk of bias was identified in missing outcome data in 4 of the 6 studies, with a high risk of bias present in O'Callaghan-Lowe et al. (2004). Some risk of bias was identified in Whay et al. (2005) in the randomization process as this was the only study that enrolled animals before diagnosing the lameness-causing lesion. This resulted in differences in the proportion of lesions between intervention groups. Two of the 6 studies had bias concerns with measurement of the outcome, with O'Callaghan-Lowe et al. (2004) only measuring the total number of animals at each LS, not the individual animal scores.

There was a range in the CONSORT compliance between each item in the checklist (Table 6). Perfect compliance for all 6 studies was achieved in the background and objectives, eligibility criteria, and outcome definitions. The most noncompliant CONSORT items included sample size (2 of 6 reporting), the randomization process (2 of 6 reporting), baseline data (2 of 6 reporting), and discussion of limitations (0 of 6 reporting).

DISCUSSION

This is the first systematic review investigating the published literature on the use of NSAID for the treatment of CH lameness in dairy cattle. From an initial 227 abstracts and titles screened from the search terms, 23 were progressed to full text screening. Only 6 of these articles met the criteria for inclusion in the review, highlighting the scarcity of evidence in this field. This is despite the recent increase in papers published on NSAID and cattle. This scarcity of evidence, combined with the between-study heterogeneity, means that we lack the data to properly evaluate the effect of NSAID use on LS, nociceptive threshold or lying times, or the factors that influence the response to NSAID use.

The validity and repeatability of research can be assessed with multiple methods. The authors chose the following 2 methods for this review: the Cochrane risk-of-bias tool designed to assess bias in randomized trials (Sterne et al., 2019) and the CONSORT reporting guidelines (Moher et al., 2010), presented as the proportion of included articles that reported each specific CONSORT item. The quality of evidence varied between the 6 studies, from low risk of bias to high risk of bias. A major difference between the 2 studies that had a low risk of bias (Thomas et al., 2015, 2016) compared with the other 4 studies was the use of reporting guidelines. This highlights the scientific benefits of following reporting guidelines to minimize risk of bias in a study and, crucially, to assist with repeatability of the research. The authors commend the *Journal of Dairy Science* on leading the movement to require the use of reporting guidelines.

One of the more challenging aspects of conducting cattle lameness intervention trials is accounting for losses to follow-up. There are many reasons why missing data for the outcome may be related to the treatment, thus creating bias. Two important reasons are that animals may require re-treatment due to welfare reasons (lameness becoming worse or no improvement over time), or if using blocks, they fall off. These reasons clearly could be related to the treatment group. The risk of bias for the 5 LS studies for missing outcome data ranged from

Table 4. Summary of data extracted from the 5 studies included that measured locomotion score (LS) as an outcome [pairwise comparisons were carried out for each intervention and control group, and based on whether LS was collected <10 d from nonsteroidal anti-inflammatory drug (NSAID) administration or ≥10 d from NSAID administration; the odds ratio (OR; 95% CI) and direction of association was reported for each pairwise comparison and an overall risk of bias for each study presented]

Time frame	Reference	Outcome	Intervention	Comparison group	Raw data	Measure of association (OR with 95% CI)[1]	CI include 1	Direction of association	Risk of bias	Comments
<10 d	Laven et al. (2008)	Lame (LS ≥3/5) or not lame (LS <3/5)	NSAID	No treatment	d 3: 0.50 (12/24) vs. 0.35 (6/17) d 8: 0.21 (5/24) vs. 0.24 (4/17)	1.32 (0.33–5.20)	Y[2]	Negative	Some concerns	Raw data re-analyzed to lame or not; OR and 95% unadjusted
			NSAID	Block	d 3: 0.50 (12/24) vs. 0.50 (9/18) d 8: 0.21 (5/24) vs. 0.18 (3/17)	1.05 (0.28–3.98)	Y	Negative		
			NSAID and block	No treatment	d 3: 0.47 (9/19) vs. 0.35 (6/17) d 8: 0.33 (7/21) vs. 0.24 (4/17)	1.6 (0.39–6.57)	Y	Negative		
			NSAID and block	Block	d 3: 0.47 (9/19) vs. 0.50 (9/18) d 8: 0.33 (7/21) vs. 0.18 (3/17)	1.28 (0.20–3.08)	Y	Negative		
			Lesion required a block	Lesion required a block; NSAID and block	d 3: 0.37 (13/35) vs. 0.33 (11/33) d 8: 0.20 (7/35) vs. 0.16 (5/31)	1.20 (0.39–3.66)	Y	Negative		
	Whay et al. (2005)	Median and quartiles of LS (1–5)	NSAID	Sterile saline	d 1: 3 (3–4) vs. 3.5 (3–5) d 3: 2 (1–3.25) vs. 2.5 (1.75–4) d 8: 2 (1–3) vs. 1 (1–2.25)	NA[3]	NA	Positive	Some concerns	Could not access raw data
	O'Callaghan-Lowe et al. (2004)	Lame (LS ≥3/5) or not lame (LS <3/5)	NSAID	No treatment	d 3–7: 0.91 (20/22) vs. 0.95 (38/40)	0.53 (0.07–4.02)	Y	Positive	High	Large number of missing animals; data obtained from PhD
			NSAID	Block	d 3–7: 0.91 (20/22) vs. 1.00 (35/35)	NR[4]	Y	Positive		
≥10 d	Laven et al. (2008)	Lame (LS ≥3/5) or not lame (LS <3/5)	NSAID	No treatment	d 28: 0.11 (2/18) vs. 0.00 (0/15) d 100: 0.06 (1/18) vs. 0.00 (0/13)	NR[4]	Y	Negative	Some concerns	Raw data re-analyzed to lame or not; OR and 95% unadjusted NR[3]: OR and CI could not be calculated, as the control group had zero lame animals
			NSAID	Block	d 28: 0.11 (2/18) vs. 0.13 (2/16) d 100: 0.06 (1/18) vs. 0.07 (1/14)	1.0 (0.06–13.6)	Y	Neutral		
			NSAID and block	No treatment	d 28: 0.13 (2/15) vs. 0.00 (0/15) d 100: 0.00 (0/13) vs. 0.00 (0/13)	NR[4]	Y	Negative		
			NSAID and block	Block	d 28: 0.13 (2/15) vs. 0.13 (2/16) d 100: 0.00 (0/13) vs. 0.07 (1/14)	NR[4]	Y	Positive		
			Lesion required a block	Lesion required a block; NSAID and block	d 28: 0.12 (4/34) vs. 0.06 (2/32) d 100: 0.07 (2/27) vs. 0.04 (1/25)	2.00 (0.34–11.8)	Y	Negative		
	Thomas et al. (2015)	Lame (LS ≥2/3) or not lame (LS <2/3)	NSAID	No treatment	0.24 (10/42) vs. 0.31 (14/45)	0.83 (0.26–2.5)	Y	Positive	Low	OR and CI calculated from adjusted model data
			NSAID	Block	0.24 (10/42) vs. 0.28 (11/39)	0.92 (0.30–2.56)	Y	Positive		
			NSAID and block	No treatment	0.14 (6/41) vs. 0.31 (14/45)	0.31 (0.09–1.11)	Y	Positive		
			NSAID and block	Block	0.14 (6/41) vs. 0.28 (11/39)	0.38 (0.07–2.07)	Y	Positive		
	Thomas et al. (2016)	Lame (LS ≥2/3) or not lame (LS <2/3)	NSAID and block	No treatment	0.84 (42/50) vs. 0.85 (44/52)	0.95 (0.33–2.78)	Y	Positive	Low	OR and CI calculated unadjusted
			NSAID and block	Block	0.84 (42/50) vs. 0.85 (46/54)	0.91 (0.31–2.65)	Y	Positive		
	Whay et al. (2005)	Median and quartiles of LS (1–5)	NSAID	Sterile saline	d 28: 1.5 (1–2.25) vs. 1 (1–2)	NA[3]	NA	Positive	Some concerns	Could not access raw data

Continued

Table 4 (Continued). Summary of data extracted from the 5 studies included that measured locomotion score (LS) as an outcome [pairwise comparisons were carried out for each intervention and control group, and based on whether LS was collected <10 d from nonsteroidal anti-inflammatory drug (NSAID) administration or ≥10 d from NSAID administration; the odds ratio (OR; 95% CI) and direction of association was reported for each pairwise comparison and an overall risk of bias for each study presented]

Time frame	Reference	Outcome	Intervention	Comparison group	Raw data	Measure of association (OR with 95% CI)[1]	CI include 1	Direction of association	Risk of bias	Comments
	O'Callaghan-Lowe et al. (2004)	Lame (LS ≥3/5) or not lame (LS <3/5)	NSAID	No treatment	d 16–20: 0.83 (5/6) vs. 1.00 (40/40) d 26–30: 0.54 (7/13) vs. 0.92 (43/47)	0.35 (0.05–2.29)	Y	Positive	High	Large number of missing animals Data obtained from PhD
			NSAID	Block	d 16–20: 0.83 (5/6) vs. 0.97 (30/31) d 26–30: 0.54 (7/13) vs. 0.83 (20/24)	0.70 (0.10–4.69)	Y	Positive		

[1]Measure of association is relative to odds of lameness in comparison group; OR <1 is reduced odds in intervention group compared with comparison group, and thus a beneficial association.
[2]Y = yes.
[3]OR could not be calculated from provided data. Article reported chi-squared test showing that NSAID treatment had no effect on LS.
[4]OR and CI could not be calculated, as control groups had zero or all lame animals.

low (Thomas et al., 2015, 2016), to some (Whay et al., 2005; Laven et al., 2008), to high concern (O'Callaghan-Lowe et al., 2004). It is of note that the risk of bias was greatest in the article that had not been through journal peer review (O'Callaghan-Lowe et al., 2004). However, even in the low-risk group, there was still a large number of animals that were lost to follow-up. Loss rates were similar across the intervention groups in those 2 trials, but an argument could be made that the study design could still result in losses to follow-up that could bias the results. One way to reduce the risk of this type of bias would be to analyze the data as time to event (i.e., time to soundness or time to nonlame). If cattle are required to be re-treated, then the animal can be censored at the time of re-treatment; therefore, not all of the animal time-at-risk would be lost to the analysis. Although a potentially more challenging study to conduct, the authors recommend that future studies using LS as an outcome use survival analysis methods. This will also increase the power of the study and remove the a priori effect of defining a time period that an animal must be sound by, which has little biological relevance to the cow or farmer.

One of the major challenges of comparing studies that report LS as the primary outcome is the variability in the LS systems and scales that are used by different research groups and countries. This was apparent in this review, with 4 different LS systems used in the 5 studies that reported LS outcomes. This issue was exacerbated by all 5 studies using different statistical methods and LS outcomes.

The use of different LS systems has been a consistent issue limiting sharing, comparing, and use of lameness data ever since the development of LS (Schlageter-Tello et al., 2014). Different systems use different criteria for scoring, and simplistic correspondence tables can obscure those differences. For example, in the International Committee for Animal Recording (ICAR) guidelines (ICAR, 2020), they claim that a score of 3 on the 0-to-3 Agriculture and Horticulture Development Board (AHDB) mobility score is equivalent to 5 on the First-Step system when the criteria for an AHDB score 3 (unable to walk as fast as a brisk human pace and lame leg easy to identify) also match the criteria for a First-Step score of 4 (gait is best described as 1 deliberate step at a time and ability to move freely is obviously diminished). Similar issues with BCS prompted Roche et al. (2004) to examine relationships across differing BCS systems; however, as far as the authors are aware, no such studies have been undertaken for LS. Although the ICAR guidelines (ICAR, 2020) recommend the use of the 1-to-5 Sprecher score, it is unlikely that there will be agreement to use only 1 LS in all countries and all systems. For example, the First-Step system has been

Table 5. Summary of data extracted from the 2 studies included that measured nociceptor threshold and the 1 study that measure lying times[1]

Variable	Time frame	Reference	Outcome	Intervention group	Comparison group	Raw data; mean (SE)	Measure of association (95% CI)[2]	CI overlap 0	Direction of association	Risk of bias	Comments
Nociceptor threshold	<10 d	Laven et al. (2008)	kPa	NSAID	No treatment	d 3: 27 (1.68) vs. 27.4 (1.72) d 8: 31.9 (1.31) vs. 31.8 (2.23)	0.76 (−4.93 to 6.45)	Y[3]	Positive	Some concerns	Point estimate and CI from estimated marginal means from adjusted linear regression model; units kPa
				NSAID	Block	d 3: 27 (1.68) vs. 25.3 (2.27) d 8: 31.9 (1.31) vs. 28.8 (1.79)	2.35 (−2.99 to 7.68)	Y	Positive		
				NSAID + block	No treatment	d 3: 25.8 (1.92) vs. 27.4 (1.72) d 8: 31 (2.14) vs. 31.8 (2.23)	1.89 (−3.79 to 7.57)	Y	Positive		
				NSAID + block	Block	d 3: 25.8 (1.92) vs. 25.3 (2.27) d 8: 31 (2.14) vs. 28.8 (1.79)	0.30 (−5.68 to 6.29)	Y	Positive		
				Lesion required a block; NSAID + block	Lesion required a block; block	d 3: 31.1 (1.38) vs. 31.3 (1.88) d 8: 33.9 (1.28) vs. 32.6 (1.49)	1.19 (−3.40 to 5.78)	Y	Positive		
		Whay et al. (2004)	N	NSAID	Sterile saline	d 1: 9.1 (0.54) vs. 9.1 (0.6) d 3: 10 (0.61) vs. 8.8 (0.57) d 8: 10.3 (0.61) vs. 9.0 (0.42)	0.00 (−1.63 to 1.63)[4] 1.20 (−0.49 to 2.89) 1.30 (−0.20 to 2.80)	Y	Positive	Some concerns	Units N; Contained 12 of 40 animals with nonclaw horn lameness
	≥10 d	Laven et al. (2008)	kPa	NSAID	No treatment	d 28: 40.5 (1.75) vs. 42.8 (1.93) d 100: 43.7 (1.36) vs. 45.4 (1.44)	−2.32 (−8.55 to 3.91)	Y	Negative	Some concerns	Point estimate and CI from estimated marginal means from adjusted linear regression model; units kPa
				NSAID	Block	d 28: 40.5 (1.75) vs. 41.2 (2.19) d 100: 43.7 (1.36) vs. 46.4 (1.17)	−1.86 (−7.70 to 3.98)	Y	Negative		
				NSAID + block	No treatment	d 28: 38.1 (2.05) vs. 42.8 (1.93) d 100: 45.4 (1.3) vs. 45.4 (1.44)	−1.99 (−8.10 to 4.12)	Y	Negative		
				NSAID + block	Block	d 28: 38.1 (2.05) vs. 41.2 (2.19) d 100: 45.4 (1.3) vs. 46.4 (1.17)	−2.45 (−8.91 to 4.01)	Y	Negative		
				Lesion required a block; NSAID + block	Lesion required a block; block	d 28: 36.6 (1.41) vs. 40.9 (1.28) d 100: 45 (1.12) vs. 46 (1.04)	−2.99 (−7.36 to 1.38)	Y	Negative		
		Whay et al. (2004)	N	NSAID	Sterile saline	d 28: 10.6 (0.73) vs. 9.2 (0.53)	1.40 (−0.42 to 3.22)	Y	Positive	Some concerns	Units N Contained 12 of 40 animals with nonclaw horn lameness

Continued

Table 5 (Continued). Summary of data extracted from the 2 studies included that measured nociceptor threshold and the 1 study that measure lying times[1]

Variable	Time frame	Reference	Outcome	Intervention group	Comparison group	Raw data; mean (SE)	Measure of association (95% CI)[2]	CI overlap 0	Direction of association	Risk of bias	Comments
Lying time	<10 d	Miguel-Pacheco et al. (2016)		NSAID	No treatment	53.88 (53.14) vs. 31.07 (49.05)[5]	22.81 (−120.44 to 166.06)	Y	Positive	Some concerns	Point estimate and CI from pairwise *t*-test adjusted model output
				NSAID	Block	53.88 (53.14) vs. 120.27 (50.44)[5]	66.39 (−79.61 to 212.39)	Y	Positive		
				NSAID + block	No treatment	−31.91 (66.63) vs. 31.07 (49.05)[5]	62.98 (−106.23 to 232.56)	Y	Positive		
				NSAID + block	Block	−31.91 (66.63) vs. 120.27 (50.44)[5]	152.18 (−13.23 to 317.59)	Y	Positive		

[1]Pairwise comparisons were carried out for each intervention and control group and based on whether the outcome was collected <10 d from NSAID administration or ≥10 d from NSAID administration. The mean difference (95% CI) and direction of association was reported for each pairwise comparison and an overall risk of bias for each study presented.
[2]Measure of association is for intervention group compared with comparison group; a value >0 indicates a greater nociceptor threshold or lying time for the animals in the intervention group compared with animals in the comparison group.
[3]Y = yes.
[4]A combined measure of association could not be produced, as the raw data were not available.
[5]Units: minutes per day.

criticized for undue focus on back arching (H. R. Whay, National University of Ireland, Galway, Ireland, personal communication) and in pasture-based herds such as those in New Zealand and Australia. In these types of herds, locomotion scoring takes place after milking (Fabian et al. 2014) with a system that depends on observing whether or not there is a back arch at standing, and walking is of limited value. Furthermore, observing for back arch during walking and standing is incompatible with large-scale, long-term studies, which are required to conduct high quality, adequately powered interventional studies. Thus, recommendations to standardize LS in interventional studies, as have been made for reporting reproductive indices (Lean et al., 2016), are unlikely to be followed. However, almost all manual LS systems have a binary cutpoint for lame versus not lame or sound versus not-sound, and it would be extremely valuable to compare those cutpoints across systems to establish a level of agreement.

A pleasing finding was that all articles included in our review had clear objectives, and eligibility criteria and outcome definitions were well defined. These factors have been reported as lacking in a previous veterinary meta-analysis (Muir et al., 2017). In contrast, sample size calculations were only reported for 2 of 6 of studies used in our review. Although this is a nonissue in Thomas et al. (2015), as a difference between groups was identified (NSAID + block associated with greater proportion of cattle with LS < 1 than block or no other treatments), the findings of the other 5 studies cannot be interpreted without information on the power or a discussion on the practical interpretation of not rejecting the null hypothesis. Only 1 of the 6 articles we included in our review (Thomas et al., 2016) discussed type 2 errors and the implications to the inferences of the study. This makes extrapolation of the individual study results difficult. The effect of some of this possible misclassification bias was reduced through the methods used in this systematic review by synthesizing the direction of the association. However, the true association between NSAID and LS, nociceptor thresholds, and lying times remains unknown. This problem of lack of transparency of sample size and power is not only related to cattle lameness research, and it remains an issue within other fields of veterinary science (Muir et al., 2017). The introduction of compulsory reporting guidelines in journals such as the *Journal of Dairy Science* should go a long way to address some of these issues.

Two of the original articles reported significant differences between NSAID intervention groups and comparison groups in lame cattle (Whay et al., 2005; Thomas et al., 2015). The authors have no reason to believe that the association identified in Thomas et al.

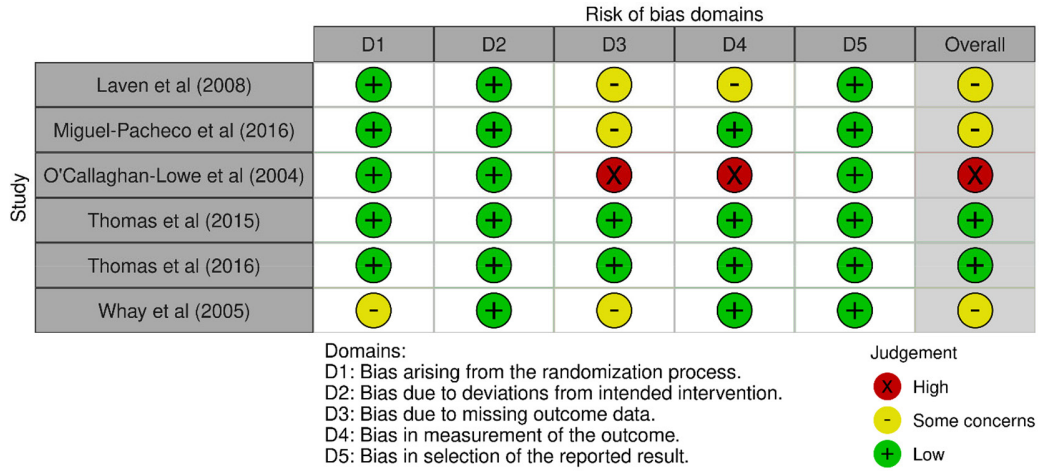

Figure 2. Risk of bias plot for the 6 studies included for each of the 5 domains, as well as an overall measure of risk of bias (McGuinness and Higgins, 2021).

(2015) does not exist. Although the lower bounds of the 95% confidence interval do overlap an odds ratio of 1 when analyzed as lame or not in this current systematic review (LS >1 or LS ≤1 on a 0–3 scale), the study effect size was large for NSAID + block compared with no treatment (odds ratio: 0.31, 95% confidence interval: 0.09–1.11). One of the major differences in the study design of Thomas et al. (2015) compared with the other studies is that they enrolled animals that had been lame for less than 14 d (based on fortnightly LS). However, we cannot ignore the findings of the other studies when considering the effect of NSAID. This is particularly relevant; even though rapid identification and treatment of lameness is strongly recommended (Pedersen and Wilson, 2021), this is unlikely to be what happens in the majority of lameness management on-farm (Leach et al., 2010; Alawneh et al., 2012; Fabian et al., 2014).

The improvement in nociceptor threshold over time in animals treated with ketoprofen reported by Whay et al. (2005) has previously been questioned by Laven et al. (2008), who surmised that the difference between the studies was in the control group, rather than the treatment group. This was confirmed by Whay et al. (2005), who, in the same article, also reported no difference between nociceptor threshold between treatment groups at each measurement day. This was also concluded in the current review from pairwise comparisons of the data presented by Whay et al. (2005). Comparing nociceptive threshold within treatment groups, and then claiming a difference because the comparison in one treatment group was significant but not in the other is a flawed approach (Sainani, 2010). Laven et al. (2008) did not identify any significant difference in the nociceptive threshold between animals treated with NSAID and those not treated with NSAID. Thus, no strong evidence currently exists that NSAID increase nociceptor threshold over time in lame dairy cattle compared with claw trimming alone.

Although there have been other studies investigating the effects of NSAID on lying times in lame cattle (reviewed by Mainau et al., 2022), this current review only identified 1 study that explicitly enrolled cattle with CH lameness (Miguel-Pacheco et al., 2016). The majority of studies investigating lying times and activity measurements in lame cattle compared with nonlame control animals highlight an increase in lying times and a reduction in activity in general (Mainau et al., 2022). Thus, for NSAID to have an effect, it would be expected that there should be a reduction in lying time in lame animals treated with NSAID compared with lame animals not treated with NSAID. However, this has not been consistently found (Mainau et al., 2022). The 1 study of lying times and NSAID use included in the current systematic review (Miguel-Pacheco et al., 2016) did not identify any significant differences in lying times in animals that received NSAID compared with those that did not receive NSAID, although the point estimate for all pairwise comparisons was in favor of an increase in lying times for animals in the NSAID groups, rather than the expected reduction. Therefore, there is no strong evidence currently that NSAID treatment has any effect on lying times in animals with CH lameness.

A critique of the search terms used for this review could be that they were too narrow. An informal sensitivity analysis was conducted to assess this, where "OR Bovine" and "OR meloxicam OR ketoprofen OR

Table 6. The presence or absence of each CONSORT (Moher et al., 2010) checklist item for each of the 6 included studies, as well as the proportion of the 6 studies included that contain each item; the included article number is cross-referenced in Table 3[1]

Section and topic	Item no	Checklist item	Included article number						Percentage with item (number of studies with relevant item)
			1	2	3	4	5	6	
Title and abstract	1a	Identification as a randomized trial in the title	N	N	N	Y	Y	N	33% (2/6)
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	Y	Y	Y	Y	Y	Y	100% (6/6)
Introduction									
Background and objectives	2a	Scientific background and explanation of rationale	Y	Y	Y	Y	Y	Y	100% (6/6)
	2b	Specific objectives or hypotheses	Y	Y	N	Y	Y	Y	83% (5/6)
Methods									
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	N	Y	N	Y	Y	Y	66% (4/6)
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	NA	NA	NA	NA	NA	NA	NA
Participants	4a	Eligibility criteria for participants	Y	Y	Y	Y	Y	Y	100% (6/6)
	4b	Settings and locations where the data were collected	Y	Y	Y	Y	Y	Y	100% (6/6)
Interventions	5	The interventions for each group, with sufficient details to allow replication, including how and when they were administered	N	N	N	Y	Y	Y	50% (3/6)
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	Y	Y	Y	Y	Y	Y	100% (6/6)
	6b	Any changes to trial outcomes after the trial commenced, with reasons	N	N	N	N	N	N	0% (0/6)
Sample size	7a	How sample size was determined	N	N	N	Y	Y	N	33% (2/6)
	7b	When applicable, explanation of any interim analyses and stopping guidelines	NA	NA	NA	NA	NA	NA	NA
Randomization									
Sequence generation	8a	Method used to generate the random allocation sequence	Y	Y	N	Y	Y	N	83% (5/6)
	8b	Type of randomization; details of any restriction (such as blocking and block size)	N	Y	N	Y	Y	N	50% (3/6)
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	N	Y	N	Y	Y	N	50% (3/6)
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	N	Y	N	Y	N	N	33% (2/6)
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	N	N	N	N	N	Y	17% (1/6)
	11b	If relevant, description of the similarity of interventions	NA	NA	NA	NA	NA	NA	NA
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	Y	Y	N	Y	Y	N	66% (4/6)
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	Y	NA	N	Y	NA	N	50% (2/4)
Results									
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analyzed for the primary outcome	N	Y	N	Y	Y	N	50% (3/6)
	13b	For each group, losses and exclusions after randomization, together with reasons	N	Y	N	Y	Y	N	50% (3/6)
Recruitment	14a	Dates defining the periods of recruitment and follow-up	Y	Y	Y	Y	Y	Y	100% (6/6)
	14b	Why the trial ended or was stopped	NA	NA	NA	NA	NA	NA	NA

Continued

Table 6 (Continued). The presence or absence of each CONSORT (Moher et al., 2010) checklist item for each of the 6 included studies, as well as the proportion of the 6 studies included that contain each item; the included article number is cross-referenced in Table 3[1]

Section and topic	Item no	Checklist item	Included article number						Percentage with item (number of studies with relevant item)
			1	2	3	4	5	6	
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	Y	N	N	Y	N	N	33% (2/6)
Numbers analyzed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	N	Y	N	Y	Y	N	50% (3/6)
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	N	Y	Y	Y	N	N	50% (3/6)
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	N	NA	NA	Y	Y	N	50% (2/4)
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	Y	NA	NA	NA	NA	Y	100% (2/2)
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	N	N	N	Y	Y	N	33% (2/6)
Discussion									
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	N	N	N	N	N	N	0% (0/6)
Generalizability	21	Generalizability (external validity, applicability) of the trial findings	Y	Y	N	Y	Y	Y	83% (5/6)
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	N	Y	Y	Y	Y	Y	83% (5/6)
Other information									
Registration	23	Registration number and name of trial registry	N	N	N	N	N	N	0% (0/6)
Protocol	24	Where the full trial protocol can be accessed, if available	NA	NA	NA	NA	NA	NA	NA
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	Y	Y	Y	Y	Y	Y	100% (6/6)

[1]NA = not available; Y = yes; N = no.

flunixin" were added to the search term and produced 30 further records. All 30 of these articles would have been excluded at the title and abstract screening phase. Furthermore, no new articles were identified from the review articles that had not already been identified through database searching, giving confidence that the search terms had a high sensitivity for identifying relevant articles. It needs to be acknowledged that the literature on NSAID use for cattle lameness is more extensive than what is presented here. The authors were principally interested in studies that mimic "real-life" on-farm situations, and on the common, more chronic lameness conditions (i.e., CH lameness). As such, any mention of acute infectious lameness (e.g., footrot or digital dermatitis), or experimentally induced lameness, were not addressed in this review. Although these studies may have identified benefits from using NSAID, this review did not attempt to address all pain-mitigating associations that NSAID have with distal limb pain.

The NSAID regimen was the same in 5 of the articles (ketoprofen at 3 mg/kg BW daily for 3 d), with only 1 other regimen used (tolfenamic acid at 2 mg/kg once; Laven et al., 2008). This potentially reduced the external validity as we did not have knowledge on whether other NSAID compounds, or various dosing regimens of ketoprofen or tolfenamic acid, would have resulted in a different outcome. The distinct lack of studies involving meloxicam, the worldwide market-leading NSAID product with respect to volume sales (Metacam; CEESA – Executive animal health study center; company data, Boehringer-Ingelheim, Auckland, New Zealand) is of note and further highlights the lack of research in this field. However, given the duration of action of all known NSAID that are used in cattle, and the timeframes of the outcomes reported, we believe this unlikely to bias the inferences.

Some positive trends have been seen worldwide in the use of NSAID in production animals, with an increase in usage being reported (Laven, 2020). One possible unseen consequence of this trend is the confirmation bias from more welfare-conscious animal health advisors and farmers. Nevertheless, from the small number of studies conducted in this area, there was no definitive evidence from this systematic review that the use of NSAID improved LS and nociceptive threshold over an extended period of time post-treatment. This is particularly true in the clinical setting, whereby the majority of cattle have been lame for an extended period of time before being diagnosed and treated.

Nonetheless, the authors strongly support the use of NSAID in even the mildest clinical lame case, as the anti-inflammatory effects are likely to have benefits during the acute and chronic phases (Stock and Coetzee, 2015). Furthermore, the act of trimming lame cows is a painful act (Chapinal et al., 2010) and should warrant NSAID treatment. If the limited published data do reflect the lack of effect of NSAID on the LS, nociceptive threshold, and lying times of lame cows, it is because these are insensitive measures of assessing whether NSAID use is beneficial for the cow rather than accurate assessments of NSAID efficacy.

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6

Randomised clinical intervention trial on dairy heifers to reduce lameness incidence

Providing a NZ-specific management intervention that could reduce lameness incidence was identified as a key objective of the project. The calving period has been identified as one, if not the, most critical period for hoof health in dairy cattle, and that management in housed systems can alter this risk factor via exposure to hard surfaces at different physiological stages of a dairy animal's life. Furthermore, as a previous case of lameness has been identified as the single greatest predictor of a future case of lameness, control efforts should be directed towards dairy heifers, a population that are less likely to have had a previous case of lameness. This chapter presents to the findings of a randomised clinical intervention study investigating exposure to concrete and exercise prior to calving in pasture-raised New Zealand dairy cattle. The link to this publication can be found at https://doi.org/10.3168/jds.2021-21640.

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Randomized clinical trial investigating the effect of exercise and standing on concrete prior to first calving on time to first lameness event in dairy heifers

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ABSTRACT

This controlled clinical trial investigated if an intervention immediately before the first calving event could reduce lameness incidence in pasture-based dairy heifers. Seven hundred ninety heifers across 6 farms in the Waikato region of New Zealand were randomly enrolled into treatment or control groups at a ratio of 1:1. The treatment consisted of heifers walking approximately 1 km from pasture along the farm race, standing on concrete for one hour, and then walking back to their paddock. This occurred once a day, 5 times a week, for 5 wk before calving. The control heifers were managed solely at pasture before calving. Just before calving, both groups were bought together and managed as one group for the remainder of the study. Heifers were followed for up to 28 wk, with fortnightly lameness scores collected to identify animals with a lameness score of $\geq$2 (lameness score 0–3). Lameness could also be diagnosed by the farmers, who had no formal lameness scoring training. The primary outcome of interest was time to first lame event. Secondary outcomes included milk solid production, change in body condition score during early lactation, time from onset of breeding season until conception, feasibility of the regimen and change in sole soft tissue thickness and profile. From a total of 782 heifers that had data collected on the outcomes, 102 (13.0%) individual first lameness events were recorded, 53 in heifers in the treatment group and 49 in control heifers. Of those 102 lameness events, 51 were first diagnosed by farmers. No apparent differences were detected in the hazard rate for time to first lame event between heifers in the 2 treatment groups. Treatment heifers had a 1.12 times hazard rate (95% confidence interval: 0.65–1.95) of a lame event compared with control heifers. No associations were identified between heifers in the 2 groups for any of the secondary outcome measures. However, farmers did report that the intervention was practical and easy to implement. It is possible that the intervention did not challenge the hoof enough, and that longer duration and distances walked may have resulted in a different outcome. Although no improvement in lameness outcomes were reported, no negative effects during and after the intervention were noted in animals in the intervention group. Further research into the area of lameness prevention is needed as there are few evidence-based solutions available to reduce lameness incidence in pasture-based systems.
Key words: lameness, prevention, pasture-based, heifers

INTRODUCTION

Lameness is one of the major production-limiting diseases, and, arguably, the most important animal welfare condition affecting New Zealand dairy cattle when prevalence (Fabian et al., 2014), incidence (Gibbs, 2010) and duration of the disease (Laven et al., 2008) are considered.

A recent review focusing on control of lameness in dairy heifers stressed the importance of focusing on heifers to control lameness (Bell and Randall, 2021), and a compelling case can be made of why insults that occur to the hoof of a heifer can have profound effects on lameness later in life (Hirst et al., 2002; Randall et al., 2016; Bell and Randall, 2021). Hirst et al. (2002) reported a 3.2 times hazard (95% CI: 1.3–7.5) of claw horn lameness in the second lactation in animals that were lame as heifers compared with those that were not lame as heifers. A negative feedback loop adds further challenge to lameness control, where a case of lameness is associated with pathological changes within the hoof that in turn predisposes cattle to future cases of lameness (Newsome et al., 2016; Wilson et al., 2021).

This suggests that an increased amount of effort should be aimed at either reducing the risk of lameness in the first lactation, or at the very least extending the time to first lame event, with particular emphasis around the transition period for the heifer (Bell and Randall, 2021). Although several control methods and

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recommendations have been published (Vermunt and Parkinson, 2002; Potterton et al., 2012; Bell and Randall, 2021), many of these recommendations are based on observational studies rather that interventional studies (e.g., Vermunt and Parkinson, 2002), and practical implementation by farmers for many of these strategies has been challenging (Bell et al., 2009; Barker et al., 2012; Bruijnis et al., 2013). This is likely a bigger challenge in pasture-based dairy systems as there are fewer practical options available to help reduce the effect of lameness (Hund et al., 2019). Of the 10 foot-health intervention categories that were proposed by Bell and Randall (2021), only 4 are likely to apply to pasture-based systems (genomic selection, heifer transition and early postcalving management, fortnightly mobility scoring and prompt effective treatment, and the development of the digital cushion with exercise and hard tracks or flooring). Only these 4 are applicable because the vast majority of dairy cows in New Zealand are never housed and the rates of prophylactic hoof-trimming are low, as described in Bryan et al. (2012).

The negative effect of housing dairy cattle on hard flooring for an extended period of time around calving on hoof health has been demonstrated in several studies (Vermunt and Greenough, 1996; Webster, 2001; Laven and Livesey, 2004; Bergsten et al., 2015), demonstrating that housing management before, and after calving can have a profound effect on future lameness events. There is also evidence that an adaptive process can occur within the hoof in response to environmental stressors, and the timing of when this occurs appears critical (Bergsten and Frank, 1996; Bergsten et al., 2015; Randall et al., 2016).

It is currently unknown what effect precalving transition management has on postpartum hoof health in dairy heifers that have spent the majority of their lives at pasture. The transition period for heifers is relatively unique in New Zealand, in that they have spent usually the majority, if not all of their life before first calving at pasture and a large proportion (>90%) of them calve over a short time frame of approximately 2 mo. Yet after calving, these animals are exposed to a host of new environmental (e.g., concrete yards, farm races of varying quality) and management stressors (e.g., introduction to new staff, mixing with other older cows, often in large groups (>300 animals) and other cows, introduction to feed sources other than grazed pasture, walking long distances along farm races), in addition to the unavoidable changes that calving has on the hoof (Webster, 2001; Tarlton et al., 2002; Knott et al., 2007). Biochemical changes associated with parturition alter and weaken the connective tissue involved with the suspensory apparatus of the pedal bone within the hoof capsule, resulting in greater laxity of the pedal bone within the hoof capsule in primiparous heifers compared with maiden heifers of a similar age (Tarlton et al., 2002). This laxity increases the loading pressure of the pedal bone and can result in damage and disorganization to the adjacent corium. Although this is a natural and unavoidable phenomenon, the clinical effect can be modified by the environment the cattle are housed in (Knott et al., 2007). The combination of parturition and housing heifers on concrete has been associated with greater sole lesion scores in the 3 mo after parturition, compared with heifers housed on straw yards around the time of parturition (Knott et al., 2007). Dairy cattle in New Zealand stand on concrete for shorter timer periods than housed cattle, with the majority of the exposure occurring immediately before milking on a collecting yard and during milking. However, exposure to concrete is still an important risk factor for lameness in these cattle (Hund et al., 2019).

Conditioning the hooves of heifers to standing on concrete and walking on tracks around the transition period could allow the hoof to adapt to the stresses it will be exposed to after calving. Gard et al. (2015) reported that weaned bull calves reared on a race consisting of mixed terrain with enforced exercise for 4 mo adapted by significantly increasing digital cushion volume compared with calves managed on a small grass paddock. This is relevant as digital cushion volume has been reported as one of the key predictors for lameness risk in dairy cows (Bicalho et al., 2009). No similar studies have been undertaken in pregnant heifers. However, exercise has been shown to increase hoof wear, and thus, horn growth in pregnant dry cows. Black et al. (2017) reported that in cows that were housed in freestalls, adding an exercise regimen (walking for 1.5 h on concrete alleyways) before calving increased both hoof growth and wear, resulting in more equal hoof horn growth and wear than in cows housed in the same freestalls, but without exercise. Black et al. (2017) concluded that their exercise regimen did not impair hoof health and may have improved it. Thus, prepartum exercise may directly increase the ability of the hoof to protect against external trauma. It may also have an indirect effect; Bergsten et al. (2015) reported that heifers reared on hard surfaces for one year before calving had sole hemorrhage before calving, but fewer sole lesions after calving. This is consistent with the findings of Randall et al. (2016) that heifers with the presence of moderate sole and white line hemorrhage immediately before calving were associated with a significant reduction in lifetime lameness risk, inferring that the development of hoof hemorrhages before calving is associated with hoof resilience.

Any reduction in the risk of lameness or a delay to the development of the first case of lameness would

Table 1. Lameness scoring descriptors used in a randomized clinical trial investigating the effect of precalving exercise and time standing on concrete on time to first postpartum lame event (adapted from DairyNZ Lameness Scoring system)

Lameness score	Descriptor
0	Walks with even weight bearing on all 4 limbs at a similar walking speed to a person, with regular stride length and rhythm. Straight back line at all times and head held in line or slightly below the backline and steady when walking.
1	Walks unevenly but reduced weight bearing on affected limb not easily obvious. May have uneven stride length or rhythm. Backline straight when standing but may be mildly arched when walking.
2	Lame, with decreased stride length on affected limb. Weight bearing reduced on affected limb, which can easily be identified. Walking speed slower than normal. Backline often arched when standing and walking and head bobs up and down when walking.
3	Severely lame, with minimal or no weight bearing on affected limb. Reluctant to move and cannot keep up with the healthy herd. Backline arched when standing and walking and often large head movements up and down when walking.

result in a long-term reduction in lameness risk across the whole of an animal's productive life. However, to be acceptable on farm, such interventions need to be practical and achievable, as well as effective. Our hypotheses were that exposure to concrete and farm tracks via an exercise regimen immediately before calving in pasture-based heifers would increase sole soft tissue thickness and that this modification would reduce lameness risk postcalving. The primary objective of this study was to assess whether exposure to standing on a concrete surface and exercise on tracks over a 5-wk period immediately before calving affected the hazard of lameness in first-lactation dairy heifers. Secondary objectives included assessing the effect on sole soft tissue thickness and sole profile, along with associations with milk solid production, change in BCS during early lactation, time from onset of breeding until conception, and the feasibility of the regimen.

METHODS

The study was a partially blinded, randomized clinical intervention study conducted on a convenience sample of 6 commercial dairy farms in the Waikato region of New Zealand. All animal procedures were approved by the Ruakura Animal Ethics Committee (AgResearch, Hamilton, New Zealand), application number 14955. The study was designed and conducted in accordance with REFLECT guidelines (O'Connor et al., 2010).

Sample size calculations for total heifer numbers were based on the primary outcome objective, time to first lameness case. As this was a novel study, there was minimal information available on which to base calculations. The assumptions were that 25% of the control animals would have a lameness score (**LS**; Table 1) $\geq$2 (lameness score range: 0–3) at least once during their first 7 mo of lactation, and that the intervention would reduce this by 25% [hazard rate ratio (**HR**) = 0.75]. Clustering of animals within farm was accounted for by including a design effect of 1.2. With an 80% power and a 95% confidence, 293 animals in both groups would be required (586 in total). Based on the herd-sizes of the enrolled farms, a total of 795 heifers were enrolled. This accounted for animal drop-out and issues with missing data; not every heifer was able to be identified on every scoring occasion due to logistical issues observing animal identification when scoring lameness. Sample size calculation was as per methods stated in Therneau and Grambsch (2000) and implemented using the epi.sscomps() function in epiR package within the statistical software R, using version 4.1.0 (2021; https://r-project.org). The secondary outcome of distance from pedal bone to sole surface, as measured by ultrasound, required 28 animals, 14 in each treatment group, to be able to detect a 1.3 mm difference in sole soft tissue thickness, with a standard deviation of 1.2 mm (as described by Laven et al., 2012a), with a power of 80% and a 95% confidence.

Study Farms

This study was conducted on a convenience sample of 6 dairy farms from the Waikato region of New Zealand from June 2020 to February 2021. The farm enrollment criteria consisted of the farm being 100% spring-calving with cows managed at pasture, undertake individual cow milk sampling including testing for weight of fat and protein (kg) on 4 occasions throughout lactation (as commonly practiced in the New Zealand dairy system for herd improvements) and undertake pregnancy diagnosis with ultrasound to confirm conception date. The heifers had to be present on the dairy farm for at least 5 wk before the planned start of calving and had to have spent the majority of their lives (>95%) on grazed pasture and had minimal exposure to concrete up to the stage of enrollment. The farmers also needed to have the necessary willingness and resources to conduct and participate in a long-term interventional study of this type. Larger herd sizes (>450 lactating cows) were preferred when convenience sampling. In

total, 8 farms were contacted from a list of dairy clients of the veterinary practice that the primary author was employed at and that the primary author thought may fit the above criteria, with 6 farmers confirming they would participate in the study. The 2 farmers that declined did so due to the perceived additional workload required to administer the intervention. Farmers were required to record any time that heifers spent standing on concrete additional to the intervention, and to report any lameness that they noticed for any heifers through the study period. Study dates were referred to relative to 2 major farm calendar dates used in the New Zealand dairy system; the date when the first heifer was predicted to start calving, and the planned start of mating for the herd. The length of time between these 2 dates are not the same for every farm, with some New Zealand dairy farms having heifers begin to start calving 1 to 2 wk before the multiparous cows. The period between the planned start of calving for the heifers and the planned start of mating on the enrolled study farms ranged from 82 to 94 d, with a median of 84 d.

Study Animals

The study population consisted of all pregnant nulliparous dairy heifers present on the enrolled study farms at the time of the initiation of the study (approximately 5–6 wk before the start of the 2020 calving period for each herd). The sample population was selected from the study population after the heifers with the following exclusions were removed; any heifer with a LS $\geq$2 on the day of enrollment, any heifer with a BCS $<$4 (using a 10-point scoring system; Roche et al., 2004) on the day of enrollment, and any animal that the farmer stated would not go on to be used for milk production. Postinclusion removals consisted of animals that were identified as lame by the farmer during the intervention, any that calved at least 3 wk before expected calving date (defined as aborted), or any systemic illness that the farmer reported to the study investigator before the animal calving. Enrolled animals were followed until approximately 6 to 7 mo of lactation (culminating with the 15th LS event on each farm), or removal from the herd (whichever occurred first). The one exception was for the secondary outcome of milk production, where data from enrolled animals was collected up until the end of their first lactation.

Randomization

Heifers were randomly allocated into intervention or control groups at a ratio of 1:1 on each farm. Randomization blocking involved BCS. A list of study animals for each farm was created with animals grouped on BCS on the day of enrollment in 0.5 unit increments. For each BCS group, animals were ordered by smallest to largest tag number. A coin was tossed by the lead technician to decide which treatment group the first animal in each block was allocated to. The next animal was then randomized into the alternate group, with this pattern continuing for the remaining of the BCS group.

For the sole profile and sole soft tissue thickness measurements, 30 heifers from 2 farms were selected, 20 from one farm and 10 from the other. The 2 farms were selected based on convenience, as they had the best handling and chute facilities. Animals within the farms were ordered within treatment group and expected calving date, and the study population consisting of animals with expected calving dates in the second week of the seasonal calving period for the heifers on each farm. The planned sample population consisted of the first 10 animals in each treatment group from farm 1 and the first 5 from farm 2. However, due to a recoding issue, 11 treatment animals and 9 control animals were enrolled on farm 1.

Intervention

Animals were drafted into either intervention or control groups, as per randomization procedure, 5 to 6 wk before the planned start of calving for the heifers on each farm. On each study farm, animals were then managed separately in their respective treatment groups until the time of calving for the animal, or once the intervention period had finished (whichever occurred first). Heifers in the intervention group were required to walk along the farm race from the paddock that they had been allocated by the farmer on a given day, to the concrete collecting yard, or concrete feed pad. The distance walked varied depending on the day and the farm, but was designed to have the animals walk a total of approximately 1.0 km (range: 0.5–1.5 km) along tracks per intervention day. The intervention animals then stood on concrete without feed for approximately one hour (minimum one hour, maximum 1.5 h), after which they were allowed to walk back to their paddock. Water was available for heifers when on the concrete surface. The intervention took place once a day, 5 d every calendar week for 5 wk (a total of 25 intervention days over a 35-d period) and was carried out by farm staff. Farmers were financially incentivized to participate in the study, to recompense them for the cost of the additional labor required to implement the intervention. Spot audits on all farms were conducted at least weekly by the lead technician to ensure that the intervention was being conducted. Control animals were managed as per normal farm practice during the

5-wk intervention period, and for 4/6 farms, heifers were kept permanently at pasture. Two farms operated the practice of standing animals off. This describes a practice where cattle are moved to a firm surface (in this case, concrete) in advance of inclement weather so as to protect sword from poaching damage caused by animals walking on wet pasture. These 2 farms used this practice sparingly during the intervention phase (twice on one farm, and once on the other). When this occurred, both treatment and control animals were moved to a concrete surface at the same time and for the same duration (up to 12 h), and for heifers in the intervention group, the intervention did not take place the following day. For all farms, feed during the intervention phase consisted solely of grazed pasture. Quantity and quality of pasture that was allocated to the heifers in their daily paddock was not measured as part of the trial and it was left to the individual farmers to make management decisions on this. However, they were instructed to manage the feeding of the 2 treatment groups such that animals in the treatment and control groups received a similar quality and quantity of grazed pasture.

At the completion of the intervention phase, just before the planned start of calving, the 2 treatment groups were merged in preparation for parturition. Once the intervention had ended, farmers managed the heifers as per their standard farm practices, and on all farms, heifers calved at pasture. On all farms, heifers were milked in a herd separate to the main mixed-age cow herd. One farm milked their heifers once a day during the mating period (a set time period to mate cattle, approximately 10–11 wk long, starting approximately 12 wk after the start of calving), and another farm milked their heifers once a day from the start of mating onwards. The remaining 4 farms milked heifers twice a day throughout the entire lactation.

The primary investigator (WM) was not blinded during the intervention, as he was aware which animals were in the intervention group when assisting with the conditioning and exercise enrollment and intervention. However, the technicians assessing the LS were blinded to treatment groups, as all heifers were managed together in one herd after calving. Before the analysis being undertaken, the treatment groups were recoded by an independent operator (i.e., treatment was changed to group X and control was changed to group Y). This allowed the biometrician to be blinded to the treatment groups during statistical analysis. Farm staff did not know which treatment group the heifers were enrolled in once lactation had commenced, although the nature of the intervention did not allow blinding while it was being administered.

Data Collection

Fortnightly LS data from heifers in milk was collected by one of 2 trained technicians, starting 2 wk after the first heifer in each herd had calved and continuing for 15 LS events. LS was based on the DairyNZ 0-to-3 grading system (Table 1) and was conducted as animals were leaving the milking parlor on a flat even concrete surface. The time when the LS data were collected could be at either the morning milking or the afternoon milking and varied between and within farms for practical reasons (e.g., on one farm lack of lighting made it difficult to visualize heifers walking after morning milking in spring, or if the primary technician had another appointment in either the morning or afternoon). The technicians were LS-trained by the authors JH and WM, and were re-assessed 4 times within the first month of the study by the lead researcher, WM. Formal training consisted of a morning of LS theory and watching of prerecorded videos, of which the technicians were quizzed on. Then during the afternoon, the 2 technicians and JH and WM scored >200 animals walking postmilking. Assessment of drift was not carried out during the observation period, and reliability measures were not assessed.

Farm staff were instructed to record the animal number and date of all cases of lameness that they diagnosed on farm. These farmer-recorded lameness cases were analyzed as lame, regardless of their LS status during routine data collection. No formal instructions were given to the farmers by the study authors on how to observe lame animals.

All heifers had BCS measurements collected at 3 time points; at enrollment (BCS1), when 50% of the heifers had been calved at least 4 wk (BCS2) and approximately 2 wk after planned start of mating (BCS3). Animals were scored on a 10-point scale by a DairyNZ certified body condition scorer (Roche et al., 2004).

Data were collected for each heifer on date of birth, breed, individual calving date, and herd removal data up until the point of drying off (~10 mo following calving) by extracting it from the herd recording software Minda Live (Livestock Improvement Cooperation). This software was also used to extract individual milk sample information collected at 4 time points during lactation (at approximately 2, 5, 7, and 9 mo following the herd start of calving). This data provided information on the fat and protein weight of the milk, commonly reported combined in New Zealand as kilograms of milk solids. Trans-rectal ultrasound was used to determine the presence and age of the fetus at approximately 35 d after the end of the mating period by veterinarians, and data on date of conception and pregnancy status

entered into the Infovet platform (Zoetis New Zealand Ltd.).

The animals enrolled for sole profile and sole soft tissue thickness assessment were restrained in a chute and had either left or right hind limbs (left on one of the farms, right on the other farm) lifted on 3 occasions: at enrollment, 7 to 14 d postcalving, and 100 to 110 d postcalving. The hoof was first washed and the widest point of the lateral claw identified. The sole profile was obtained by placing a contour gauge at this position and transposing the profile with pencil onto graph paper. Sole depth from the abaxial aspect of the claw was measured at 10 mm, 20 mm, and 30 mm from the abaxial edge, with vertical measurements from these points to where the abaxial surface would have contacted the ground. The methodology followed that proposed by Tranter and Morris (1992). Ultrasonographic images of the plantar surface were then collected from the lateral claw of the elevated limb with an Easi-scan curvi-linear scanner (BCF Technology Ltd.) following the methodology proposed by Laven et al. (2012b). Briefly, sole soft tissue thickness was defined as the vertical measurement from the sole surface to the tip of the distal phalanx over the midline of the claw, perpendicular to the sole surface. Further details including pictorial illustrations are available in Tranter and Morris (1992) and Laven et al. (2012b).

Statistical Analysis

All analyses were carried out using the statistical software R, using version 4.1.0 (2021; https://r-project.org). The experimental unit of observation was the cow for all analyses. Descriptive statistics for animals from each farm and both treatment groups were described. Counts and proportions of categorical variables were tabulated and continuous variables described with respect to either mean and standard deviation, or median and interquartile range. The proportion of animals removed from the herd during the study period was reported for each farm and for the 2 treatment groups. The proportion of lame animals, and 95% confidence intervals, within each treatment group was reported for the entire observational period.

The primary outcome was the number of days from the end of the intervention to first case of lameness (either LS >1/3 or farmer diagnosed lameness); any subsequent lameness events were not analyzed. The outcome variable was right censored to either the last LS event on a farm or when an animal was removed from the herd, whichever occurred first. Data were initially presented in the form of Kaplan-Meier curves, with treatment group or farm as the predictor, respectively, to visualize the survival curve between farms and animals in each treatment group. To assess the statistical association between treatment group and time to first lameness case, a Cox proportional hazard model was developed, with ties handled using the Efron approximation. The predictor of interest was treatment group; breed was included as a possible confounding variable. It was also of interest to assess whether the effect of treatment on lameness risk differed between farms, so initially a farm × treatment interaction term was included into the model. Both breed and treatment group were included in the initial multivariable model, as was the farm × treatment interaction term; starting with the interaction term, variables were removed from the multivariable model if partial likelihood ratio test statistic between 2 nested models had a $P > 0.05$. If the farm × treatment interaction term was removed, then farm was treated as a frailty term, to account for clustering of animals within farm. Results from the model were reported as HR with associated 95% confidence intervals. Proportional hazards assumption was assessed using a global statistic based on Schoenfeld residuals, and scaled Schoenfeld residuals plotted over time for each variable with a smoothing line and 95% confidence interval to visually assess any deviation from proportional hazards. The proportional hazards of animals in the 2 treatment groups within each farm (farm × treatment interaction) were also assessed using the methods described above to ensure that the assumption of proportional hazards was constant over each farm. Deviance residuals from the final model >3 were further investigated as potential outliers. The effect of influential observations were assessed with dfbetas for each model coefficient. Any dfbetas >0.10, or any observations that had dfbetas substantially greater than the bulk of the observations, were investigated further. If any reason was found to remove these observations (e.g., data entry issue), then they were removed. Otherwise, they remained in the model.

Secondary outcomes included time from the date where the herd started mating to conception, herd removal, BCS, and milk fat + protein (kg of milk solids). Sole profile and sole soft tissue thickness from the examined subset of animals were also analyzed.

Reproductive data were recoded as the number of days from the herd start of mating to conception date and was analyzed as time-to-event data. The methodology was the same as described for time to first case of lameness above, with the same model building strategy and predictors assessed. All nonpregnant animals were right censored to the median mating length of the farms (77 d).

Milk solids per cow per herd-test day was analyzed using mixed linear regression techniques. As there were repeated temporal herd-test measurements for each

heifer, heifer was included as a random intercept term, and a first-order autoregressive correlation structure for herd-test number within heifer was included in the error term. Farm was included as a fixed effect to avoid model complexities of 3 levels of hierarchy. Predictors of interest were treatment group, breed, DIM, farm, and herd-test number. A saturated initial multivariable model was produced, as per recommendations of Zuur et al. (2009). Variance inflation factors for all variables were produced before any variable selection was conducted, as it was likely that DIM and herd-test number would be highly correlated. If the variance inflation factor was >4 for either of those 2 variables, then herd-test number would not be included into the model. Variables were then removed from the model if the likelihood ratio test between 2 nested models was $P > 0.05$, until all variables remaining had a likelihood ratio test $P \leq 0.05$. Treatment group was forced into the model as the predictor of interest. Various polynomials, including the Wilmink function, were assessed for improved model fit over a linear term for DIM; the DIM variable with the model with the lowest Akaike information criterion was selected as the DIM function. Standardized residuals >3 from the final model were investigated further to assess if there was any reason to remove them (e.g., data error entries). Cook's distances were produced for each observation from the final model and ranked in order from largest to smallest. Any of those that were substantially greater than the bulk of the observations were reported and had their raw data investigated further. The assumptions of homoscedasticity and normality of residuals were assessed graphically.

Body condition scores at each time point were tabulated, and the BCS change between first and third BCS (BCS 1 to BCS 3) and second and third BCS (BCS 2 to BCS3) reported. Data were collapsed into reductions in BCS of >0.5 or ≤0.5 units. For each binary outcome, BCS 1 to BCS 3, and BCS 2 to BCS 3, a mixed logistic regression model was used to assess the relationship between treatment group and BCS change over time. The only predictor included was treatment group; farm was included as a random effect.

Sole soft tissue thickness (mm) was analyzed using linear regression, with the outcome for each heifer the difference between the measurements at the second (postcalving) and first (enrollment) visit, and between the third (mating) and first visit, respectively. A single model accounting for repeated sole measurements over time was produced. The hypothesis was that the intervention altered the sole soft tissue thickness over time. As such, an interaction between treatment and timing of measurement (postcalving or mating) term was forced into the final model. This interaction term also accounted for the clustering within animal, so no random effect of animal was needed. It was also possible that the effect of treatment may have been modified by farm. A 3-way interaction term between farm, treatment, and timing remained in the model if the log-likelihood ratio test between 2 nested models was $P \leq 0.05$. If this was not met, then the 3-way interaction term was removed, and farm assessed for its inclusion into a multivariable model. No other predictors were included in the model. Data were reported as estimated marginal means and 95% confidence intervals adjusted for multiple pairwise comparisons using the Šidák correction. Linear regression assumptions of homoscedasticity and normality of residuals were assessed, as well as linearity for the continuous predictor, sole soft tissue thickness at enrollment. The outcome for sole profile was the difference of the distance vertically between the 30 mm and 10 mm measurement from one lateral hind claw on a given measurement day. Linear regression was conducted to assess the association between treatments over time on the sole profile of the claw. Inclusion of farm in the model, and model reporting was as per sole soft tissue thickness.

RESULTS

Of the 795 animals in the study population, 790 were enrolled into the study (Figure 1). Of those, 397 were randomly enrolled into the treatment group and 393 into the control. A total of 782 heifers remained in the study at the completion of the intervention phase, and this was the denominator for all analyses, unless otherwise stated. Two animals were diagnosed as lame during the intervention phase; one from the treatment group and one from the control group. Three hundred seventy-nine treatment animals and 376 control animals completed the study. Descriptive statistics for the 790 enrolled heifers in both treatment groups are presented in Table 2. Seventeen animals were culled, and 3 died, during the course of the study period (up to approximately mid-February, 2021); 11 of these were control animals and 9 were in the treatment group. The number of removed animals per farm varied from zero to 12, with a median of 3 removed animals per farm.

Lameness Outcomes

Fifteen lameness assessments were conducted on each farm, starting between July 14 and August 6, 2020, and continuing until between January 25 and February 19, 2021, depending on the start of calving of the farm. Due to the range of calving dates, heifers had a median of 14 lameness assessments, with a range of 12 to 15. A total of 102/782 (13.0%; 95% CI: 10.9–15.6%)

6. Heifer intervention

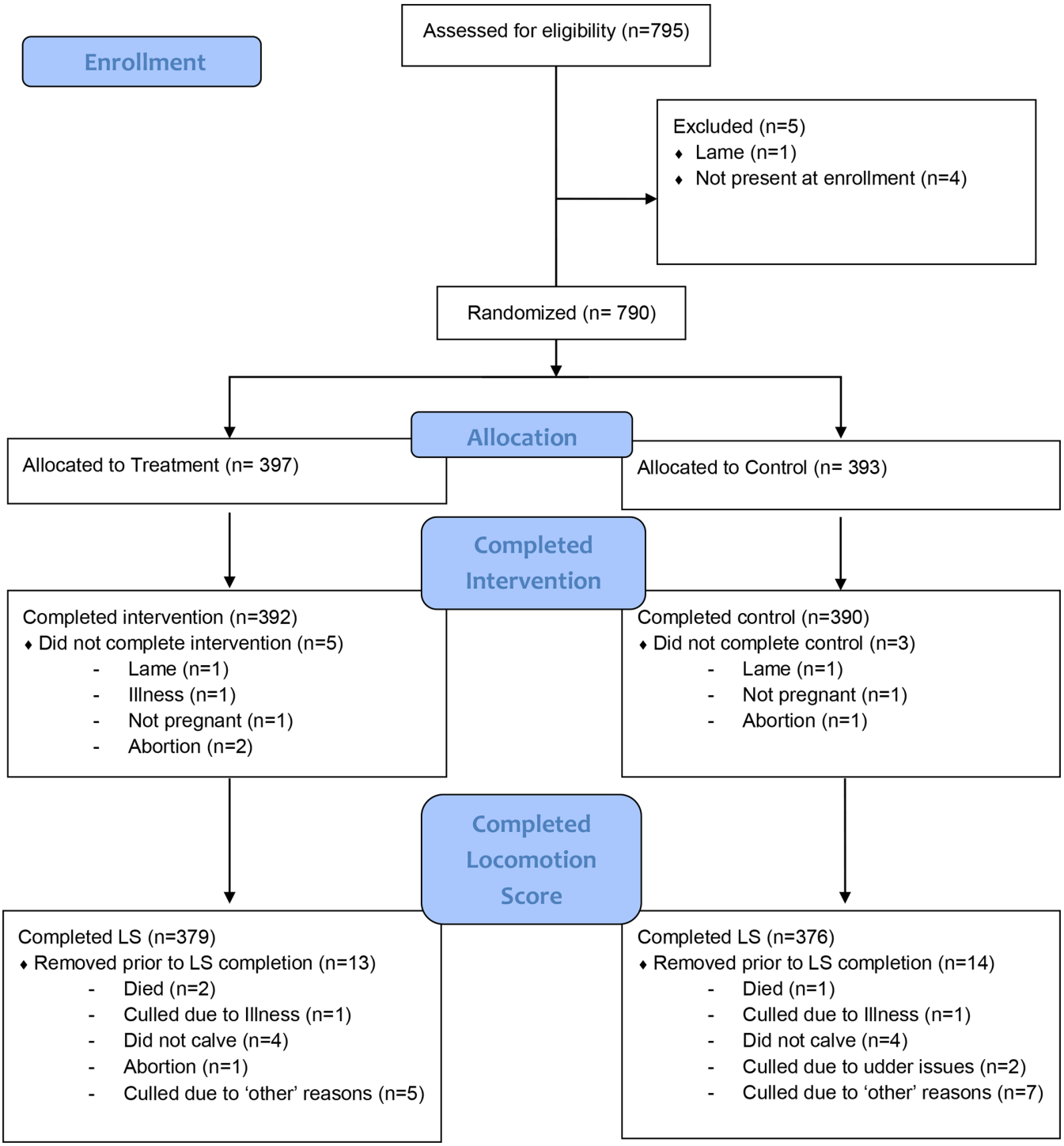

Figure 1. Flowchart outlining reasons for inclusion, exclusion, and removal of animals from a randomized clinical trial investigating the effect of exercise and time standing on concrete on time to first lame event. Only animals that completed lameness scoring were included in the analysis. LS = locomotion score.

Table 2. Descriptive statistics for 790 enrolled heifers, across 6 farms, in a randomized study investigating the effect of exercise and standing on concrete precalving, on the risk of lameness during lactation; number of heifers in each category presented, with percentage in parentheses

Variable	Level	Control	Treatment	Overall
Farm	1	95 (50.3)	94 (49.7)	189
	2	58 (50.4)	57 (49.6)	115
	3	55 (49.1)	57 (50.9)	112
	4	41 (49.4)	42 (50.6)	83
	5	51 (50.0)	51 (50.0)	102
	6	93 (49.2)	96 (50.8)	189
BCS	≤4.5	49 (47.1)	55 (52.9)	104
	5	65 (46.4)	75 (53.6)	140
	5.5	207 (49.4)	212 (50.6)	419
	≥6	72 (56.7)	55 (43.3)	127
Breed	Holstein-Friesian	60 (48.0)	65 (51.6)	125
	Jersey	87 (49.4)	89 (50.6)	176
	Kiwi cross and other	230 (50.0)	230 (50.0)	460
	NA[1]	16 (55.2)	13 (44.8)	29

[1]Animals did not have breed data available as they had been culled or removed from the study before study completion.

heifers were diagnosed as lame between the end of the intervention phase and the end of the LS phase; 51 of these were diagnosed during LS events, and the other 51 were diagnosed by farmers, before the technician visit. Fifty-three of the lame animals belonged to the treatment group (13.6%; 95% CI: 10.6–17.4%), and 49 to the control group (12.6%; 95% CI: 9.6–16.2%).

The data were compatible with there being no effect of treatment group on the hazard of lameness with the hazard rate in the treatment group being 1.12 times (95% CI: 0.65–1.95; $P = 0.94$) the hazard of a case of lameness in the control group (Figure 2). If the true hazard ratio was 0.65, we would almost never (2.5% of the time) expect a HR as large as we observed. Thus HR <0.65 are contradicted by the data. If the true HR was >1.95, we would almost never (2.5% of the time) expect an HR as small as we observed. Thus HR >1.95 are contradicted by the data. Breed was not associated with hazard of lameness ($P = 0.52$). There was no evidence of a farm × treatment interaction ($P = 0.71$). The proportional hazard assumptions were not violated for treatment, nor were they violated for groups of animals in the 2 treatment groups within each farm. Four observations were identified with deviance residuals >3; no reason was identified to exclude these observations. No influential observations were identified.

Reproductive Outcomes

A total of 754 heifers had pregnancy data; 20 heifers were removed from the herd before pregnancy testing, and 8 had had missing pregnancy test data. The data were compatible with no difference in the hazards of pregnancy between treatment and control animals ($P = 0.72$). The hazards of pregnancy in the treatment heifers was 0.97 times (95% CI: 0.84–1.13) the hazards of pregnancy in the control animals.

Milk Production

Milk test data were collected for 2,892 individual samples from 758 study heifers. The outputs of the mixed linear regression model can be found in Table 3. Heifers in the treatment group produced 0.010 (95% CI: 0.016–0.036) kg of milk solids/cow per day less than control heifers across the entire lactation, but the data were compatible with no difference between the groups ($P = 0.46$). As there were few herd-test measurements within the first 50 d of lactation, a linear term for DIM provided a better fit for the model than polynomial functions such as the Wilmink lactation function. DIM and herd-test number demonstrated collinearity issues (variance inflation factor for DIM of 5.6), and therefore, only DIM was included in the model. Farm, breed and DIM were all associated with daily MS production (Table 3). There were 3 observations that had Cook's distance >0.060 (at least 20% greater than the next closest observation). All 3 of these were the first herd-test value from Jersey animals from the same farm, 2 in the control group and one in the treatment group. No reason was found to exclude these values. No outlier observations were identified, and there were no deviations from homoscedasticity or normality or residuals.

Body Condition Score

The BCS change from BCS 1 to BCS 3, and BCS 2 to BCS 3 is presented in Table 4. The data were compat-

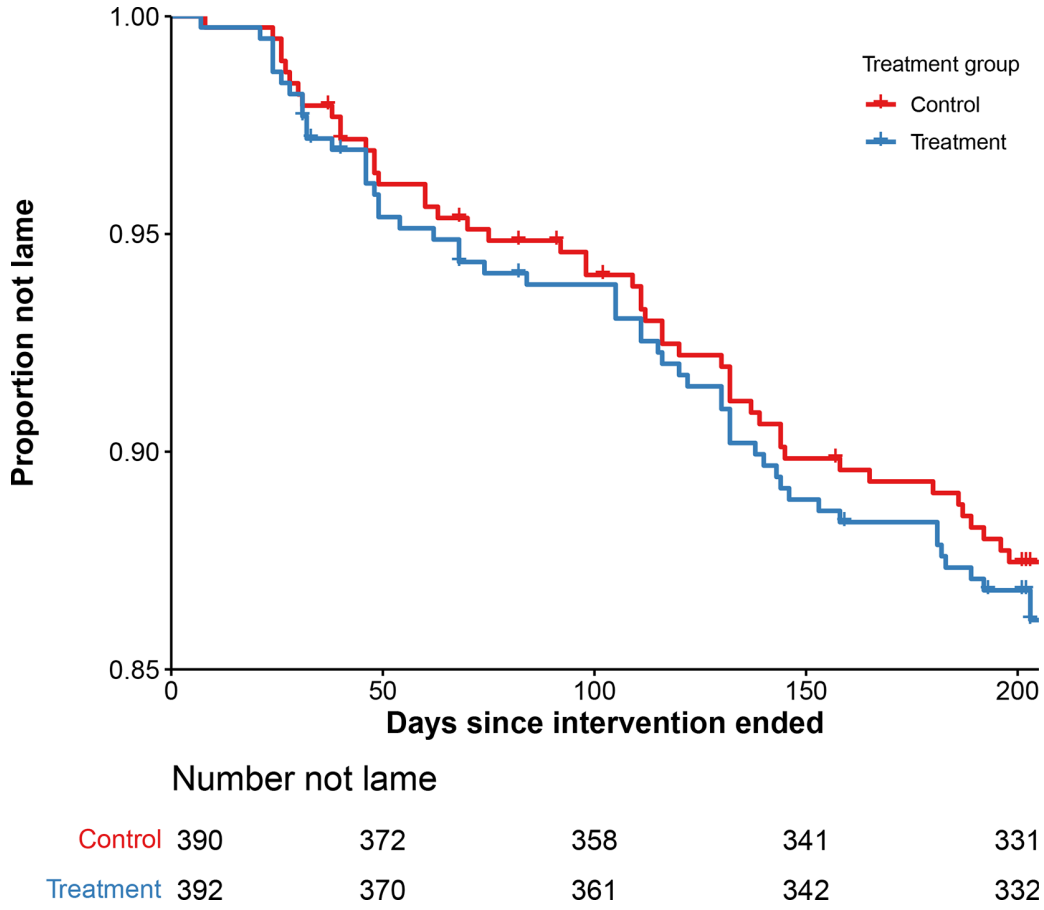

Figure 2. Kaplan-Meier survival plot for treatment group and time in days since the end of intervention to first case of lameness from a randomized clinical trial investigating the effect of exercise and time standing on concrete on time to first lame event. Lameness was defined as either lameness score (LS) >1 by a trained technician, or diagnosed by farmer. The + represent censored nonlame animals removed from the herd before the end of the study. A risk table of the number of heifers that remain eligible for first case of lameness at 50-d increments throughout the study period is presented below the Kaplan-Meier plot.

Table 3. Output from mixed linear regression model with kilograms of milk solids/heifer per day as the outcome (n = 2,892 samples from 758 heifers); animal was included as a random intercept and an autoregression correlation structure for herd-test within animal included in the error term

Variable	Category	Coefficient	SE	Lower 95% CI	Upper 95% CI	*P*-value
Intercept		1.967	0.026			
Treatment	Control	Referent				0.46
	Treatment	−0.010	0.013	−0.036	0.016	
Farm	1	Referent				<0.001
	2	0.007	0.027	−0.045	0.058	
	3	−0.321	0.028	−0.376	−0.267	
	4	−0.201	0.038	−0.275	−0.126	
	5	−0.253	0.026	−0.303	−0.203	
	6	−0.587	0.027	−0.639	−0.535	
Breed	Friesian	Referent				<0.001
	Kiwi cross and other	0.026	0.021	−0.015	0.067	
	Jersey	−0.091	0.032	−0.154	−0.028	
DIM		−0.003	0.000	−0.003	−0.003	<0.001

Table 4. The unit of BCS change at 2 time intervals between treatment and control heifers from randomized study investigating the effect of exercise and standing on concrete precalving

		Unit of BCS change						
Interval	Category	−0.5	0	0.5	1	1.5	2	2.5
BCS 2–BCS 3[1]	Control	14	160	137	13	0	0	0
	Treatment	16	148	138	14	0	0	0
BCS 1–BCS 3[2]	Control	2	8	66	150	107	18	0
	Treatment	0	16	74	144	98	20	1

[1]The numerical difference between BCS measured approximately 4 wk postcalving and BCS measured approximately 2 wk after the start of mating (~14 wk after the completion of the intervention).

[2]The numerical difference between BCS measured at the initiation of the intervention (5–6 wk before the herd expected calving start date) and BCS measured approximately 2 wk after the start of mating (~14 wk after the completion of the intervention).

ible with no difference between treatment groups in the number of animals that lost >0.5 BCS from the second and third BCS assessment ($P = 0.24$) and from the first to third BCS assessment ($P = 0.36$).

Sole Soft Tissue Thickness and Sole Profile

A total of 28 (14 of which were treatment) and 25 (11 treatment) heifers had sole soft tissue thickness measurements at the second and third examination, respectively. Due to recording errors with saving of images, there were only 2 treatment heifers from farm 2 that had measurements at the third examination. A 3-way interaction existed between farm, examination number and treatment group ($P = 0.05$; Figure 3). There was no difference between treatment and control heifers on farm 1 at the calving and mating measurements, nor between calving and mating. However, treatment heifers from farm 2 had 3.37 (95% CI: 0.24–6.49) mm greater sole soft tissue thickness at the mating visit compared with the calving visit, and also had 3.82 (95% CI: 0.92–6.71) mm greater increase in sole soft tissue thickness than treatment heifers from farm 1. On farm 1 heifers had a reduction in sole soft tissue thickness from enrollment to calving of 1.22 (95% CI: 0.04–2.42) and 1.48 (95% CI: 0.42–2.55) mm for control and treatment heifers, respectively.

At the postcalving visit, there were 30 heifers, 16 of which were in the treatment group with sole-profile measurements. Twenty-nine heifers, 15 of those in the treatment group, had sole profile measurements at mating. Farm was not included in the final multivariable model as it did not modify the effect of treatment ($P = 0.45$), nor was it associated with sole profile overall ($P = 0.39$). The data were compatible with treatment having no effect on sole profile at calving ($P = 0.77$) or mating ($P = 1.0$). Averaged across both treatment and control groups, at calving heifers had 1.58 mm (95% CI: 0.85–2.30) smaller difference between measurements taken 30 mm and 10 mm from the abaxial hoof margin compared with measurements collected at enrollment. There was less variation in sole profile between calving and mating (mean difference 0.19; 95% CI: −0.55 to 0.92 mm).

DISCUSSION

This article reports findings from a randomized controlled trial, conducted and reported in accordance with the REFLECT guidelines (O'Connor et al., 2010), investigating the effects of exercise and standing on concrete precalving in pasture-based dairy heifers on time to first lame event. No associations were identified between treatment group with respect to time to lame event, nor any of the secondary outcomes. Despite not finding clear evidence of differences between heifers in the treatment and control groups, we believe it is important that study outcomes are reported to inform future research in the important areas of study for dairy cow health and welfare.

This study was powered to detect a 25% reduction in the hazard of lameness from an assumed baseline hazard of 25%. This a priori hazard rate reduction equated to an absolute reduction in lameness incidence of ~6%, and was selected as a large enough difference that may appeal to farmers to implement the intervention. With the apparent lameness incidence risk in the control group being half that expected before the study (12.6 vs. 25.0%), an HR of ~0.5 for lameness in animals in the intervention group compared with animals in the control group would have been required to detect an absolute difference of ~6%. Post hoc power calculation revealed that this study had a 93% probability of detecting that difference, if it indeed existed. Therefore, we have reasonable confidence that this intervention, in its current form at least, is unlikely to result in a biologically meaningful reductions in the rate of lameness in first-lactation dairy heifers. It is possible that both

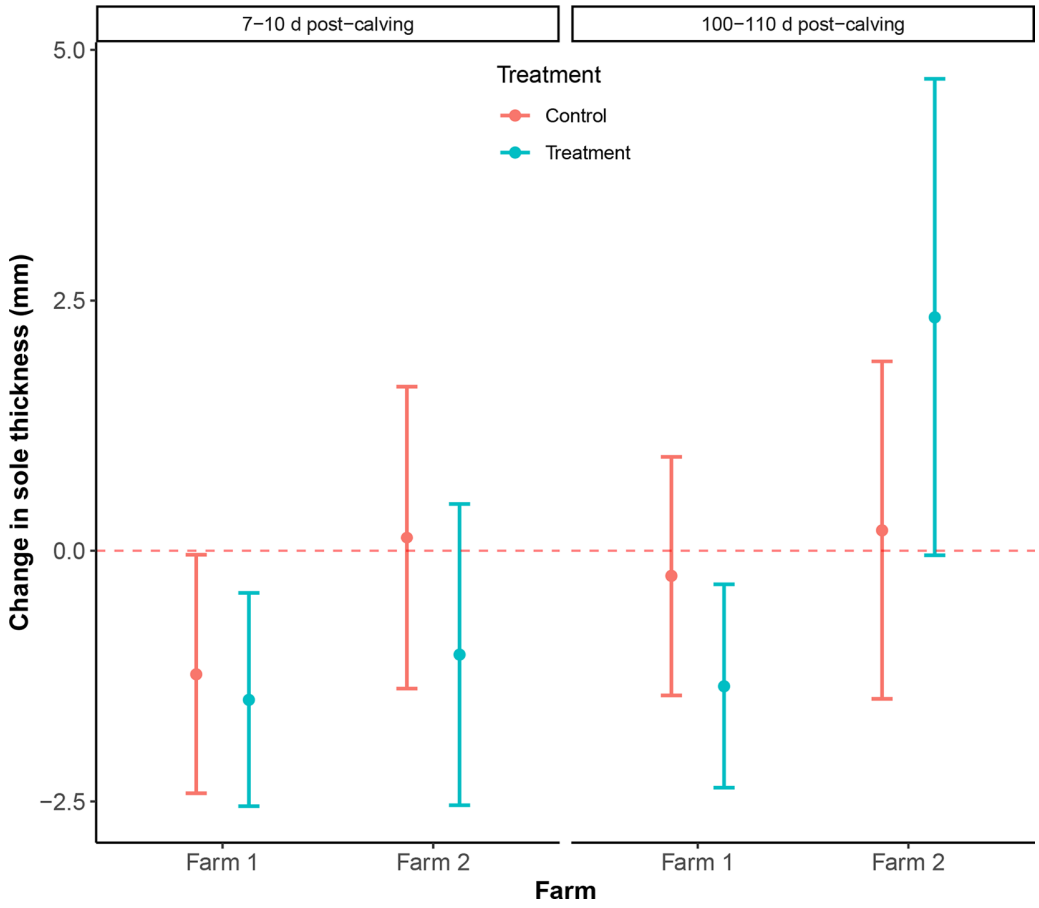

Figure 3. Error plot of estimated marginal means of the differences (mm) in the distance between the sole surface and the tip of the pedal bone, from the initial measurement at enrollment. Two outcome measurements were collected; 7 to 10 d postcalving and just before the start of mating on 2 of the 6 enrolled farms. Outputs are from a linear regression model, with 95% confidence intervals adjusted for multiple comparisons.

the distances walked, and the length of time standing on concrete, were not great enough to elicit a response in the hoof. This statement is supported by the findings of sole soft tissue thickness and sole profile in the current study where there was no difference in sole soft tissue thickness or sole profile after calving between intervention and control animals. Although there was a 3-way interaction present between farm, treatment group and time, due to this only involving 2 treatment animals on one of the farms, it needs to be corroborated in future studies before much weight is applied to it. It was expected that even if a reduction in hazards of lameness was not observed that the intervention should at least result in sole measurement changes over time, however we found no effect on sole concavity or sole soft tissue thickness. The lack of treatment effect on these measures adds weight to the argument that the intervention may not have been sufficient to promote changes in the hoof. As this was a proof-of-concept study, the study could have been designed with a more extreme version of the intervention, where heifers were expected to walk much longer distances and stand on concrete for extended periods of time (>6 h/d). The authors considered it important to not exaggerate the time on concrete and potentially cause harm. Although prolonged exposure to hard surfaces in the transition period alone has not been investigated before, enough evidence exists on the negative associations between hard surfaces around calving and claw horn health (Webster, 2001; Laven and Livesey, 2004; Knott et al., 2007; Bergsten et al., 2015) that erring on the side of caution was appropriate for the first clinical study of its kind. Importantly, the intervention was also designed to be practical for farmers to implement. The one hour standing time enabled time for staff to have a break or do small jobs around the milking parlor. In addition, the intervention was only conducted on 25 d across a period of 35 d to allow some flex in the staffing schedule. Requiring longer intervention times per day and for it to be conducted every day for an extended time

period would have likely resulted in poor uptake of the intervention on farm, regardless of the outcome.

There is little argument that the management and housing environment before and after calving can have an effect on hoof health and lameness risk (Bergsten and Frank, 1996; Webster, 2001; Laven and Livesey, 2004; Knott et al., 2007; Bergsten et al., 2015). Bergsten et al. (2015) investigated one of the more extreme examples using a 2 × 2 factorial design investigating hard and soft flooring with one intervention occurring a year before calving and a second intervention occurring for an additional 12 mo after first calving in dairy heifers. By the end of the first intervention, in the second year of life, the proportion of white line hemorrhages was greater in heifers wintered on hard surfaces than in heifers wintered on soft surfaces. After the second year of the intervention, white line and sole lesions, along with LS, were significantly greater in heifers managed postcalving in a cubicle yard with slatted concrete floors compared with those managed in a yard with slatted rubber floors. Importantly, an interaction was reported between the 2 treatment groups and type of flooring. Heifers managed on hard surfaces as pregnant heifers and soft surfaces after they had calved had a lower prevalence and severity of sole and white line hemorrhage compared with the other 3 combinations of housing management (soft-hard, soft-soft, hard-hard). Furthermore, heifers managed on soft flooring when pregnant and hard surfaces after calving had the highest prevalence and severity of claw horn lesions, a group most similar to conditions experience in pasture-based systems. The inference from this study is that exposure of the hoof during the rearing period to surfaces that increase wear, and thus stimulate hoof growth (Telezhenko et al., 2009; Laven et al., 2012a), and the prevalence of mild-moderate hoof horn hemorrhages is actually beneficial to hoof health postcalving. This is consistent with the clinical findings of Randall et al. (2016) where heifers with mild white lesions, zero to 2 mo before first calving had a 66% reduction in odds of lifetime lameness compared with heifers with no white line lesions precalving.

As this was a novel experiment, it is difficult to directly compare findings to any previous research. Although several studies had investigated the effect of different housing environments pre- and postcalving in dairy heifers (Vermunt and Greenough, 1996; Webster, 2001; Laven and Livesey, 2004; Knott et al., 2007; Bergsten et al., 2015), only 2 investigated an intervention that incorporated both an exercise and housing component (Gard et al., 2015; Black et al., 2017). The most comparable study, with respect to intervention, was conducted on recently weaned bull calves split into 2 groups (Gard et al., 2015); the control group was managed on a small grass paddock, and the treatment group on a race consisting of mixed terrain for 4 mo. The treatment calves were also fed at opposite ends of the access way to stimulate exercise. At the conclusion of the study, calves in the treatment group had 37% greater digital cushion volumes (measured by magnetic resonance imaging and computed tomography scan) compared with calves in the control group, suggesting the adaptive capability of the hoof to respond to the animal's environment and degree of movement. Black et al. (2017) also investigated an exercise regimen during the precalving period but in housed dry cows rather than heifers at pasture. Cattle in the exercise group over the dry period had equal horn growth and wear at the cranial aspect of the claw compared with the cows that were not exercised, which had an increase in horn growth relative to wear at that point. The authors reported no association between treatment and LS; however, this study would have been severely underpowered to find such an association if it did truly exist (n = 60 across 3 treatment groups). Even with these 2 studies, comparisons to the current study and extrapolation to pasture-based dairy heifers are difficult. All of the enrolled animals in the study conducted by Black et al. (2017) had completed at least one lactation, and were thus more likely to have had previous lameness issues and Gard et al. (2015) enrolled 2-mo-old weaned bull calves. Given the association previously reported between age (Newsome et al., 2016), and parturition (Tarlton et al., 2002) on hoof health, respectively, the findings of this current study probably need to be interpreted in isolation.

Another limitation of comparing the aforementioned studies with the current study is that the primary outcomes were not clinical lameness events. Rather, they focus on hoof factors that increase the risk of lameness, such as digital cushion volume (Gard et al., 2015), hoof horn hemorrhage (Vermunt and Greenough, 1996; Bergsten et al., 2015) and net hoof growth (Telezhenko et al., 2009; Black et al., 2017). Despite recommendations and reviews existing for lameness control (Vermunt and Parkinson, 2002; Potterton et al., 2012; Bell and Randall, 2021), implementation of control programs remains a major issue (Bell et al., 2009; Barker et al., 2012; Main et al., 2012). Observing a reduction in clinical lameness and the pride of having a healthy, nonlame herd was one of the major motivating factors for controlling lameness from a survey of 222 UK dairy farmers (Leach et al., 2010). Yet only 25% of 500 surveyed Dutch dairy farmers believed that subclinical hoof disorders (such as hoof horn hemorrhage) were animal welfare concerns (Bruijnis et al., 2013), thus, likely reducing motivation to implement a control strategy directed toward reducing the incidence of such lesions. To promote behavioral

change from farmers, the authors wanted the primary outcome to be clinical lameness. Hence, the focus during the current study was to enroll as large a number of heifers as possible and concentrate predominantly on LS outcomes. This did, however, come at the expense of recording lesion incidence. With this lack of lesion information, we cannot be confident that all of the reported lameness cases were due to claw horn lesions. However, they were unlikely to be digital dermatitis, as the within-herd prevalence of digital dermatitis in the Waikato region in New Zealand has been reported to be 3.2% (Yang et al., 2019), and within those animals <1% were reported to be clinically lame (A. Yang, Department of Veterinary Epidemiology, Nanjing Agricultural University, China; personal communication)

It is unknown if the nonrandomly selected 6 study farms are representative of the total population, and the degree to which the results can be extrapolated to heifers in other pasture-based systems in unknown. An overall lameness incidence risk of 12% in the control animals is below the median lameness incidence reported from all cows from 43 farms in the South Island of New Zealand (Gibbs, 2010) and could be considered low. Accurate lameness incidence and prevalence for all lactating animals were not available on any of these farms, so any inferences on overall lameness risk could not be made. However, in the first author's opinion, the facilities and track maintenance on all 6 farms could be considered good. It is possible that in farms with a high baseline lameness incidence, where poor management of tracks and concrete were responsible for much of the lameness, that an intervention such as this may have had a greater effect on the time to first lame event (either positively or negatively). Animals were managed within treatment groups during the intervention phase. Although it was attempted to manage these in a similar manner, apart from the intervention itself, it was still possible that the diet and external environment may have differed slightly between the 2 groups. Although unlikely, this may have biased the association toward the null hypothesis. These limitations withstanding, the internal validity of the study likely remained high, with large numbers of heifers involved, and strong adherence to protocol intervention and follow up.

Measurement bias was a possibility in this study due to the 2 different methods of diagnosing lame cattle, trained technician and farmer. No formal reliability measurements between technicians were carried out, nor was the possibility of observer drift assessed. There currently is also no formal LS training program available in New Zealand, so the authors produced their own training based on combined experiences. These factors could have resulted in misclassification bias. As the technician was blinded to the treatment groups, any misclassification would have likely erred toward the null. However, we do not believe that this would have had a large effect on this study, as the technicians were experienced in LS and involved in lameness studies with LS as outcomes running in parallel. Furthermore, only 2 technicians were used, with one technician conducting 80% of scoring events, limiting the interobserver error common with LS (Schlageter-Tello et al., 2014). The other source of potential misclassification derived from farmer reporting of lameness. Half of the lame animals were first identified by farmers. This was an important source of lameness diagnosis and was included as the authors did not want an animal to be lame for up to 14 d in between LS visits. Once animals are identified by a farmer as lame, they are often removed from the milking herd and managed separately. These animals are then often not milked at every milking and thus, may not have been presented at a LS assessment visit. Although not formally trained in scoring, all of the farm managers in the 6 enrolled farms were experienced stockpersons, and all of them diagnose and treat their lame cattle on farm. Although it was possible a farmer could have recorded the numbers of the animals as they were conducting the intervention, the likelihood of this was very low. It was far more likely that the farmer did not know what treatment group the animals belonged to, so again, if there was any risk of bias, it was toward the null.

Despite the data being compatible with no association between treatment group and lameness rates, we can also conclude that the intervention produced no deleterious effects both during the intervention, and for up to 7 mo after the cessation of the intervention. There was no increase in lameness risk during the intervention, with only 2 heifers identified as lame during the intervention period, one in the treatment group and one in the control group. After the intervention, no biologically relevant differences were found between the treatment groups with respect to BCS, MS and reproductive indices. Furthermore, the farmers all reported that the intervention was easy to implement, and, on at least 3 of the farms, the farmers believed the intervention heifers became accustomed to the intervention and anecdotally reported that the heifers appeared quiet and settled with human interaction.

Enough prior evidence exists to suggest that management of heifers before calving can have a large effect on the subsequent hoof health. Therefore, rather than conclude that transition management in the New Zealand situation cannot reduce the effect of lameness, it is more likely that this current method was not sufficient to elicit a response. This information is critical as it gives us confidence that future investigations in this research topic should involve increasing the time on

concrete or increasing the exercise component. We urgently require other practical science-based methods to proactively reduce the incidence of lameness in pasture-based dairy cows.

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7

Farmers' barriers and motivators for lameness control

The final research chapter revolves around farmer beliefs and values around lameness control. The preceding chapters describe the extent of lameness across New Zealand dairy farms, and set the scene for improving lameness treatment and prevention. However, regardless of how successful the intervention may be in a research setting, the successful implementation of lameness treatment and prevention strategies requires the buy-in of farmers. From the 120 dairy farms enrolled into the prevalence study, 101 responded to a second questionnaire on the barriers, motivators and perceived impacts of lameness. The farmer beliefs and values with respect to lameness and perception of lameness on their farm is reported in this chapter. The link to the publication can be found at https://doi.org/10.3168/jds.2023-23862.

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Can lameness prevalence in dairy herds be predicted from farmers' reports of their motivation to control lameness, and barriers to doing so? An observational study from New Zealand

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ABSTRACT

Understanding what motivates and prevents behavioral change in farmers is a critical step in disease control in dairy cattle. A total of 101 New Zealand dairy farmers across 8 regions were randomly enrolled into a cross-sectional study to investigate farmer barriers and motivators to lameness control for cows managed 100% at pasture, and the relationship between these responses and the true lameness status on farm. Trained technicians lameness scored all lactating cows on the enrolled farms on 2 occasions during one lactation. Farm-level prevalence proportions were calculated as the mean of the 2 lameness scores. Enrolled farmers were asked their perception of lameness in the current milking season and responded to 26 ordinal Likert-type items with 5 options ranging from not important at all to extremely important. The questions were grouped under 3 categories; barriers to lameness control (n = 9), impacts of lameness (n = 10), and motivators to control lameness (n = 7). The association between farmer perception of lameness and lameness prevalence was reported using linear regression. Multiple factor analysis was conducted to identify latent variable themes within the responses. Linear discriminant analysis was used to assess if barriers, impacts and motivators could be used to predict farmer perception of lameness, and lameness prevalence.

Lameness prevalence was 0.8% greater on farms where farmers perceived lameness as a moderate or a major lameness problem compared with on farms where the farmer perceived lameness as a minor/not a problem. Farmers ranked all potential motivators to lameness control as important, and declared few barriers to be important at preventing them from controlling lameness. Feeling sorry for lame cows and pride in a healthy herd were the most important motivators, with lack of time and skilled labor the most important barriers. The most important impacts of lameness were cow-related factors such as pain and production, with farm and industry impacts of less importance.

Farmers place different weightings of importance on barriers to lameness control compared with motivators for lameness control. The impacts and motivators were strongly correlated with the first dimension from the multiple factor analysis, with only weak correlation between barriers and the first dimension. Linear discriminant analysis identified that the importance that farmers place on barriers motivators and impacts of lameness were poor predictors of farmers' belief in regard to their lameness problem, or actual lameness prevalence (above or below the median lameness prevalence for the study cohort).

Despite relatively low lameness prevalence, many New Zealand dairy farmers believe lameness is a problem on their farm, and they rank welfare impacts of lameness of high importance. To investigate how farmer behavior change can be used to manage lameness, future studies should consider theoretical social science frameworks beyond the theory of planned behavior, and/or involve prospective interventional studies investigating farmer actions instead of beliefs.

Key words: **Dairy cow**, **farmer beliefs**, **lameness**, **barriers**

INTRODUCTION

Despite lameness being one of the major animal health and welfare concerns of dairy cattle farming internationally (Huxley, 2013), there are few control methods that are associated with a consistent large percentage reduction in lameness incidence across a population, or in epidemiological terms, interventions that have a large population attributable fraction. For example, while evidence exists for routine foot-trimming impacts on reducing lameness prevalence and incidence (Griffiths et al., 2018), in many countries where routine foot trimming is recommended, lameness

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prevalence remains greater than 20% (Solano et al., 2015, Griffiths et al., 2018). This highlights the complex multi-factorial interaction between risk factors for lameness, and that concentrating on specific interventions, even if they are evidence-based, may not result in meaningfully large reductions in lameness prevalence (Hueston, 2003, Biesheuvel et al., 2021).

Instead, it may be appropriate to elicit from the main stakeholders, the farmers, what they believe are the barriers to controlling lameness on their farm and the factors that motivate them to control lameness. Farmers are a critical piece of the puzzle in disease control (Kristensen and Jakobsen, 2011, Biesheuvel et al., 2021) and often underappreciated and underrepresented in lameness disease control and research. Involving farmers in the process of lameness control has resulted in greater acknowledgment of lameness problems on farm (Main et al., 2012), and subsequent reduction in lameness prevalence (Main et al., 2012, Chapinal et al., 2014). True lameness control success is thus likely to be in the form of interventions that influence farmers' behavior in regard to lameness control (Biesheuvel et al., 2021).

There are a wealth of data from multiple countries and various dairying systems on the poor agreement between the proportion of the herd that the farmer believes is lame and what a trained locomotion scorer reports as lame (summarized in Fabian et al. (2014) and Sadiq et al. (2019)). Thus, lack of acknowledgment of the lameness problem by farmers appears to be a universal issue for managing lameness. Until these discrepancies are eliminated, or at least reduced, then optimal lameness control is nearly impossible, as the prompt identification and treatment of lameness is critical to lameness control success (Alawneh et al., 2012, Newsome et al., 2016, Pedersen and Wilson, 2021). Therefore, understanding and influencing barriers to lameness control and motivations to control lameness become an important piece of the lameness puzzle (Sadiq et al., 2019, Biesheuvel et al., 2021).

Acknowledging that there is an issue with lameness, or becoming more aware of lameness, on farm is critical to controlling lameness. In a multi-year randomized clinical trial, a reduction in farmer tolerance to a lameness problem resulted in a reduction in lameness prevalence over time (Leach et al., 2013). Therefore, the key questions may be how this lameness tolerance can be influenced. Lameness prevalence is reportedly lower in pasture-based herds common in New Zealand compared with cattle which are housed for some of the year (Fabian et al., 2014, Griffiths et al., 2018, Browne et al., 2022). However, anecdotally, New Zealand dairy farmers still do report lameness as a concern, and there are ranges of lameness incidence and prevalence reported on these units (Gibbs, 2010, Fabian et al., 2014). Investigating farmer beliefs around lameness in these pasture-grazing dairying systems may provide valuable insight into lameness control on such farms. Therefore, repeating a similar survey to that conducted in the United Kingdom over 10 years prior (Leach et al., 2010a, b) was of interest to identify barriers to and motivators for lameness control.

In addition, previous analyses of such data have used statistical techniques that may not be appropriate for Likert scale data which is ordinal in nature. Previously both Pearson correlation (Leach et al., 2010b) and Spearman's rank correlation coefficients (Bruijnis et al., 2013, Leach et al., 2013) have been used when polychoric correlations may be more appropriate (Holgado–Tello et al., 2010, Ekström, 2011), Furthermore, previous studies have focused on correlations (Leach et al., 2010a, b, Bruijnis et al., 2013) or thematics (Croyle et al., 2019, Wynands et al., 2022) and have not explored whether farmer beliefs and themes have a predictive ability in regard to whether a farmer believes they have a lameness problem or whether they have high lameness prevalence. Recent improvements in machine learning techniques has made it possible to produce quantitative inferences from qualitative data (Harpe, 2015, Biesheuvel et al., 2021). If farmer barriers to, and motivators for, lameness control can be used to predict a farmer's tolerance in relation to lameness, this could significantly aid the development of lameness control strategies (Main et al., 2012, Leach et al., 2013). The application of quantitative methods such as multiple factor analyses can also rank farmer beliefs and thoughts, providing evidence-based control priorities on farm (Abdi et al., 2013).

There were thus several objectives of this study. First, to describe the relationship between whether New Zealand dairy farmers believed lameness to be a problem on the farm and lameness prevalence as evaluated by a trained external observer. Second, investigate the variables that motivate farmers to control lameness, factors that farmers report as barriers to lameness control variables and variables that they believe are important consequences of lameness in grazed pasture systems. Third, identify correlations between barriers, motivators and impacts of lameness, and to investigate underlying themes and sources of variance both within and between the 3 groups of questions. And finally, investigate if the themes identified in the farmers' responses to barriers, motivations and importance of lameness can be used to predict whether a farmer believes they have a lameness problem, and whether lameness prevalence is high.

METHODS

The study was designed as a cross-sectional descriptive study, with all procedures approved by Massey University human ethics committee, application number 4000025095 and Massey University animal ethics committee application number 22/36 and 21/55.

Farm enrolment

This study was part of a larger body of work investigating lameness prevalence and risk factors on New Zealand dairy farms. A one-stage cluster sampling method was performed, with a systematic randomization sampling framework used to enrol farms. A total of 120 pasture-grazing non-housed dairy farms across 8 major dairying territorial regions in New Zealand were enrolled in a cross-sectional study, investigating lameness prevalence over 2 time points across these farms. Enrolment was carried out by local veterinary practices within each region. Each practice listed their dairy clients in alphabetical order, and excluded farms that were greater than one hour drive away, or that were known to have a parlor design that meant post-milking lameness scoring was challenging. From the remaining eligible population, 15 farm clients were then systematically randomly enrolled. To do this a random number between 1 and 10 was generated in Microsoft Excel, with this number used to select the first farm on the list. Then every Nth farm (where n = Total number of eligible farms/15) on the list was enrolled. No farmers refused to be involved in the study.

The study was split into 2 years, with 60 North Island farms in year one (2021/22 dairy season) and 60 South Island farms in year 2 (2022/23 dairy season). Lameness score (LS) data collected were collected on 2 occasions from each farm, once between September–November (peak-lactation, spring) and again between January–March (mid-late lactation, summer).

Lameness scoring

Details on lameness score methods are described in full in Mason et al. (submitted). In brief, all lactating animals present on the farm on each of the 2 visit days were lameness scored by a trained observer using a 4-point LS scale (0–3), adapted from DairyNZ Lameness Scoring system (Supplementary Table 1). Animals were scored immediately after milking while walking on a flat concrete surface by trained and calibrated observers (one observer for each region). This included animals that had been previously identified as lame by the farmer and had been placed into a separate herd at the time of the lameness scoring visit. The prevalence of lameness at each visit was defined as the proportion of animals with a LS $\geq$2.

Survey design

The full questionnaire consisted of an 11-question survey, adapting that used by Leach et al. (2010a, 2010b) for New Zealand dairy farmers. Farmers were asked to select one of 3 options on their perception of lameness in the current milking season (June–May); major problem, moderate problem and minor/not a problem. Farmers then listed the sources from where they get their advice about treating and/or preventing lameness.

A total of 26 ordinal Likert-type items with 5 options ranging from not important at all to extremely important were asked of the farmers, grouped under 3 questions: motivators for lameness control, barriers to lameness control and impacts of lameness. The motivator grouping of questions (n = 7) revolved around how important certain factors were in motivating them to manage lameness. For barriers to lameness control, farmers were asked how important certain factors were at preventing them from controlling lameness on their farm (n = 9 items). For impact-related questions (n = 10) farmers were asked to rank the importance of potential problems arising from lame cattle on their farm.

Before release of the survey, draft versions of the survey questions were trialled on several veterinarians and local dairy farmers (who were not eligible for the study) to mitigate any areas of ambiguity.

The primary decision maker on each farm was selected to respond to the survey – this could be the owner, manager or share-milker, depending on the farm. A share-milker is a dairy farmer that owns the dairy cattle being milked and operates the farm on behalf of the farm owner. They receive a percentage of the milk income (most commonly 50%) and all money from the sale of livestock.The LS data was not communicated to the farmers until the completion of the study. The survey was distributed to the farmers around the time of their second LS visit. Three response methods were implemented to attempt to maximize response rate; first, the surveys were distributed to all 120 farmers online via Survey Monkey® (California, USA). If they had not responded via this method, each veterinary clinic called the non-responders. Finally, surveys could be answered in person on farm with the questions asked by a veterinary clinic representative.

Statistical analysis

Statistical analysis was split into sections: first, the relationship between farmer beliefs in relation to the

lameness problem on their farms and lameness prevalence, and, second, the analysis of the association within and between Likert-type items relating to barriers to lameness control, impact of lameness, and motivations to control lameness.

Descriptive statistics were tabulated and presented for the number of responding farmers by geographical region and North and South Island. Boxplots and unconditional linear regression were used to describe the relationship between farmers' belief of lameness problem on farm and lameness prevalence. For statistical analyses, due to low numbers in the major problem group, farmers reporting lameness as major and moderate problems were collapsed into one category, resulting in farmers' belief in regard to their lameness problem becoming a binary variable. For the purpose of this study, prevalence was reported as the mean value of the 2 prevalence scores, and all subsequent mention of lameness prevalence relates to this definition unless stated otherwise. Before this, the lameness prevalence at the first and second lameness score were compared using a Wilcoxon rank sum test to identify if differences existed between the 2 scores. Assumptions of normality of residuals and heteroskedasticity were assessed graphically, with transformation of non-normal variables and variance weighting if heteroskedasticity was identified. Bar graphs centered around the neutral response were used to present the Likert items for the motivations, barriers and lameness impacts.

The polychoric correlations between each of the 26 Likert items were calculated and presented with a correlation matrix plot, with the size and direction of the polychoric correlation coefficient represented by the size and color of the circle in the plot (Supplementary Figure 1).

Polychoric correlations between barriers, motivations and lameness impacts, and underlying themes both within and between the 3 groups of questions were assessed using 2 methods. First, factor analysis (FA), and then multiple factor analysis (MFA), accounting for the grouping within the survey questions. The aim of FA is to reduce several often highly correlated variables into a smaller number of uncorrelated variables or dimensions. In this way, FA can identify 'latent' factors that the original variables are explaining (Yong and Pearce, 2013). Thus, in the current study, the aim was to reduce the 26 variables across the 3 groups into themes or 'factors' that could explain most of the variation in responses between farmers. The number of factors identified was determined using the scree-plot, with all further components removed after the plot of eigenvalue against components formed an "elbow." Maximum likelihood was then employed to determine the factors, with varimax rotation used to minimize correlation between the identified factors. Outputs are presented as supplementary information, with the main purpose of this analysis to produce predictor factors for the linear discriminant analysis (LDA) described below.

Multiple factor analysis was used to stratify the factor analysis by the question grouping. Thus, each group of questions is equally weighted in regard to its influence on the dimensions identified by the MFA. This method reflects our a-priori grouping of the survey questions, which may have resulted in farmers responding differently within each group of questions. It also gives us information on correlations between the groups (i.e., barriers, motivations and impacts) allowing us to study the links between these groups (Lê et al., 2008, Abdi et al., 2013). A scree-plot was used to determine the number of dimensions to include, as described above under FA. The proportion of variation explained by the 3 groups for each dimension was calculated, as was the correlation between the 3 groups and each dimension. The coordinates for the first and second dimension calculated during the MFA were plotted for both the groups of questions and each individual Likert item, colored by their grouping. The relative contribution to the first and second dimension for each of the Likert items was calculated, with the 5 variables that contributed the greatest amount of variation reported.

The last analysis used was LDA, a form of supervised learning used for class separation (classification). We used LDA to investigate whether barriers, motivators or impacts could be used to predict whether a farmer believed they had a lameness problem (i.e., if they responded they had a major or moderate problem with lameness), and second, if they actually did have a lameness problem based on locomotion scoring (i.e., their farm level prevalence exceeded the median for this study). The factors identified in the FA were used as the predictors for the LDA models. As there were only 2 possible classifications for both outcome variables, only one linear dimension was produced for each model. The eigenvector of the first linear discriminant for each farmer was plotted in a boxplot, grouped by the 2 outcomes. The predictive abilities of the models were reported as 1) area under the curve of the posterior probabilities of the LDA and 2) the accuracy at correctly predicting based on a contingency table of predicted and actual classification.

Missing data were imputed depending on the data type by multiple imputation chained equations, provided that such data constituted less than 5% of a variable. If more than 5% of data were missing from a variable, then it was removed from any analysis. The unit of interest for all analyses was the farm, with all analyses and data manipulation undertaken using R Version 4.2.3 (R Core Team, 2022; R Foundation for

Statistical Computing, Vienna, Austria). Specific R packages used for the analyses included FactoMineR (Lê et al., 2008), missMDA (Husson et al., 2013), psych (Revelle and Revelle, 2015), as well as the suite of packages contained within the Tidyverse (Wickham et al., 2019).

RESULTS

Descriptive

Of the 120 enrolled farms, 101 responded to the survey. The median herd size was 430 (IQR 315 – 623) cows, with the predominant breed on 47/101 farms a Holstein-Friesian/Jersey cross; the predominant breed on 38 farms was Holstein-Friesian and 15 farms was Jersey. One hundred percent spring calving occurring on 94/101 farms: the other 7 farms calved majority of their cows in the spring and a minority in the autumn. All farms continually managed cattle at pasture during lactation and the dry period. Reasons for the 19 non-responders were not formally collected, although lameness prevalence was similar between the responders and non-responders. Eighty-six percent of responses were via the online survey method. The 101 participants were located throughout the 8 dairying regions, with a median of 14 farms per region (range 8 – 15). Only 8/15 Northland farmers that participated in the prevalence study responded as a result of communication issues when emailing the surveys out to farmers. All Likert items had between one and 4 percent missingness, and thus these missing data points were imputed before undertaking analyses, with no variables removed. Median lameness prevalence was 2.7% (IQR 1.6 – 4.2%), with a range from 0.4% to 13.2%. The median farm-level lameness prevalence at the first LS (spring) was 2.99 (IQR 1.36 – 4.73) and at the second score (summer) was 2.57 (IQR 1.52 – 4.20), with no difference in the median LS between the seasons identified ($P = 0.50$).

Median lameness prevalence versus farmer perception of lameness problem

Of the respondents, 45/99 (46%; 95% CI 36 – 55%) perceived lameness as minor/not a problem, with 40/99 (40%; 95% CI 31– 50%) perceiving it as a moderate problem. Farmers who perceived lameness as a major problem had a median lameness prevalence of 3.3% across the 2 visits (range 1.1 to 13.2%; Figure 1). In contrast, those that perceived lameness as minor/not a problem had a median lameness prevalence of 2.3% (range 0.5 to 8.9%).

Log-transformation of lameness prevalence data resulted in normal distribution of the residuals as illustrated by a straight line QQ-plot. When back-transformed, lameness prevalence was 0.80 (95% CI 0.61 – 1.04) % greater on farms where farmers perceived lameness as a moderate or a major lameness problem than on farms where they perceived lameness as a minor/not a problem.

Where farmers go to for lameness advice

Eight options were available for farmers to select where they get advice on treating and preventing lameness. The most frequent response was the veterinarian, with 89% (89/101) of respondents noting that this was where they got their lameness advice from (Table 1). Their own ideas and other farmers were the second and third most frequent source of lameness advice.

Barriers, motivators and impacts of lameness

The top 3 motivating factors for putting time and resources into improving lameness were pride in a healthy herd, feeling sorry for lame cows, and feeling guilty for lame cows, with greater than 80% of farmers responding that these factors were very or extremely motivating (Figure 2). The importance of farm assurance plans and wanting to do better than peers scored lower than other factors, yet still over half of the farmers ranked these as very or extremely important motivating factors.

The 3 barriers to management of lameness that farmers ranked the most important were a lack of time, lack of skilled labor and poor foot-crush facilities, however, 40% or fewer farmers ranked these are very or extremely important (Figure 3). The least important barriers to lameness control were solutions not affordable, conflicting advice and lack of information, with at least 69% of respondents stating that these were either slightly or not important barriers to lameness control on their farm.

Most of the potential impacts of lameness were considered important to farmers overall, with the exception of the requirement for extra labor and the hassle of another herd (Figure 4). All farmers ranked the impact of lameness on the pain and suffering on the cow as very (11%) or extremely (89%) important. Factors related to the individual cow were generally ranked higher than those that related to the farm or industry.

Relationships between lameness motivators, barriers and impacts

With the grouping structure of farmer responses related to motivators, barriers and impacts of lameness retained, MFA identified 3 dimensions that explained

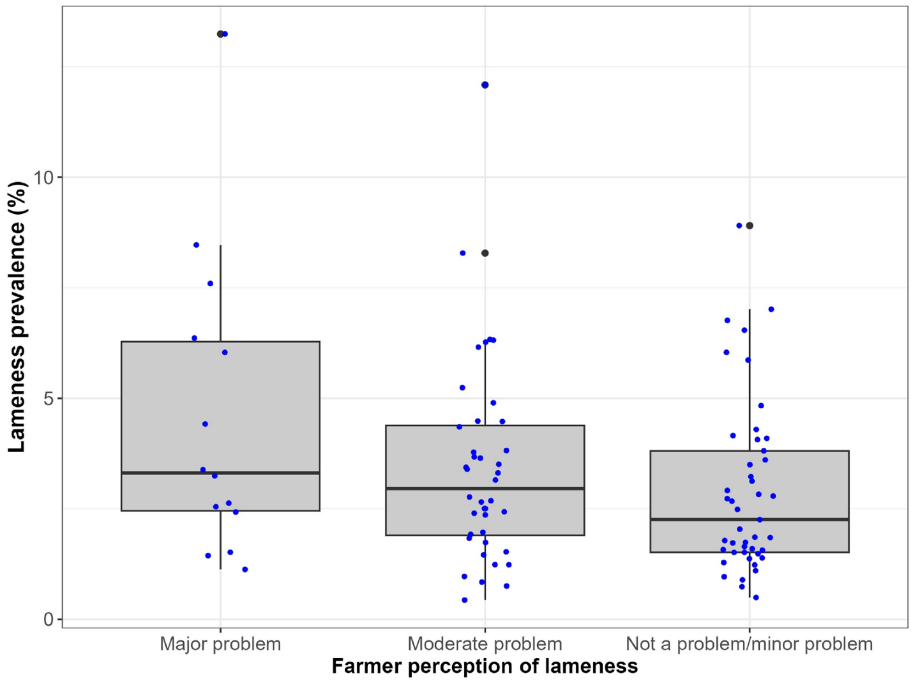

Figure 1. Boxplots of the lameness prevalence (mean of 2 scoring events), as defined by trained lameness scorers, grouped by the farmer perception of lameness problem. The blue dots represent each farm within each farmer lameness perception category (n = 99 farmers across the 8 dairying regions in New Zealand)

53.5% of the total variance from the 26 Likert items. The first dimension explained 27.5% of the variation, the second dimension 17.5% and the third dimension 8.6%. The correlation plot of the first and second dimensions, illustrates that motivators and impacts both contributed equally to the variance in both the first and second dimension, indicating that these 2 groupings of questions elicit similar responses by farmers (Figure 5; Table 2). In other words, farmers that believed motivators for lameness control to be important also thought that impacts of lameness were important. In the first dimension, motivators and impacts each contributed 46% of the variation, with correlations of 0.90 between the motivators and the first dimension, and 0.91 for impact and the first dimension, respectively. In contrast, the variance contribution that the grouping of barrier Likert items provided suggests a different theme to the other 2 groups of questions (Figure 5a). Barriers contributed 8.2% of the variation of the first dimension and had a correlation coefficient with the first dimension of 0.39.

All Likert items were positively correlated with each other in the first dimension (Figure 5b). In the second dimension, the barriers to lameness control variables were negatively correlated with some, but not all, motivators to control lameness. The coordinates were close together for the first and second dimensions for all the barrier items, indicating little variations in responses by farmers for each of these Likert items. The 5 variables that contributed the greatest amount of variation across dimensions 1 and 2 were all motivators. Lame cows losing money, good public image, losing farm assurance plans, wanting to do better than peers and pride in a healthy herd each explained between 4.8% and 5.6% of the total variation in the first 2 dimen-

Table 1. Sources of advice for farmers on treating and/or preventing lameness. Farmers could select as many options as applicable (n = 101)

Advice source	Number of responses
Veterinarian	89
Farmer's own ideas	44
Other farmers	40
Hoof trimmer	34
DairyNZ	23
Nutritionist	12
Farm consultant	12
Other	13

sions. The remaining Likert items contributed between 2.2 and 4.7% of the variation.

Predicting lameness and lameness perception from farmer themes

The screen-plot identified 4 factors that were responsible for 63.3% of the variance in farmer responses to the questionnaire (Table 3). The first factor explained 22% of the variance and was influenced by all the barriers to lameness control with the addition of the importance of the requirement for extra labor that lameness creates. The theme of this factor was thus defined as lameness control barriers. The theme of factor 2 (which explained 16% of the variance) was public perception and challenges beyond the farm gate as the importance of farm assurance, public perception and benchmarking were the most influential variables in this factor. Factor 3 (which explained 14% of the variance) was related to cow welfare as the variables with the greatest correlation weighting for this factor consisted of the importance of lameness as a cause of pain and suffering as well as both feeling guilty and sorry for lame cows as a motivator for lameness control. The other key influencing variables for this factor were the impact of lameness on reproduction and of the impact of lameness on body condition. The final factor (which explained 11% of the variance) had a theme of profitability as it was most influenced by the importance of the impact of lameness on profitability and on milk production.

These 4 factors were used as the predictors for the LDA. The boxplots of the first linear discriminant show clear overlap with outcome for both farmers' belief of lameness problem and for median lameness prevalence (Figure 6). With farmers' belief as the outcome, the LDA had an accuracy of 0.59 (95% CI 0.49 – 0.69) and an AUC of 0.69 (95% CI 0.59 – 0.80). With lameness prevalence as the outcome (less than median vs greater than median), the LDA had an accuracy of 0.53 (95% CI 0.43 – 0.63), and AUC 0.58 (95% CI 0.49 – 0.72).

DISCUSSION

Despite lameness prevalence being much lower than in most studies of lameness prevalence recently reviewed by Thomsen et al. (2023), many farmers in this survey believed that lameness was a moderate or major problem on their farm. Our data suggests that farmers place different weightings on barriers to lameness control compared with motivators for lameness control. However, the importance that farmers place on barriers to controlling lameness, motivators for lameness con-

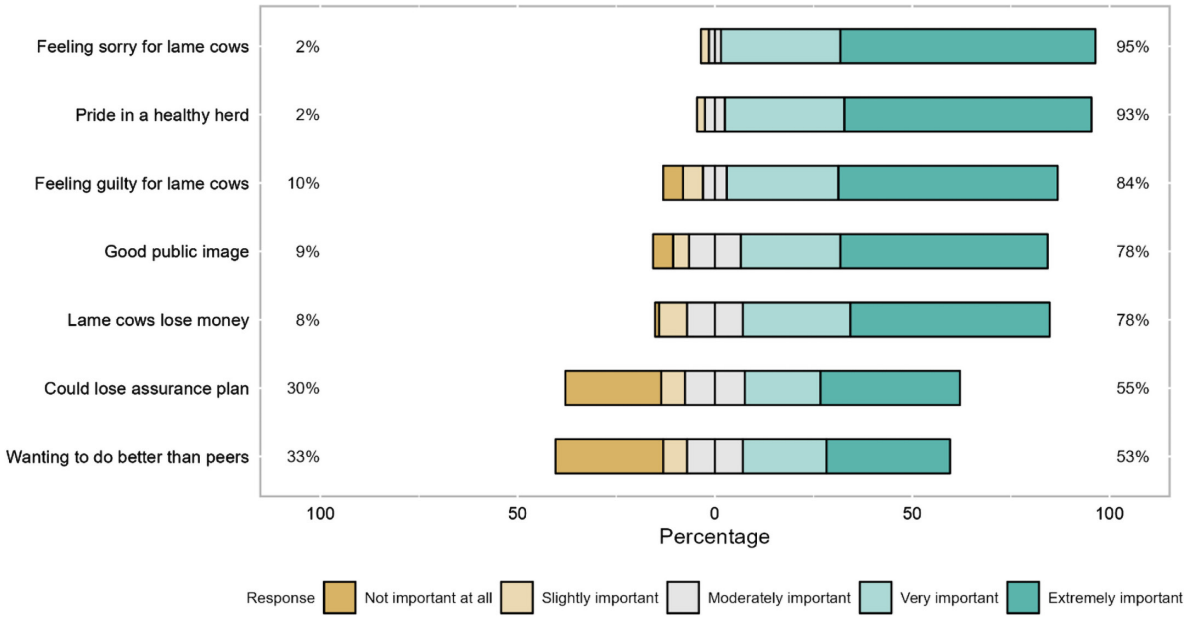

Figure 2. Likert items of farmer ranking the importance of each factor for motivating them to put time and resources into improving lameness (n = 97 to 101). The percentages represent the proportion of respondents giving an answer of 'not or slightly important' (left axis) or 'very or extremely important' (right-hand axis).

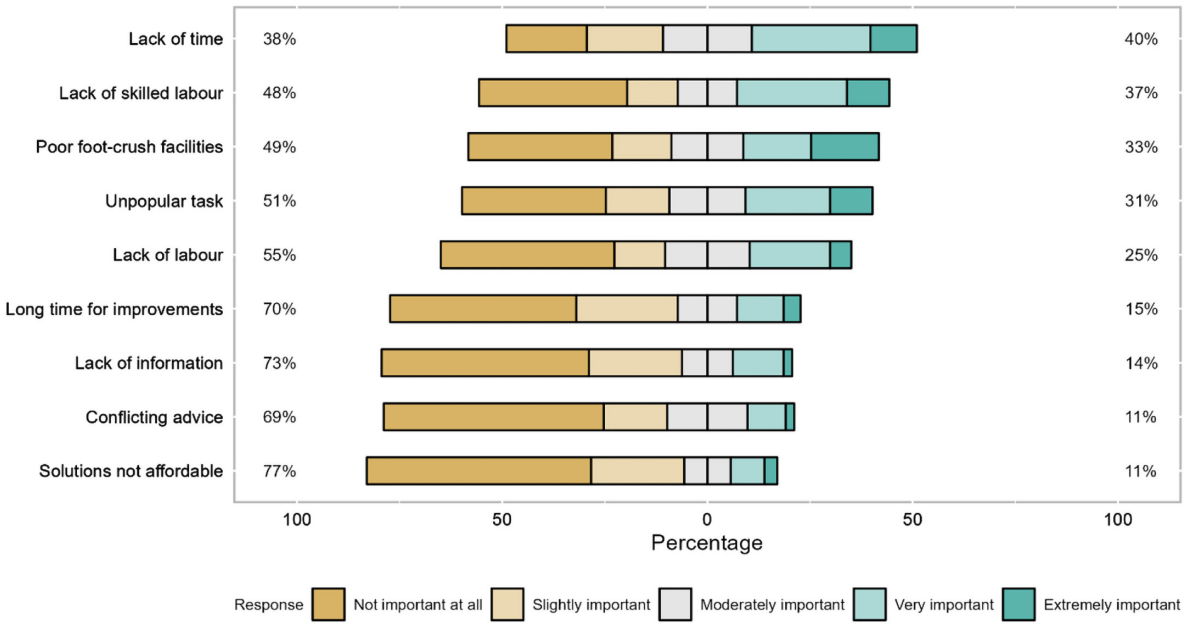

Figure 3. Likert items of farmer ranking barriers that prevent farmers from managing lameness in an ideal way (n = 97 to 101). The percentages represent the proportion of respondents giving an answer of 'not or slightly important' (left axis) or 'very or extremely important' (right-hand axis).

trol and impacts of lameness are not good predictors of farmers' belief in regard to their lameness problem on their farm, or actual lameness prevalence.

Forty 5 percent of farmers believed lameness to be a moderate problem on their farm, and 40% minor/not a problem. Very few believed lameness to be a major problem. In comparison, Leach et al. (2010a) reported that 33% of their UK respondents described their lameness problem as minor, 56% as moderate and 11% as major, suggesting that New Zealand farmers believe lameness to be less of a problem than their United Kingdom colleagues. However, these differences are relatively small and in stark contrast with the median lameness prevalence of the 2 studies, with Leach et al. (2010a) reporting a median lameness prevalence of 36% (>10 times that of the current study). Furthermore, despite the large difference in median prevalence, the relative importance farmers placed on barriers and motivators were similar to those reported by Leach et al. (2010a, 2010b). Thus despite vastly different dairy farming systems, risk factors and baseline lameness prevalence, there may be mutually beneficial international research opportunities to assess lameness control strategies that influence farmer behavior that could result in success across different systems (Green et al., 2020).

Dairy farmers have diverse awareness and perception of lameness. While associations between farmer belief of a lameness problem and true lameness prevalence were reported in the current study, with less than 1% predicted difference between farmers that perceived lameness to be a problem or not, this association can be considered biologically weak. Leach et al. (2010a) reported a similar association. Furthermore, in both the current study and Leach et al. (2010a), there were farmers that believed they did not have a lameness problem with a lameness prevalence in the top 5% of all enrolled farmers, and conversely farmers that believed they had a major lameness problem having lameness prevalence in the bottom 5% of farmers. While awareness of a disease problem alone is not usually enough to motivate change (Ritter et al., 2017), it is still often a prerequisite step in the process (Leach et al., 2013, Ritter et al., 2017). Further research is required to investigate how farmer perception of lameness can be improved, in a country with a relatively low baseline of lameness such as New Zealand.

A key finding of our study is that farmers do care about the welfare of lame animals, with the most extreme responses in both the motivation and importance of lameness groupings of questions related to the pain that lameness causes an animal. Similar themes have

been expressed before, with the majority of Swiss dairy farmers reporting that reducing lameness pain to the lowest possible level was of 'absolute' importance (Becker et al., 2013). Yet at the same time, farmers' beliefs about the welfare of lame cattle was not associated with intention to implement or the cost-effective nature of the intervention (Bruijnis et al., 2013), nor the cost of treatment deemed an important barrier in this current study or from Swiss dairy farmers (Becker et al., 2013). There is an apparent disconnect between dairy farmers claiming to care about the welfare of lame cattle and lack of appreciation by farmers of welfare implications of lameness. This is further highlighted both with the previously discussed large contrast between lameness prevalence as determined by farmers and lameness prevalence by trained lameness scorers, and also in the lack of awareness by farmers regarding the need for analgesia when confronted with extremely painful hoof lesions such as sole ulcers (Becker et al., 2013).

The veterinarian was the primary source for lameness treatment and prevention advice, with a proportion greater than double the nearest advisory source in this current study. The veterinarian was also the most common source of advice for lameness control by UK dairy farmers (Leach et al., 2010a). Veterinarians have a unique role in their ability to influence dairy farmer behavior with respect to animal health and welfare (Biesheuvel et al., 2021). Similar to Swiss dairy farmers (Becker et al., 2013), we report that cost of treatment of lameness is not of major importance/concern for farmers. Yet veterinary practitioners considered pain reduction to the lowest possible level less important than did dairy farmers (Becker et al., 2013). The upside of all of this is that these findings challenge animal health advisors, particularly veterinarians, to improve their advice for welfare control of lameness, and prejudices and biases of what animal health advisors believe a farmer will act upon should be left at the door. Jorritsma et al. (2023) conclude that as most Dutch farmers report they are aware of the importance of preventative lameness measures, veterinarians may not need to spend time on convincing farmers of the importance. However, there remains ample opportunity for animal health advisors, particularly veterinarians, to improve the welfare of lame cattle by providing farmers with more tools such as non-steroidal anti-inflammatory drugs and hoof blocks, and educating farmers on the benefits of these as well as implementation of strategies such as early detection of lameness (Pedersen and Wilson, 2021).

There are also contradictory responses from farmers with respect to the cost of lameness control. Over 80% of surveyed UK farmers did not consider the afford-

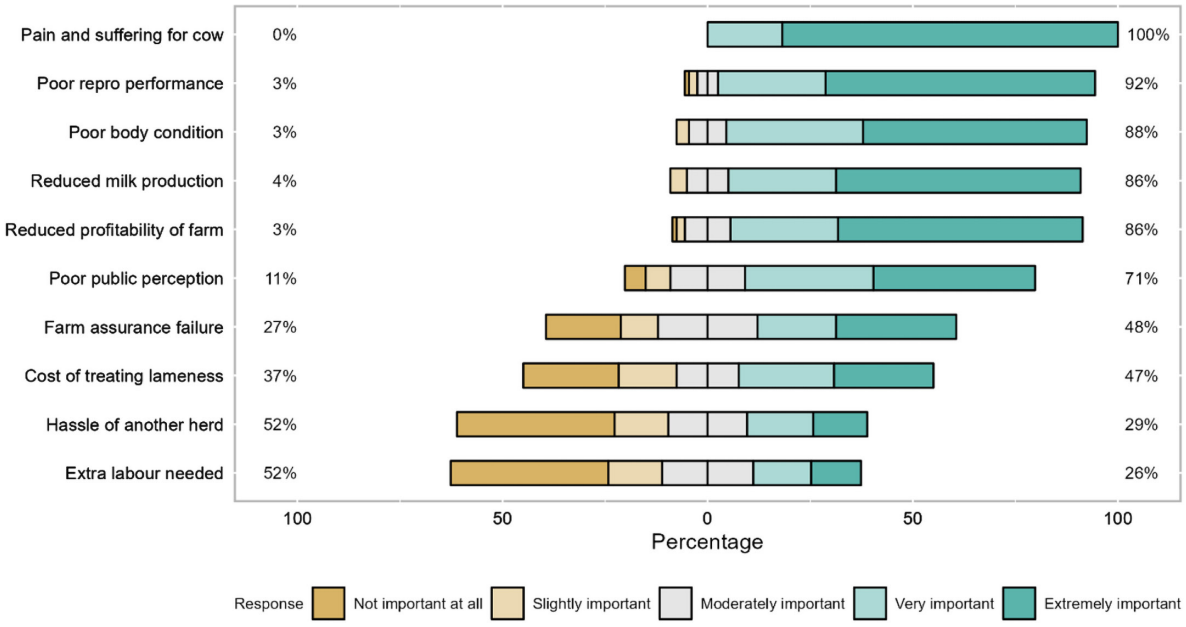

Figure 4. Likert items of farmer ranking of the importance of impacts of lameness on the cow, the farm and the industry (n = 97 to 101). The percentages represent the proportion of respondents giving an answer of 'not or slightly important' (left axis) or 'very or extremely important' (right-hand axis).

Table 2. The contribution of variance and correlation of question groupings on the first three dimensions from a multiple factor analysis. The three groupings of questions were barriers, impacts and motivators. The percentage of variation that they explained for each of the three dimensions, respectively, and the correlation coefficient between each grouping and each dimension, are reported

	Dimension 1		Dimension 2		Dimension 3	
	Contribution (%)	Correlation	Contribution (%)	Correlation	Contribution (%)	Correlation
Barriers	8.2	0.39	71.3	0.90	6.9	0.30
Impacts	46.0[1]	0.91[2]	19.7	0.65	58.5	0.79
Motivators	45.8	0.90[2]	9.0	0.41	34.6	0.59

[1]Impacts of lameness contributed 46% of total variation for the first dimension.

[2]Impacts of lameness and motivators had very strong polychoric correlation coefficient (0.90 and 0.91, respectively) with the first dimension.

ability of control solutions to be an important barrier for lameness control (Leach et al., 2010a), similar to the 78% in this current survey. Yet in the same survey, the UK farmers were asked whether they implemented new control ideas they had sought advice for. Only 21% of farmers that had searched out lameness control advice implemented all of the lameness control suggestions, with the most common reason for not implementing the control measures being cost. While we did not ask farmers if they implemented control plans in the current survey, given their similar responses for barriers and motivators, there is no reason to believe this to be any different in New Zealand. This may be in part a function of dairy farmers already believing they have done enough to control lameness (Bruijnis et al., 2013).

This study reports on how farmer beliefs could influence lameness outcomes, but not how we can predict farmer behavior, nor explicitly assess the decision-making process for lameness control. It is one thing for a farmer to claim an intention to change, but something quite different to act on it (Biesheuvel et al., 2021). There may be opportunities for animal health advisors and farmers to think laterally to address some of the barriers identified. For example, in this current study, the authors were surprised to find farmers did not believe that needing extra labor was an important barrier

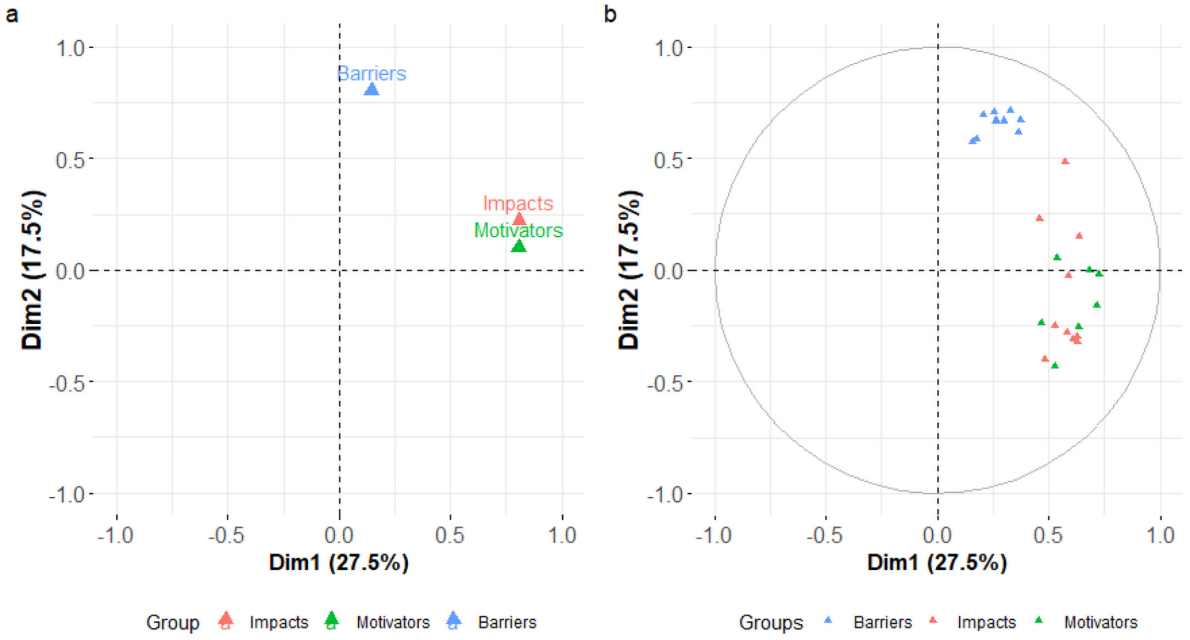

Figure 5. First and second dimensions from a multiple factor analysis of the barriers, impact and motivators for lameness control as reported by New Zealand dairy farmers (n = 101) for a) the grouping of questions of barriers, motivators and impacts and b) the 26 Likert items, colored by barrier, motivators and impacts of lameness. The x and y-axis of both plots are the squared correlation coefficient and represent respectively the proportion of variation explained for the first and second dimensions.

to lameness control. With the low lameness detection risk ubiquitous among dairy farmers, one way to address low detection would be via the addition of extra labor dedicated to the task of detecting and treating lameness, even in the form of external hoof trimmers or veterinarians. Lack of time was the most important barrier in our study, and moderate correlation existed between time and labor, preventing farmers from controlling lameness (rho = 0.68). Lack of time was reported as the biggest barrier for lameness control by UK dairy farmers (Leach et al., 2010a) and the most needed resource for claw health by Dutch dairy farmers (Jorritsma et al., 2023). Furthermore, a prospective study identified that farmers who placed time as a significant barrier to lameness control were able to reduce lameness to a greater extent than those where time was not an important barrier to lameness control (Leach et al., 2013). So, while farmers may not see the lack of labor as a major barrier, the provision of extra labor may address what they saw as the biggest barrier to lameness control, a lack of time.

The latent factors influencing what farmers perceive as barriers to lameness control on farm were different to the factors that influence farmers' motivation to control lameness. This was irrespective of the farmers' perception of the lameness problem and of the true status of lameness on farm. This makes interpretation of farmers' responses challenging. Although barriers and motivators were not directly compared in Leach et al. (2010a, 2010b) and reported in separate manuscripts, the overarching themes of the barriers and motivations between UK and NZ dairy farmers were similar. There were few factors that UK farmers identified as important barriers to lameness control, yet at the same time, the majority of the factors influencing their motivation were considered very important. It is possible farmers in these types of surveys are responding with what they believe the survey authors and society are wanting to hear – that they are motivated to control lameness, and that there are no major factors preventing them for controlling lameness. This phenomenon, known as social desirability bias (Grimm, 2010), is well documented when the public are surveyed on animal welfare issues (Lusk and Norwood, 2010, Lai et al., 2022), and the authors hypothesize that similar biases may be present in this current study. This phenomenon may have been less of an issue in the farmers enrolled in Leach et al. (2010a, 2010b) as they were enrolled into an intervention study, in contrast to the current study, where farms were enrolled in a monitoring study with no goal of direct improvement in their farms lameness prevalence. These differences in study objectives may have resulted in different answers from farmers, with those agreeing to be involved in an intervention study

Table 3. Polychoric correlation matrix of 26 Likert items on lameness barriers (B), impacts (I) and motivators (M), on the first four factors identified from a factor analysis. Values are in bold when polychoric correlation coefficients for that factor were >0.6, and represent Likert-items that are explaining a significant proportion of the latent theme of that particular factor

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Labour (B)	0.735	0.271		
Skilled labor (B)	0.709	0.106		
Time (B)	0.720			−0.145
Facilities (B)	0.604			−0.180
Not affordable (B)	0.666			
Unpopular task (B)	0.725		−0.103	0.101
Conflicting advice (B)	0.822		−0.147	0.116
Long time (B)	0.768			0.173
Knowledge (B)	0.879			
Pain (I)	−0.135	0.173	0.933	0.202
Profit (I)		0.250	0.338	0.799
Milk production (I)		0.158	0.433	0.884
Reproduction (I)		0.108	0.637	0.467
Body condition (I)		0.238	0.753	0.324
Farm assurance (I)		0.826		
Public perception (I)		0.704	0.289	
Treatment cost (I)	0.317	0.382	0.160	0.454
Extra labor (I)	0.639	0.306		0.267
Lame herd (I)	0.367	0.126	0.136	0.355
Pride (M)	−0.126	0.330	0.654	0.140
Sorry for lame (M)		0.284	0.665	0.100
Guilty for lame (M)	0.221	0.470	0.452	0.164
Money (M)		0.508	0.329	0.590
Public image (M)		0.698	0.321	0.175
Farm assurance (M)	0.143	0.913	0.148	0.166
Benchmarking (M)	0.193	0.671	0.296	0.198

Table 4. Themes from the four factors, ordered from factor explaining greatest to least % of variation

	Variance %	Cumulative Variance %
Factor 1 – "barriers"	22.1	22.1
Factor 2 – "public perception"	16.0	38.1
Factor 3 – "cow welfare"	14.3	52.4
Factor 4 – "profitability"	10.8	63.3

potentially more likely to provide a more honest response. Further targeted interviewing of farmers using strategies such as forced-choice items is warranted to investigate the impact of social desirability bias directly (Nederhof, 1985).

Another limitation of the study was the possible ambiguity with some of the questions. For example, "preventing you from being able to manage lameness" could be interpreted by some farmers to be related to managing lameness that is already present, with other farmers interpreting this as relating to all components of lameness control. We do not know how this may have biased the study, although it is possible that this could have accounted for the range of responses from farmers for time and skilled labor. However, as the rankings for the lameness barriers were similar to that reported by UK dairy farmers (Leach et al., 2010a), we have no reason to believe that this is an important source of bias.

This study reports for the first time that the barriers and motivators to lameness control that farmers report have very little predictive ability at detecting whether a farmer perceived lameness to be a problem, or whether true lameness prevalence was high on their farm. The 4 main factors identified in the factor analysis resulted in a predictive accuracy not much greater than a 50:50 guess on whether farmers believed they had a lameness problem or not, or the true status of the lameness problem. To be of any practical use, the authors would have liked to have seen accuracy of at least 0.80. Thus, the value of the theory of planned behavior (Biesheuvel et al., 2021), as used in the current study, to directly assess lameness control in dairy cattle is questionable. Researchers are encouraged to investigate further theoretical frameworks designed to elicit sociological themes (Biesheuvel et al., 2021), such as the COM-B models, or transtheoretical models, investigated by Jorritsma et al. (2023) or changes in the methods of delivery such as focus groups involving various stakeholders (Wynands et al., 2022).

Evidence-based scientific advice does have the potential to reduce lameness prevalence, but for sustained and widespread reductions in lameness prevalence, changes in farmer behavior and multi-party engagement are required (Wynands et al., 2022). A great practical success

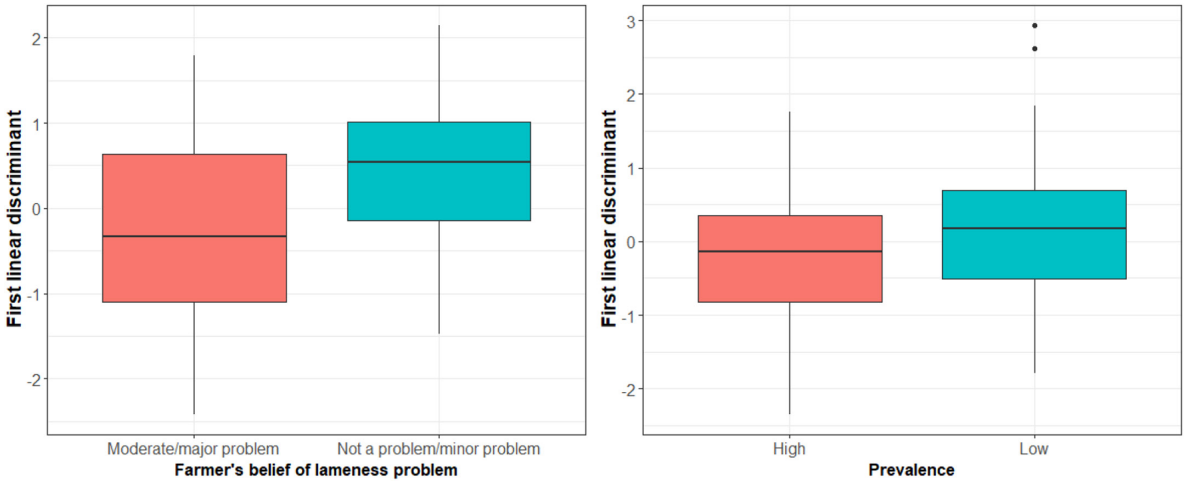

Figure 6. Boxplots of the discriminant function from 2 linear discriminant analyses, a) Farmer perception of lameness, and b) Lameness prevalence above (high) and below (low) the median lameness prevalence, from 4 latent factors produced by a factor analysis from 26 Likert items on lameness barriers, impacts and motivators. A good class prediction should result in little overlap between the linear discriminants between the 2 classes.

story is footrot in sheep in the United Kingdom (Green et al., 2020). The use of systemic antibiotics, instead of foot-trimming, for the treatment of footrot in sheep has demonstrated significant improvements in the recovery risk of these animals to such an extent that the global burden of the disease would be substantially reduced if implemented routinely (Kaler et al., 2010). While lameness prevalence in sheep declined somewhat from 2004 to 2013, since 'best-practice' recommendations of prompt appropriate treatment of cases, the majority of the UK sheep farmer population were still not following best-practice (Winter et al., 2015). The behavior shift has come more recently, following targeted extension of the evidence. In response to education, training and one-on-one discussions of the evidence, both veterinarians (Higgins et al., 2013) and farmers (Green et al., 2020) shifted their beliefs on appropriate footrot control strategies. Critically, sheep farmers in Green et al. (2020) initially saw time and money as one of the major barriers to implementing changes into their system to control footrot. Yet after one-on-one discussions around the current best-practice in footrot control, cost and time became a major driver of change (Green et al., 2020). If it is possible to change the behavior of sheep farmers from a method that historically been seen as 'good' (hoof trimming; (Green et al., 2020)) resulting in reductions in the prevalence of footrot on farms, then there is promise that similar approaches can be successful for dairy cattle lameness control.

We conclude that New Zealand dairy farmers do care about the welfare of lame cattle, despite considerably lower lameness prevalence compared with their counterparts in the United Kingdom, and that they do have strong beliefs on the welfare implications of lameness for their cows. The latent themes expressed by farmers on their barriers appear different to those expressed by farmers on their motivators for lameness control. These themes were not able to predict the prevalence of lameness on the days of measurement of the herd nor farmer perception of lameness.

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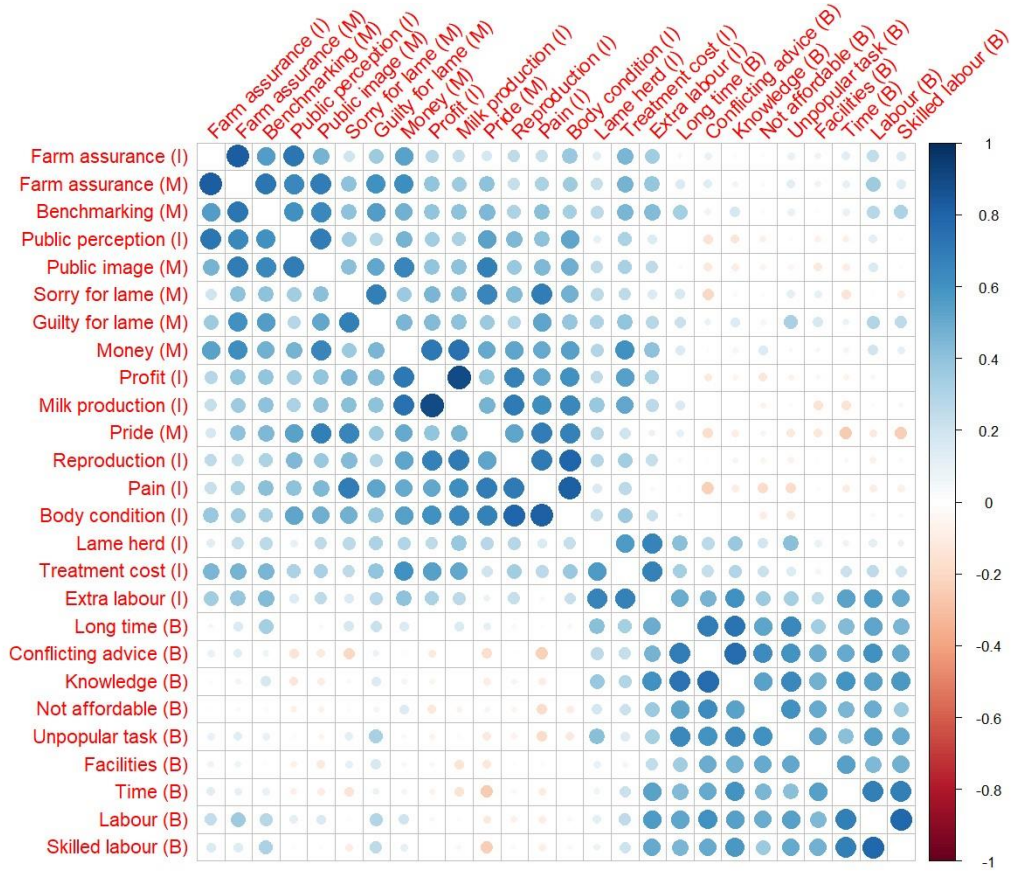
Supplementary Table 1. Lameness scoring descriptors used in a cross-sectional observational study investigating farmer motivators and barriers to lameness control (adapted from DairyNZ Lameness Scoring system)

Lameness Score	Descriptor
0	Walks with even weight bearing on all 4 limbs at a similar walking speed to a person, with regular stride length and rhythm. Straight back line at all times and head held in line or slightly below the backline and steady when walking
1	Walks unevenly but reduced weight-bearing on affected limb not easily obvious. May have uneven stride length and/or rhythm. Backline straight when standing but may be mildly arched when walking.
2	Lame, with decreased stride length on affected limb. Weight bearing reduced on affected limb which can easily be identified. Walking speed slower than normal. Backline often arched when standing and walking and head bobs up and down when walking
3	Severely lame, with minimal or no weight bearing on affected limb. Reluctant to move and cannot keep up with the healthy herd. Backline arched when standing and walking and often large head movements up and down when walking.

Supplementary Figure 1. Polychoric correlation matrix of 26 Likert items on lameness barriers (B), impacts (I) and motivators (M), with the direction and scale of the correlations represented by the color (blue positively correlated, red negatively correlated) and the size (the larger, the stronger the correlation) of the circle.



8

Conclusions - A review of lameness in New Zealand dairy cattle and a summary of the thesis

8.1 Introduction

Lameness remains one of the biggest animal health challenges that dairy farmers face internationally. Lameness not only results in significant reduction in the lifetime productivity of an animal (Huxley 2013) and animal welfare concerns (Whay and Shearer 2017), it also negatively impacts greenhouse gas emissions (Mostert *et al.* 2018) and is one of the key challenges to the social license to operate a dairy business (Hampton *et al.* 2020). Furthermore, the unacceptably high prevalence (Thomsen *et al.* 2023) and incidence (Afonso *et al.* 2020) of lameness reported globally create a strong argument for dairy cattle lameness to be the most important animal health disease of dairy cattle.

Throughout this project, there has been an unrelenting New Zealand-centric focus to the research. This is important due to the unique management systems in New Zealand and different infection pressures. For example, digital dermatitis is one the most important causes of lameness in dairy cattle worldwide (Bicalho and Oikonomou 2013). Despite New Zealand reporting digital dermatitis lesions on farms across many regions in New Zealand (Yang *et al.* 2017), clinical lameness due to digital dermatitis is very rare (Yang *et al.* 2018). Thus, lameness management policies for digital dermatitis currently have little impact on reducing lameness in New Zealand. New Zealand dairy cows also spend almost 100% of their lives at pasture, a phenomenon that is rare internationally. Even in many 'pasture-grazed' systems, dairy cows still spend a portion of the year housed (O'Connor *et al.* 2020; Browne *et al.* 2022). As housing management is one of the most important risk factors for lameness (Cook and Nordlund 2009; Beaver *et al.* 2021), it is not surprising that much of the international lameness research on the pathogenesis of claw-horn lesions focuses on housing management. These housing-focused control plans have little relevance to control of lameness in New Zealand.

Lameness is a multi-factorial disease, usually requiring risk factors from at least two of cow, environment and management to result in lameness (Figure 8.1). An example of this is the calving effect, the process of weakening of the connective tissue that holds the pedal bone in situ within the hoof capsule around calving

(Tarlton *et al.* 2002; Knott *et al.* 2007). This phenomenon happens in both beef cows and dairy cows, and in both housed cows and pasture-based cows. Yet the lameness prevalence and incidence are vastly different between these groups of animals that all undergo the component cause of calving.

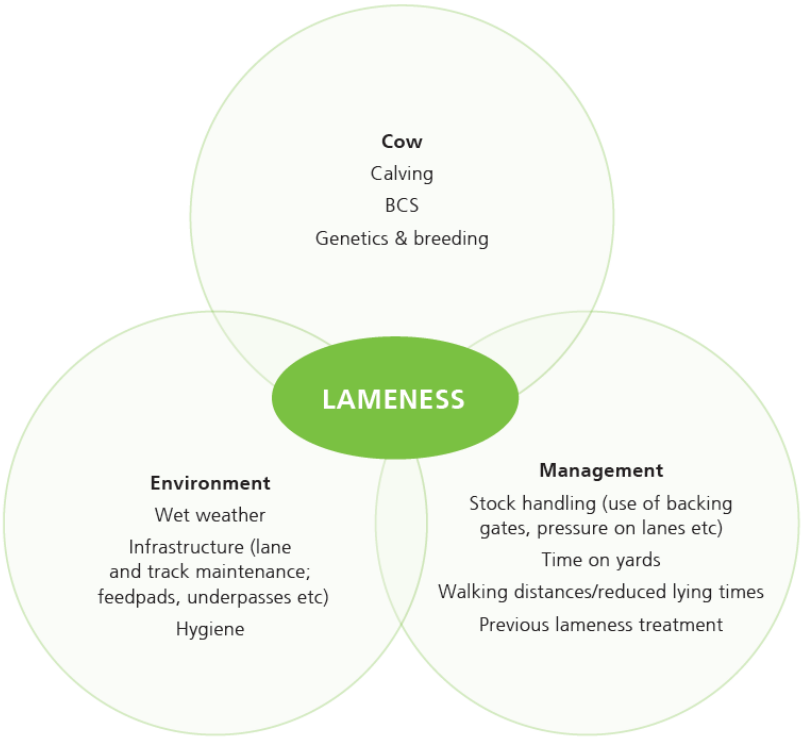


Figure 8.1 Venn diagram of the relationship between environment, cow and management as causal components of dairy cattle lameness. Used with permission from DairyNZ Healthy Hoof Preventing and Managing Lameness

Thus, the sufficient and necessary causes of lameness in New Zealand dairy cattle are different to many of those reported overseas. We, therefore, require New Zealand focused lameness research in order to identify, address and start to provide solutions for dairy cattle lameness in New Zealand.

The New Zealand dairy industry prides itself on promoting a welfare-friendly pasture-based farming system. Whilst the perception of the welfare on pasture-based New Zealand dairy farms from an international lens

remains predominantly positive (Webster *et al.* 2015; Mee and Boyle 2020), recent welfare grading from international standards have seen a reduction in welfare scores. An animal protection grade of A was given to New Zealand by World Animal Protection in 2014 (https://www.worldanimalprotection.org.nz/news/new-global-index-shows-new-zealand-world-leader-animal-welfare), yet more recently in 2020 was given a grade of C from the same organisation (https://api.worldanimalprotection.org/country/new-zealand). This decrease in score is unlikely the result of deteriorating welfare metrics, but rather a change in focus from regulation to application of improving wellbeing. One of the inferences from these changing grades is that New Zealand needs to demonstrate welfare outcomes to international partners. Thus, in order to maintain the social license to dairy farm, and for the New Zealand dairy industry to prove that it is 'world leading in animal care' (Dairy Tomorrow strategy; https://www.dairytomorrow.co.nz/strategy/animal-care/), we need data to back up these statements.

The three over-arching goals of this project were:

1) to identify the current burden of lameness in New Zealand dairy cattle,
2) improve the treatment of claw-horn lameness and
3) provide information on ways to prevent new cases of lameness.

To achieve these goals, the project was broken down into six specific objectives. These are described below and make up the individual chapters and manuscripts for the thesis (with associated goal in parentheses):

1) Define the prevalence of lameness in New Zealand dairy cattle *(Goal 1)*
2) Identify farm-level risk factors for lameness in New Zealand dairy cattle *(Goal 3)*
3) Define the duration of lameness after best-practice treatment of claw-horn lameness *(Goal 1 and 2)*
4) Review the literature on the use of NSAID for cattle lameness treatment *(Goal 2)*
5) Investigate a practical lameness prevention method involving conditioning of heifers' hooves prior to calving *(Goal 3)*
6) Identify farmer barriers and motivators to lameness control *(Goal 3)*

The aims of this summary chapter are to review and comment on the six manuscripts produced as part of this thesis, to provide a coherent framework for the project and to provide my thoughts on the most important findings and areas to investigate next.

8.2 Prevalence of lameness

In order to fix a problem, first the problem must be defined and described. Quantifying lameness can be achieved by either describing the incidence risk (the number of cows or cases of a given length of time) or the prevalence (the number of cows on a given day). Data on either incidence or prevalence of dairy cattle lameness within New Zealand prior to this study were sparce. The monthly and yearly incidence risk of 43 Canterbury farms in 2005/06 season have been reported (Gibbs 2010), but that remains the only prospective incidence study reported over the past 30 years in New Zealand. Farmer-reporting of lameness cases is sporadic (Chawala *et al.* 2013) and New Zealand farmers have a poor understanding of the true prevalence of lameness (Fabian *et al.* 2014). Thus, even if farmers reported all of the cases they identified and treated, this incidence measure would likely be an underestimate of the true status. Due to these issues and the logistical challenges of collecting incidence data over a large number of farms across New Zealand, lameness prevalence instead was decided as the metric that would be reported to define the lameness problem. This is in line with the primary lameness metric used internationally (Afonso *et al.* 2020; Thomsen *et al.* 2023).

The only previous multi-farm lameness prevalence work in New Zealand was a 2011 study of lameness prevalence from 58 New Zealand farms, reporting a median farm-level lameness prevalence of 6.7% (farm range from 1.2 - 36.0%) (Fabian *et al.* 2014). Whilst this was a well conducted study, the external validity of the estimates to extrapolate to all of New Zealand is likely biased as the enrolled farms were convenience sampled and only from a few regions of New Zealand.

To obtain an unbiased estimate of New Zealand, it was critical that farms across the nation were represented, and that the selection process was randomised. Protected data exists from disease auditing programmes such as Welfarm from a large number of New Zealand farms. However, these farms voluntarily sign up to these programmes and are potentially a biased population of farms. In this project, farms were randomly selected from eight major dairy regions. We were pleased to report that not a single farmer declined to be involved in the study. This was unexpected but provides confidence that farmers do really want to know the lameness status of their herd. If a practical, cost-effective solution for lameness detection can be produced, then this response gives confidence that many New Zealand farmers may take advantage of it.

It can now be reported that New Zealand dairy cattle have some of the lowest lameness prevalence anywhere in the world, and that prevalence may even be decreasing. The median farm-level prevalence of 2.8% from 120 farms is significantly lower than the 6.7% reported by Fabian *et al.* (2014). We would like to see the DairyNZ Health Hoof documentation updated to a median of 2.8% (currently at 8.1%), and to seek help if above 4.5% (currently at 10%), to give farmers and animal health advisors more realistic and relevant information on expected lameness prevalence data.

One of the major aims of the prevalence study was to provide benchmarking metrics for the New Zealand dairy industry. Whilst we achieved the goal of updating the prevalence of lameness across New Zealand, we also unearthed data that question the value of sporadic lameness prevalence scores of farms to identify farms with large lameness problems at any given time. The range between farms was not unexpected, with a sigmoid curve of prevalence apparent where the best and worst 10% of farms were considerably removed from the median farm. This is a common finding in animal disease prevalence studies and has been reported in New Zealand previously for cattle diseases and outcomes (Cuttance *et al.* 2017a; Cuttance *et al.* 2017b). However, we also reported a very large range of differences in prevalence between the two scores within the same farm. The difference in lameness prevalence between spring and summer ranged from a 12.3% reduction in lameness prevalence to a 7.6% increase. These farms were not provided data on their prevalence result during the study, and no advice was given from the study personnel on managing lameness. Therefore,

it is unlikely that being involved in this study altered their behaviour. Most farms that were above 4.5% lameness prevalence at one score were unlikely to be above 4.5% at another score, questioning the value of a one-off prevalence as an audit to identify farms with lameness problems. This is a sentiment that has been echoed in the United Kingdom (Archer *et al.* 2010).

Instead, I recommend that the NZ dairy industry communicates the value of LS in two different areas. Firstly, automated repeated real-time lameness monitoring needs to be considered as a critical part of the future success of lameness control programmes (Alsaaod *et al.* 2019; O'Leary *et al.* 2020). Whilst there are still practical considerations and solutions needed, on-farm technology is undergoing a rapid uptake on New Zealand dairy farms, particularly in the South Island (Dela Rue *et al.* 2020). Automated lameness detection systems offer the panacea of lameness detection solutions, whereby real-time prevalence and incidence measures within farm and between farm can be reported, individual lame animals can be identified early and then drafted for treatment, response to lameness treatment tracked and metrics provided on the success of a control plan. However, investment in these technologies, and their practical implementation will require multi-party involvement.

Secondly, the industry could promote lameness scoring as a method to identify and treat lame animals, rather than an auditing tool. The main purpose of lameness scoring has historically been for auditing and monitoring purposes, both internationally and locally, with very little uptake by farmers. Only one of 99 Irish farmers reported that they undertook lameness scoring on their farm (Browne *et al.* 2022), and we report over three quarters of the 119 in this project did not have any formal dedicated lameness identification systems in place on farm. Without formal systems in place, the evidence is clear that farmers do not identify the majority of lame animals on a given day compared to a trained observer (Sadiq *et al.* 2019). This association is as apparent in New Zealand as anywhere else, where on a given day, farmers identified a median of 27% of lame animals as defined by a trained observer (Fabian *et al.* 2014) and took a median of almost three weeks to identify lame animals (Alawneh *et al.* 2012). There is no evidence that pasture-based farmers (Fabian *et*

al. 2014; Bran *et al.* 2018; Beggs *et al.* 2019; Ranjbar *et al.* 2020) are any better at identifying lame animals than farmers in housed systems (Espejo *et al.* 2006; Leach *et al.* 2010; Cutler *et al.* 2017).

The message is clear that formal lameness identification is required to be able to identify lame cows early. However, the goals for achieving this need to be acknowledged and addressed, and the farmer and cow need to be front-of-mind when these tools are being suggested and implemented. Merely recommending these tools are used is not sufficient, as this does not consider the most important barrier to lameness control, farmer time (Mason *et al., submitted*) For dedicated lameness identification to be considered a success, a farmer only needs to identify more lame animals than they currently are. Thus, the low-hanging fruit for improving lameness management in New Zealand is to encourage farmers to do *any* lameness scoring, even if it is just, for example, half of the herd once a month.

Much is made of the seasonality of lameness, and in the authors experience, is an oft-use excuse for an increase in lameness - “I always get lameness in October, there is nothing I can do about it” (Waikato dairy farmer, anonymous, personal communication). However, the evidence for seasonality is weak. Gibbs (2010) reported an increase in farmer-reported lameness incidence in January (mid-late lactation, summer) compared to other months. However, the difference between the incidence risk between months was not large, and the farms were located entirely within the Canterbury region of NZ. Lawrence *et al.* (2011) reported a peak in October (peak lactation, spring), although this was from a case series of cows treated by a veterinarian, with no denominator, entirely within one region of New Zealand. This is not strong data that a seasonal pattern exists, with no data comparing lameness between seasons across New Zealand available prior to the work conducted in this current project.

Seasonality has been reported in other ‘pasture-based’ systems, such as Ireland and England (Laven and Lawrence 2006; O’Connor *et al.* 2020; Browne *et al.* 2022). However, these systems also include a period of housing, with seasonality strongly confounded by the period of housing. Thus, in these systems, seasonality of lameness is understandable. In New Zealand, season is confounded by stage of lactation, where although the majority of cows are managed on pasture over the winter, most of these are not lactating.

Although we reported an interaction between season and region, this was not as simple as North Island farms peaking in spring and South Island farms peaking in summer/autumn, as previously mooted. When comparing the change in lameness prevalence between two lameness scores carried out in spring and summer on the 120 enrolled farms, there was little difference in the LS within farm on the majority of these farms. Thus, there are clearly many more factors beyond 'season' that are influencing lameness, and suggestion that lameness peaks at certain times in some regions and different times in other regions is too simplistic and not a useful narrative for controlling lameness in New Zealand.

Finally, the prevalence estimates are only a snapshot in time, and like any good disease monitoring metric, these values should be updated as more information becomes available. We propose that the best use of these lameness prevalence estimates is to challenge veterinarians and farmers to understand the lameness situation on *individual* farms. We can say with confidence that the overall New Zealand lameness prevalence is low, but an individual farm could be between 0% and 17%, with little predictive ability by farmers to understand the true status on their farm (Mason *et al., submitted*). And even if a farm has the *'average'* lameness prevalence of ~3%, we should be asking the question to a farmer *"would you be happy with 3% of your herd lame on any given day across the year?"*. I would suggest that if the disease in question was mastitis, farmers would both not be happy with the prevalence and also know their current mastitis prevalence. With lameness, the majority of New Zealand dairy farmers do not know the true lameness status on farm. Knowing prevalence and incidence of disease is a critical first step at controlling a disease. Thus, our biggest hurdle, and also our biggest opportunity, is to increase awareness and monitoring of lameness on New Zealand dairy farms.

8.3 Duration of Lameness

From an epidemiological perspective, prevalence, incidence rate and duration of disease are inherently related; incidence rate is the product of prevalence and duration. Therefore, if duration of lameness can be reduced, then the prevalence of lameness will reduce. There is also data suggesting that a reduced duration of lameness could be associated with a reduction in incidence rate. In fact, a previous case of lameness has been reported to be the single biggest predictor of a future case of lameness (Newsome *et al.* 2016; Mason 2017; Randall *et al.* 2018). A "get lame-stay lame" hypothesis has also been proposed in the USA (Cook and Nordlund 2009). Claw-horn lameness is associated with exostosis of the weight-bearing plantar surfaces of the pedal bone, and that this is associated with increased risk of future lameness (Newsome *et al.* 2016; Figure 8.2). Thus, appropriate treatment of lameness can become a preventative measure (Pedersen and Wilson 2021).

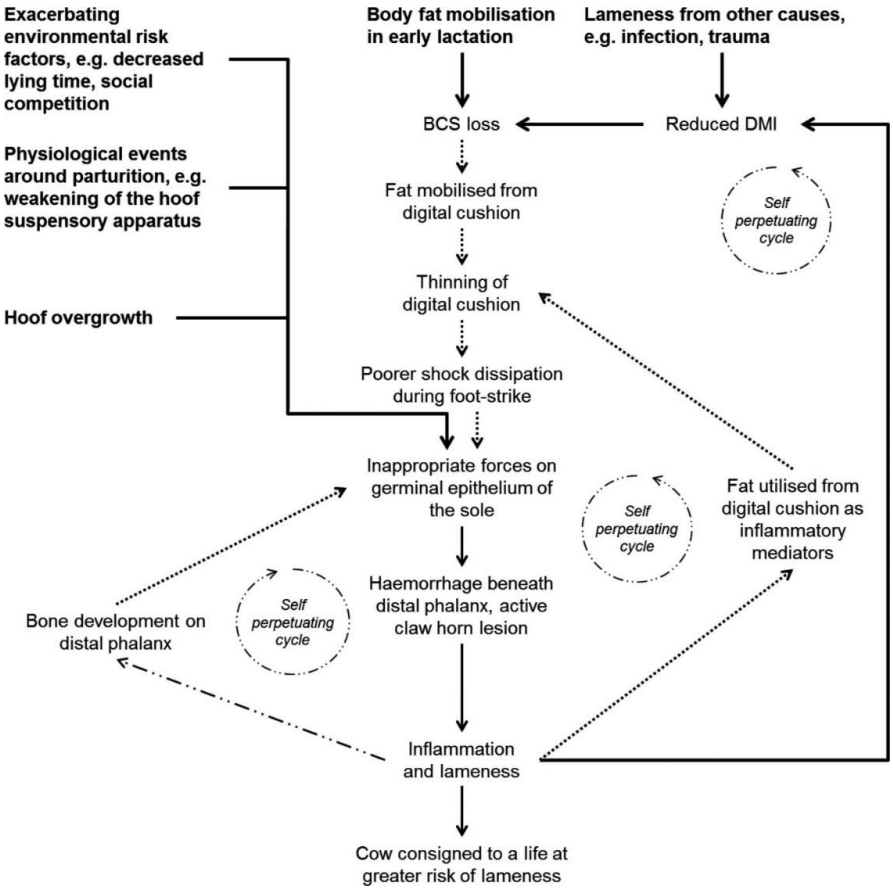


Figure 8.2 Proposed pathogenesis of claw-horn lameness in dairy cattle (Newsome et al. 2016). Used with permission

We reported rapid cure rates from 241 lame cows across five farms, with a median of 18 days taken from enrolment to become sound and a median of seven days to become non-lame (Mason *et al.* 2023). It is important to stress that whilst Mason *et al.* (2023) provided free veterinary treatment of lame animals, no advice or assistance in identifying lame animals was provided. The authors could not identify more rapid cure rates of lameness in controlled studies anywhere in the world, even when lame animals were identified promptly (Thomas *et al.* 2015; Miguel-Pacheco *et al.* 2017). Between 24 - 55% of animals had lameness score = 0 at 35 days post treatment in Thomas et al. (2015); in comparison, 90% of animals in our study had a lameness score = 0 at 35 days. We also reported a difference in the hazard of cure between farms. As the treatment and enrolment were the same between farms, we infer this farm difference may be due to the farmer identification of lameness and previous lameness history.

Acknowledging the external validity limitations of lameness cure rates from just five farms within the Waikato, we can still be confident that due to high internal validity of the study that these cure rates are 'real' and possible on New Zealand farms. From our findings, we propose that if an animal is still lame (LS ≥ 2) for greater than one week after, then it should be re-examined by the farmer or, ideally, a veterinarian. Furthermore, if more than 50% of animals are still lame after seven days post treatment on a farm, then this can be used as a guide to suggest improvements in the identification, treatment and/or recovery management of lame cattle.

These rapid cure rates also provide further evidence that managing lame cows on pasture is beneficial for hoof health, and this short duration of lameness is certainly responsible for at least part of the low prevalence of lameness we reported (Mason *et al*, *submitted*). In order to maintain, and even reduce lameness prevalence, emphasis should be placed on the recovery management of lame cows, with farmers, in consultation with their veterinarians, producing lameness recovery protocols. Next steps could also include conducting clinical trials or observational studies on the benefits and costs of commonly implemented control strategies, such as milking once-a-day and running designated lame herds, and their associations with lameness outcomes and farm efficiency.

8.4 Farm-level risk factors and treatment protocols for lameness

DairyNZ, the New Zealand dairy farmers levy board, have produced an excellent lameness management program, The Healthy Hoof programme (https://www.dairynz.co.nz/animal/cow-health/lameness/healthy-hoof/, accessed 12 August 2023). The Healthy Hoof programme involves a training and certification component, as well as resources on treatment and prevention of lameness. However, the update of the programme has been limited (Katie Saunders, pers. Comm) and the recommendations provided in the resources are primarily based on expert opinion, rather than empirical evidence. Thus, investment into

identifying more risk factors that can be manipulated to reduce the prevalence and incidence of lameness on New Zealand dairy farms is critical.

We identified strong associations for the odds of lameness with the use of a concrete stand-off pad and season of peak lameness. In 100% of samples, the risk of lameness increased on farms that used concrete stand-off pads during periods of inclement weather, with a most likely value of an increase in odds of lameness by 49%. The code of dairy cattle welfare has acknowledged the welfare concern that standing cows off on concrete has by updating Minimum Standards 9: *"where dairy cattle are kept in off-paddock facilities for more than 16 hours a day for more than three consecutive days they must be provided with a well-drained lying area with a compressible soft surface or bedding that is maintained to avoid manure accumulation, and artificial or natural shelter or other means of minimising the effects of exposure to the weather"* (Code of Welfare Dairy Cattle; https://www.mpi.govt.nz/dmsdocument/46024-Code-of-Welfare-Dairy-cattle accessed 12 August 2023).

Although this is an acknowledgement that the use of concrete stand-off pads limits the natural behaviours of dairy cattle, and results in negative animal wellbeing, we believe that the update to the minimum standards does not go far enough. If it is a standard farm practice to stand cows off during period of inclement weather, then the farm should provide a surface that can satisfy their natural need to lie down (Webster *et al.* 2015). Concrete stand-off pads should not be used for any longer than six hours, over a 24-hour period, if at all. Practical, effective and cost-conscious options exist, including wood-chips and rubber matting (Schütz and Cox 2014; Webster *et al.* 2015), and this should be discussed and encouraged to all farms that regularly use stand-off pads as part of pasture management.

In my study (Mason *et al., submitted*), over three quarters of farmers reported they had some form of lameness control plan. However, most of the answers to the text portion of this question suggested that the plans they had in place were informal guidelines on how to handle lame cattle. Thus, the proportion of farmers that had formal lameness management plan was likely much lower, and likely similar to, or lower than, the 15% of Irish dairy farmers who had a herd-health plan that included lameness (Browne *et al.* 2022a).

In addition, only 23% of farmers in Mason et al. (submitted) reported they used formal lameness identification methods on farm (either lameness scoring and/or precision livestock technology). These two points alone provide ample opportunity to farmers and veterinarians. One of the major advances in disease prevention on dairy farms has been the development of farm-specific disease control plans (LeBlanc *et al.* 2006). The creation of farm-specific lameness control plans, complete with farmer goals and targets, should be the first step of all lameness control programmes, and is applicable whether a farm does or doesn't have a lameness problem (Figure 8.3). As the primary source of advice for lameness management, veterinarians are in the ideal position to be initiating this service for all of their dairy farming clients.

Figure 8.3 The health management cycle proposed by LeBlanc et al. (2006), illustrating the conceptual framework by which monitoring and continued improvement of specific management areas on a dairy farm – this is pertinent to lameness control.

Finally, despite identifying clear areas of improvement that can be implemented on NZ dairy farms, we acknowledge that the majority of the variance in lameness prevalence between farms was not explained. Thus, until we are able to explain where this variation can be partitioned to, we hypothesise that an area with likely a bigger 'bang-for-your-buck' will be to improve the identification and treatment of lame cattle (Pedersen and Wilson 2021).

8.5 Review of NSAID treatment as part of lameness treatment

Up until the early 2010s, there was a critical lack of high quality scientific evidence for the treatment of claw-horn lameness (Potterton *et al.* 2012), and the aetiology of the majority of lameness cases in New Zealand (Lawrence *et al.* 2011; Mason *et al.* 2023). Over the past decade, this has been addressed, at least in part, by several research groups investing significant resources into the pathogenesis and treatment of claw-horn lameness (Thomas *et al.* 2015; Newsome *et al.* 2016; Sadiq *et al.* 2022; Wilson *et al.* 2022).

One of the major areas of interest has been to assess if lameness treatment protocols could be improved with the use of non-steroidal anti-inflammatory drugs (NSAIDs). NSAIDs are a family of compounds that all act by inhibiting the enzyme cyclooxygenase thus subsequently decreasing the release of prostaglandins (Laven *et al.* 2012). As of 2023, there are five NSAIDs licensed for use in New Zealand dairy cattle; flunixin, ketoprofen, meloxicam, carprofen and tolfenamic acid, with positive welfare trends seen in New Zealand in the use of NSAID in production animals and increase in usage being reported (Laven 2020). One possible unseen consequence of this trend is the confirmation bias from more welfare-conscious animal health advisors and farmers. It appeared to the author that the positive NSAID findings for an increase lameness cure at 35 days post treatment reported by Thomas *et al.* (2015) was not what was being reported by other authors (Whay *et al.* 2005; Laven *et al.* 2008). Yet it is the findings of Thomas *et al.* (2015) that are cited more than the others and used routinely in non-peer reviewed communications. It was this conflicting messaging that prompted a systematic review into the associations between NSAID drug use at the time of diagnosis and treatment of claw horn lameness in dairy cattle and lameness scores, algometer readings, and lying times (Mason *et al.* 2022b). In order to provide the best advice and the best chance for sustained farmer behaviour change, veterinarians must provide a 'united front' of the messaging and use of NSAIDs (Mills *et al.* 2017), and this was one of the drivers of the systematic review.

One of the major findings was the relative scarcity of evidence in the area, with only six studies included in the systematic review. Whilst there were a greater number of studies that investigated NSAIDs and lameness, the study population in many of these were in experimentally induced (non-claw horn lameness), and thus

excluded from the systematic review. Nevertheless, from this small number of studies, we were still able to conclude that there was no definitive evidence of the use of NSAIDs to improve LS and nociceptive threshold post treatment. This was particularly so in studies where the majority of cattle have been lame for an extended period of time prior to being diagnosed and treated (Laven *et al.* 2008; Thomas *et al.* 2016), similar to what happens in the commercial clinical setting. The only comparison group to report significant difference was that discussed above by Thomas *et al.* (2015), and then only when NSAID were used in combination with a hoof block. Therefore, this result is actually the outlier, not the norm, and its more frequent use as evidence of a benefit is an example of positive confirmation bias.

We speculate that the limited published data do not reflect the lack of a NSAID effect, but instead reflect the insensitive measures of assessing treatment response (i.e., LS) and the population of cows that we are routinely treating (i.e., chronically lame). The major difference between Thomas *et al.* (2015) and the other studies included in the systematic review was the chronicity of lameness; the enrolled population in Thomas *et al.* (2015) were acutely lame dairy cattle, whereas the study population in the other four studies were from animals that we would define as chronically lame. This is almost solely the population that veterinarians (and the hoof trimmers and farmers) are presented with in New Zealand by the time the farmer has identified and drafted the lame animals. To reinforce this theory, since the systematic review was completed, two new pieces of research have reported a positive association between NSAID treatment on LS (Sadiq *et al.* 2022; Wilson *et al.* 2022). Both studies enrolled acutely lame animals with claw-horn lesions and reported either a significant improvement in cure risks, in conjunction with a block, (Sadiq *et al.* 2022) or a trend for a reduction in repeat lameness (Wilson *et al.* 2022), in NSAID treated animals. Both of these studies provide further evidence for the hypothesis that early identification and effective treatment (involving both blocks and NSAID) can result in major improvements in the outcomes of lame animals (Pedersen and Wilson 2021).

With lameness identified as a severely painful condition in dairy cattle, immediate and short-term pain relief of identified lame animals is critical (Whay and Shearer 2017). The scope of the systematic review was of claw-horn lameness. Whilst there have been some studies demonstrating benefits in gait within hours of

NSAID treatment in experimentally-induced and lameness with no lesions defined (Wagner *et al.* 2017; Warner *et al.* 2021), there have been remarkably few studies investigating the impact of NSAIDs and acute pain responses in dairy cattle with claw-horn lameness. Where evidence does exist, however, is with hoof trimming. The act of trimming a hoof itself results in responses consistent with pain and stress, both in lame and non-lame animals (Sadiq *et al.* 2020), and that NSAID treatment at the time of hoof trimming can mitigate some of these (Chapinal *et al.* 2010). Thus, one of the better arguments for NSAID use actually comes from the 'first do no harm' mantra. As we are providing a treatment that itself is a painful husbandry procedure, the use of NSAID is justified and should be promoted by veterinarians (Stock and Coetzee 2015).

We did not investigate long-term outcomes associated with NSAID treatment of lame cows within the systematic review for the sole reason that none existed at the time of review. The findings of Wilson *et al.* (2022) has changed that. The inflammation process in response to mastitis in cattle can have pronounced negative long-term effects in dairy cattle, and appropriate treatment, including the use of NSAIDs, can result in pronounced longer-term positive outcomes for these animals, including reduced culling and improved 100-day in-calf rate (McDougall *et al.* 2009; McDougall *et al.* 2016). The negative long-term effects of lameness on reproduction and longevity in the herd are well documented and pronounced (Huxley 2013). Longer-term impacts of lameness consist of poorer reproductive outcomes, increased risk of culling and repeat lameness episodes, and it is around the reduced culling and potential for improved reproductive outcomes that there is great excitement. Wilson *et al.* (2022) report a 45% reduction in the hazard of culling in heifers treated with NSAID when diagnosed lame. This is a significant reduction, both statistically and biologically, in culling compared to lame animals not treated with NSAID. The fact that the effect was apparent in heifers, yet not in adult cattle (Wilson 2021), adds evidence that identifying lame animals early and treating appropriately will likely reduce their lifetime 'lameness burden'.

When the findings of Mason *et al.* (2022b) are combined with the recent studies and the addition of the short-term impacts of claw-trimming, there now exists evidence of positive short-, medium-, and long-term effects of NSAID use as part of lameness treatment (Figure 8.4). Our next challenge is how to encourage both early

identification of lameness to maximise the response to NSAID and increase the usage of NSAID for all lame cows.

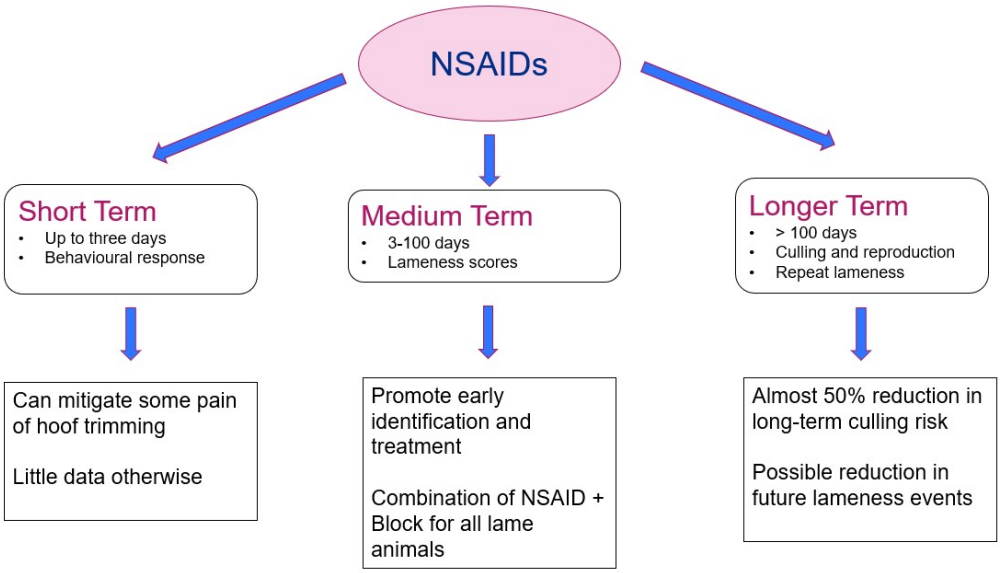


Figure 8.4 Short-, medium- and long-term outcomes of the effect of NSAID treatment at the time of treatment for dairy cattle diagnosed with claw-horn lameness

8.5 Preventing lameness in dairy heifers through a pre-calving hoof conditioning programme

Providing practical cost-effective solutions to reduce the incidence of lameness was one of the major goals of this project. However, randomised clinical intervention studies for lameness control and prevention are notoriously expensive and time consuming, often needing to be carried out over several years (Bergsten *et al.* 2015; Thomas *et al.* 2015; Wilson *et al.* 2022). Therefore, we only had one opportunity at selecting an

intervention to investigate. After much deliberation, it was decided that the pre-calving heifer would be the best group of animals to investigate. If the time to the first lameness case could be extended, then the evidence would suggest that this will result in an exponential reduction in the lifetime risk of lameness (Newsome *et al.* 2016; Randall *et al.* 2018). The specific intervention selected needed to be practical, be able to be undertaken by the farmer, be applicable to most farms in New Zealand and be based on strong scientific principles. We decided to investigate a pre-calving 'hoof conditioning programme' whereby dairy heifers were exposed to concrete and exercise immediately pre-calving.

The hypothesis of Mason *et al.* (2022a) was that if a heifer is exposed to external environmental stressors (i.e., concrete and walking long distances) over a period of time where the hoof is more able to withstand and adapt (pre-calving), this will enable the heifer to be able to withstand these external stressors that a lactating animal in New Zealand will be exposed to, during a period where the hoof is at its weakest (i.e., calving) (Tarlton *et al.* 2002; Knott *et al.* 2007). Specifically, we hypothesised that this intervention may increase sole soft tissue thickness, as described by Gard *et al.* (2015), and reduce the hazards of lameness across their first lactation.

No strong association was identified in either soft sole thickness or the hazards of lameness in animals in the intervention group compared to the control animals. Whilst a 'non-significant' effect can sometimes be seen as a negative result, we believe that this is a useful finding. This was a well-powered study carried out to high-quality randomised clinical study standards. The fact that we did not identify associations provides confidence to dairy farmers and animal health providers that undertaking pre-calving hoof conditioning as described in Chapter 6 is unlikely to result in large changes in their lameness incidence, and that their resources may be better spent elsewhere with lameness control.

It is possible that our intervention of one hour a day on concrete and 1 km walked on farm tracks for five days a week, for five weeks pre-calving may not have been sufficient enough to induce the changes required. That little difference in sole soft tissue thickness existed between animals in the control and treatment groups adds evidence to this theory. The intervention was decided on as a compromise between minimising the risk

of harm and ensuring practicality, and also having enough power to identify a positive difference. We did not want to extend time on concrete for too long, as there is evidence that an extended period of time on concrete around the transition period can result in large lameness issues (Mason *et al.* 2012). Future research may now have confidence that the length of time on concrete and/or the distance walked may be able to be increased without too greater risk of increasing lameness. We also stress that whilst we did not report any positive improvements in hoof health, we also did not report any negative effects either. The evidence of the harm that we can do is still apparent (Mason *et al., submitted)*, so minimising the exposure to concrete surfaces during and after the calving period should be encouraged (Knott *et al.* 2007; Mason *et al.* 2012).

8.6 Farmer motivators and barriers to lameness control

To make a large difference in the incidence of a farm-animal disease, a preventative or therapeutic action needs both high efficacy, and also a wide-spread uptake of the practice (Mills *et al.* 2017; Biesheuvel *et al.* 2021; Figure 8.5). The harsh reality is that, despite claw-horn lameness being one of the major animal health and welfare concerns of dairy cattle farming internationally (Huxley 2013), there are few control methods that provide both high efficacy and widespread uptake. This is no more evident than the recent reports of ~25% of dairy cattle lame at any point in time worldwide (Afonso *et al.* 2020; Thomsen *et al.* 2023). The review of NSAID use presented earlier in this summary, and early identification of lameness (Pedersen and Wilson 2021) strongly suggest that large improvements in lameness can be made with what can appear as 'simple' critical control points – identify lame cows early and provide lame cows with NSAIDs. However, expecting farmers to do this just because they are told to do it would be naïve, and will fail (Bell *et al.* 2009; Browne *et al.* 2022; Mason *et al., submitted*).

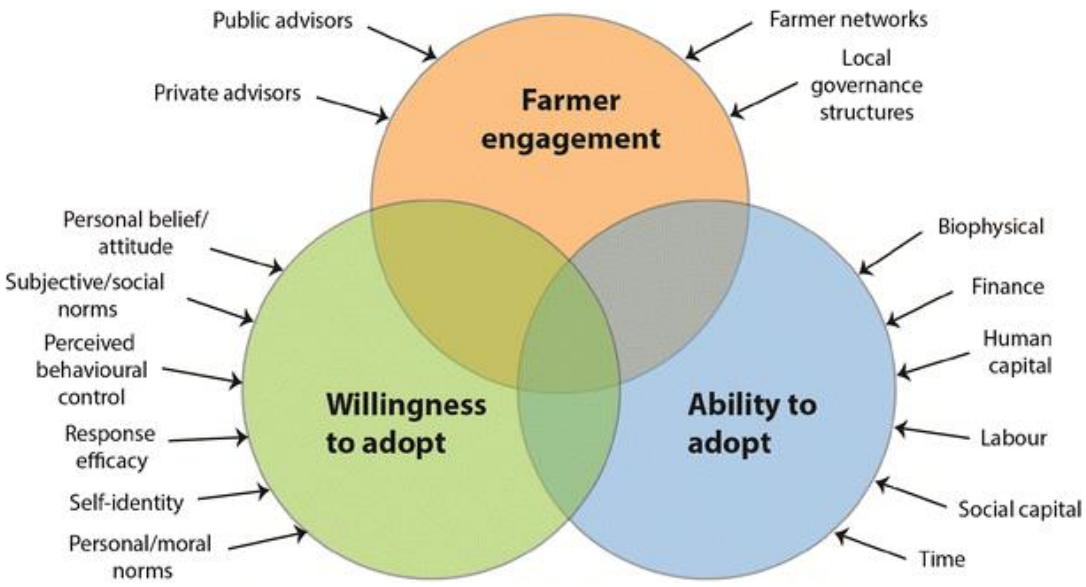


Figure 8.5 Factors influencing farmer decision-making, from Mills et al. (2017)

Our approach, instead, was to ask the main stakeholders, the farmers, what they believe are the barriers to controlling lameness on their farm and the factors that motivate them to control lameness. Farmers are a critical piece of the puzzle in disease control (Kristensen and Jakobsen 2011; Biesheuvel *et al.* 2021) and often underappreciated and underrepresented in lameness disease control and research. Involving farmers in the process of lameness control has resulted in greater acknowledgement of lameness problems on farm (Main *et al.* 2012), and subsequent reduction in lameness prevalence (Main *et al.* 2012; Chapinal *et al.* 2014). True lameness control success is thus likely to be in the form of interventions that influence farmers' behaviour in regard to lameness control (Green *et al.* 2020; Biesheuvel *et al.* 2021). If we can identify the key barriers and motivators to lameness control, we can apply control methods and solutions that address these key areas, rather than what often happens where a solution is provided by researchers that farmers either cannot or will not implement, regardless of the evidence of the effect.

8. Conclusions

New Zealand dairy farmers reported that time was the most important barrier to lameness control, in agreement with data from UK dairy farmers (Leach *et al.* 2010), followed closely by skilled labour. Thus, suggesting a control method that involves a large on-farm labour contingent is likely to fail. This is pertinent to early identification and treatment, which require both time and skilled labour – a farmer is unlikely to buy into this suggestion without these two barriers being addressed. Critically, animal health advisors such as veterinarians and hoof trimmers can offer their services to remove both of these barriers. This can result in a win-win-win for the cow, the farmer and the animal health professional. The cow gets treated by a skilled operator, the farmer, who wants to control lameness, gets the solution sorted for them and the animal health provider obtains income from providing the service. In the author's experience, whenever he has offered to assist a farmer with their lame cow treatment when they were dealing with an outbreak, this offer has never been turned down.

Following on from this point, another critical learning from this project was that animal health professionals, such as veterinarians, should not assume that cost is a major barrier to lameness control. Granted, surveys will often result in responder bias with questions about the cost of a service. However, regardless of any potential responding bias here, farmers are expecting veterinarians to provide the farmer with the best advice, regardless of cost. Veterinarians were ranked as the most trusted advisor for lameness information by a considerable margin, and if veterinarians can have a 'united front' on the advice and services being provided, the uptake of lameness control plans will be greater.

Other key messages we reported were that farmers ranked all potential motivators to lameness control as important and the most important impacts of lameness, from a farmer's perspective, were cow-related factors such as pain and production, with farm and industry impacts of less importance. Farmers place different weightings of importance on barriers to lameness control compared to motivators for lameness control and the importance that farmers place on barriers, motivators and impacts of lameness were poor predictors of farmers' belief regarding their lameness problem, or actual lameness prevalence.

Finally, we reported that, despite relatively low lameness prevalence, many New Zealand dairy farmers believe lameness is a problem on their farm, and they rank welfare impacts of lameness of high importance. To investigate how farmer behaviour change can be used to manage lameness, future studies should consider theoretical social science frameworks beyond the theory of planned behaviour, and/or involve prospective interventional studies investigating farmer actions instead of beliefs. The control of lameness in sheep in the United Kingdom provides a great example of veterinary science and social science working together to alter farmer, and veterinary, behaviour to improve outcomes for lame sheep (Higgins *et al.* 2013; Green *et al.* 2020). Following in their footsteps would provide an excellent next step for the future of lameness research in New Zealand.

8.7 Summary

The combination of the lower-than-expected lameness prevalence and the rapid time to lameness cure reported during this body of work provide an excellent *'good-news'* story for the New Zealand dairy industry. Whilst still acknowledging that many improvements in lameness management can be made, it is important to acknowledge that on a global scale, New Zealand dairy industry has one of the lowest, if not *the* lowest, lameness burden of any developed dairy nation. And that despite this low lameness burden, New Zealand farmers feel strongly about having a lameness problem on their farm and have a strong desire to minimise the animal welfare consequence of cattle lameness.

The major unanswered question from this project is how do we combine the findings into a coherent story of how we can continue to have a low lameness burden, and even reduce lameness further on New Zealand dairy farms? There are two main areas that we would like to investigate next to assist with this question, improving treatment outcomes of lame cows, and further investigations into farmer behaviour. As there is mounting evidence that prompt and effective early treatment may in itself act as a preventative strategy for future lameness events (Newsome *et al.* 2016; Pedersen and Wilson 2021; Wilson *et al.* 2022), we need to

establish the return on investment for a farmer for this strategy. This is likely also an intervention that should have benefits across dairying systems and lesions, although this hypothesis still needs assessing in New Zealand.

Following on from the farmer behaviours survey, a logical next step would be to attempt to replicate, in part, the work that Green and colleagues in the UK have carried out on footrot treatment in sheep (Higgins *et al.* 2013; O'Kane *et al.* 2017; Green *et al.* 2020). A combination of surveys, questionnaires, one-on-one interviews, randomised interventional studies, and focus groups with multi-disciplinary stakeholders all came together to result in profound and sustained farmer behavioural change and associated reduction in sheep lameness. Whilst this would be a massive undertaking to repeat with cattle lameness in New Zealand, the first part has already been achieved by carrying out quantitative questionnaires on farmer beliefs and lameness prevalence surveys. We now have a much better understanding of the lameness prevalence and the barriers and motivators of farmers in regard to lameness. A focus on early identification and effective treatment would be an ideal starting point for the second stage, following on the same success for footrot treatment in sheep. Provided that research into early identification and treatment does show large improvements, the implementation and uptake of it requires input from multiple stakeholders. Early identification is synonymous with treating more lame cows earlier, and thus more time and skilled labour required in the short-term at least. The applied solutions to these problems will require the 'buy-in' of multiple stakeholders and where the one-on-one interviews and focus groups will provide the greatest benefit.

Like with any good research project, it is tempting to conclude that *more research is needed*. Whilst undoubtably this is the case here, concentrating on a few key findings from the research is an appropriate conclusion:

1. The median farm-level prevalence of lameness was 2.8%, lower than almost any previously published dataset on cattle lameness prevalence.

2. The range of lameness on a given day was between 0% and 17%, and an interquartile range of 1.5% to 4.5%

3. A lack of seasonality of lameness was apparent on most dairy farms, with a change in lameness prevalence from spring to summer scores between -1.8% to 1.0% on half of the farms

4. A one-off lameness score provides very little information for an audit trying to identify farms with a severe lameness problem. We reported that most farms that had a lameness prevalence above 4.5% at one score were unlikely to be above 4.5% at another score.

5. Duration of lameness on five New Zealand dairy farms undergoing best-practice lameness treatment methods was shorter than any previously reported lameness cure-rates. A median time to soundness of 18 days and a median time to non-lame of 7 days was reported; 50% of animals were diagnosed as non-lame within seven days post treatment. We also identified different cure rates between farms, highlighting that monitoring recovery rates may be a useful tool for animal health professionals to identify farms where treatment and identification of lameness may be sub-optimal.

6. Despite the low lameness prevalence, New Zealand dairy farmers still do care strongly about the welfare of lame animals. The most important impacts of lameness, from a farmer's perspective, were cow-related factors such as pain and production, with farm and industry impacts of less importance. Time and skilled labour are the most important barriers to lameness control on farm.

7. Farmer belief of their lameness problem is a poor predictor of lameness prevalence. We cannot rely on farmers to tell us if they have a lameness problem, nor, their lameness incidence risk across the season.

8. Veterinarians are the primary sources of advice for lameness treatment and prevention on New Zealand dairy farms, with 89% of responding farmers selecting veterinarians, over double the next source.

9. A pre-calving 'hoof conditioning' programme involving dairy heifers standing on concrete for an hour and walking 1km along farm tracks for five weeks pre-calving did not result in a reduction in lameness incidence during their first lactation.

10. The practice of using concrete stand-off pads should cease across New Zealand. Appropriate cost-effect alternative solutions exist, and farmers should be encouraged to move to these systems.

11. The combination of early identification and effective treatment of lame cows (consisting of NSAIDs and blocks) increase lameness cure risk by 2 times, and NSAIDs have been associated with a large reduction in the culling risk of lame animals in the United Kingdom. The use of NSAIDs without blocks in chronically lame animals is unlikely to result in any improvement in lameness cure rates.

12. The survey of farm lameness management practices revealed there are ample opportunities to improve the education of farmers, and animal health advisors, with respect to lameness identification. The dairy industry should move away from using lameness scoring as an audit tool, and instead promoting lameness scoring, and/or automated lameness identification, as a means to improve the identification and subsequent treatment, of individual lame animals.

It is my hope and desire that these learnings are added to the body of research on New Zealand and are taken up by the New Zealand dairy industry. In particular, achievable lameness prevalence metrics should be updated to those reported here, with a lower prevalence threshold of ~5% indicating a lameness concern on farm. The unawareness of the lameness problem on farm by both the farmer and animal health advisors should be the first area to be addressed when undertaking a lameness investigation. Farmers should be encouraged to treat lameness identification as a dedicated task, and early identification and prompt effective treatment of lameness stressed.

8. Conclusions

As the most trusted advisor for lameness treatment and prevention, the veterinarian has a duty to play a critical role in improving lameness control, whilst being cognisant of the major farmer barriers of lameness control of time and skilled labour. When planning lameness control programmes, it is important that the veterinarian considers that farmers care more about the impact that lameness has on the wellbeing of their animals than the impact lameness has on farm productivity and the greater dairy industry, and that the cost of a prevention plan should not be seen as a major deterrent. Farmers are after veterinarians to provide the best advice; the farmers will then make the judgement call on the cost-benefit of the solution. Annual consultations between dairy farmers and veterinarians provide a great opportunity to discuss and plan for lameness control across. Rather than merely asking how many lame cows the farmer thought they had for the season, this is the time to develop a clear and defined plan for identifying and recording lame cows, something that is currently lacking on the majority of dairy farms. This seems almost too simple, but I believe one of the biggest wins we can have nationally is just to start talking to farmers about lameness; it is currently left to a handful of veterinarians and hoof trimmers that are passionate about the topic. These consults can include discussing the benefits of early identification and treatment (e.g., improved lameness cure rates, reduced incidence of lameness and reduced culling) and solutions for early identification (e.g., the use of automated lameness identification technology and/or providing the services of veterinary technicians for the identification and treatment of lameness). Finally, a veterinary practice can offer the farmer a solution to their two biggest barriers to lameness control, time and skilled labour. This is a great opportunity for veterinary clinics to expand their offering, with the development of a ‘lameness identification and treatment service’ through a team of paraprofessional hoof-trimmers, under the guidance and prescribing powers of a veterinarian. I believe that the only way to achieve continued and meaningful reduction in lameness across New Zealand dairy farms is for multiple groups working together with the aim of reducing the impact of lameness on farm.

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Appendices

A

Statements of Contribution

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GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Winston Mason
Name and title of main supervisor:	Professor Richard Laven
In which chapter is the manuscript/published work?	2 - Prevalence

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

The student obtained funding, designed the proposal and protocol, managed and oversaw the data collection, analysed all outcomes and wrote the first draft of the manuscript. They were also the primary person responding to reviewer comments

Please select one of the following three options:

(●) **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

Mason, W., K. Müller, J. Huxley, and R. Laven. 2023. Prevalence of lameness on pasture-based New Zealand dairy farms: An observational study. Prev. Vet. Med. 220:106047. https://doi.org/10.1016/j.prevetmed.2023.106047 . This is embargoed from inclusion in the University repository until November 2024

( ) **The manuscript is currently under review for publication**

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Student's signature:	Winston Mason Digitally signed by Winston Mason Date: 2024.02.02 14:02:34 +13'00'	Main supervisor's signature:	Rlaven Digitally signed by Rlaven DN: cn=Rlaven, c=NZ, email=r.laven@massey.ac.nz Date: 2024.02.02 14:35:17 +13'00'

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We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Winston Mason
Name and title of main supervisor:	Professor Richard Laven
In which chapter is the manuscript/published work?	3 - Duration

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

The student obtained funding, designed the proposal and protocol, managed and oversaw the data collection, analysed all outcomes and wrote the first draft of the manuscript. They were also the primary person responding to reviewer comments

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Mason W, Laven LJ, Cooper M, Laven RA. Lameness recovery rates following treatment of dairy cattle with claw horn lameness in the Waikato region of New Zealand. New Zealand Veterinary Journal 71, 226-35, 2023

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Student's signature:	Winston Mason Digitally signed by Winston Mason Date: 2023.09.04 16:40:37 +12'00'	Main supervisor's signature:	Rlaven Digitally signed by Rlaven DN: cn=Rlaven, c=NZ, email=r.laven@massey.ac.nz Date: 2023.09.05 09:20:42 +12'00'

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Student name:	Winston Mason
Name and title of main supervisor:	Professor Richard Laven
In which chapter is the manuscript/published work?	5 - NSAID systematic review

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

The student obtained funding, designed the protocol, managed and oversaw all stages of systematic review and wrote the first draft of the manuscript. They were also the primary person responding to reviewer comments

Please select one of the following three options:

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  Mason W, Cuttance E, Müller K, Huxley J, Laven R. Graduate Student Literature Review: A systematic review on the associations between nonsteroidal anti-inflammatory drug use at the time of diagnosis and treatment of claw horn lameness in dairy cattle and lameness scores, algometer readings, and lying times. Journal of Dairy S

- ( ) **The manuscript is currently under review for publication**

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Name and title of main supervisor:	Professor Richard Laven
In which chapter is the manuscript/published work?	6 - Heifer intervention

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Mason W, Huxley J, Laven R. Randomized clinical trial investigating the effect of exercise and standing on concrete prior to first calving on time to first lameness event in dairy heifers. Journal of Dairy Science 105, 7689-704, 2022

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Name and title of main supervisor:	Professor Richard Laven
In which chapter is the manuscript/published work?	7 - Farmer barriers

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Mason, W. A., L. J. Laven, J. N. Huxley, and R. A. Laven. 2023. Can lameness prevalence in dairy herds be predicted from farmers' reports of their motivation to control lameness, and barriers to doing so? An observational study from New Zealand. J. Dairy Sci. https://doi.org/10.3168/jds.2023-23862

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