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INVITED REVIEW: Prevalence, risk factors, treatment, and barriers to best practice adoption for lameness and injuries in dairy cattle: A narrative review

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ABSTRACT

Lameness and leg injuries are both painful and prevalent across the dairy industry, and are a major welfare concern. There has been a considerable amount of research focused on investigating the risk factors associated with lameness and injuries and how they might be prevented and treated. The objectives of this narrative review were to summarize herd-level prevalence estimates, risk factors, strategies for prevention, control, and treatment of these conditions, and the barriers to best practice adoption for lameness and injuries on dairy farms. There is a relatively high within-herd prevalence of lameness on dairy farms globally, with a recent systematic review estimating the mean prevalence at 22.8%. Similarly, there is a relatively high prevalence of hock injuries, with within-herd estimates ranging from 12 to 81% of cows affected. Knee and neck injuries have been reported to be less common; 6–43% and 1–33%, respectively. Numerous risk factors have been associated with the incidence of lameness, notably housing (e.g., access to pasture, bedding depth, bedding type, flooring type, stall design), management (e.g., stall cleanliness, frequency of trimming, holding times, stocking density), and cow-level (e.g., body condition, parity, injured hocks) factors. Risk factors associated with hock injuries can be similarly classified into housing (e.g., bedding type and depth, outdoor access, parlor type, stall design), management (e.g., bedding depth, cleanliness), and cow (e.g., parity, days in milk, lameness) factors. Key preventative approaches for lameness include routine preventative and corrective hoof trimming, improving hoof cushioning and traction through access to pasture or adding rubber flooring, deep-bedded stalls, sand bedding, ensuring appropriate stocking densities, reduced holding times, and the frequent use of routine footbaths. Very little research has been conducted on hock, knee, and neck injury prevention and recovery. Numerous researchers have concluded that both extrinsic (e.g., time, money, space) and intrinsic (e.g., farmer attitude, perception, priorities, and mindset) barriers exist to addressing lameness and injuries on dairy farms. There are many diverse stakeholders in lameness and injury management including the farmer, farm staff, veterinarian, hoof trimmer, nutritionist, and other advisors. Addressing dairy cattle lameness and injuries must, therefore, consider the people involved, as it is these people who are influencing and implementing on-farm decisions related to lameness prevention, treatment, and control.
KEYWORDS: animal welfare, dairy cattle, lameness, injuries

INTRODUCTION

Lameness in dairy cows is a common multifactorial condition defined as any painful condition that causes a cow to change the way she walks to limit the amount of weight placed on affected limbs (Solano et al., 2015). This condition is a leading animal welfare concern in the dairy industry and represents a significant challenge due to the complex set of environmental, management, and cow-specific factors that contribute to its occurrence. Several behavioral and physiological changes have been associated with lame cows, including reduced consumption of feed DM, reduced meals per day, reduced milk production, increased likelihood of cystic ovaries and delayed cyclicity, poorer reproductive performance, and increased chance of being culled (Huxley, 2013; King et al., 2017), in addition to being in pain and distress (Kleinhenz et al., 2021). Due to these changes, lameness can have a substantial economic impact on dairy farms, with reported cost estimates between $120 and $216 USD per case (Cha et al., 2010).

Injuries to the hock (tarsus joint), knee (carpus joint), and neck of dairy cattle represent similar concerns for the dairy industry, as they are widely accepted as being painful and a welfare concern (Huxley and Whay, 2006). Leg injuries, in particular, have been associated

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with decreased lying time and production (Rushen et al., 2007; Robichaud et al., 2019). While more research is needed to verify the causal relationships between injuries and these types of outcomes, there appears to be an opportunity for farmers to improve welfare and economic margin per cow if the prevalence of injuries is reduced. However, comparatively little research has been conducted with a focus on injuries, with few studies in which prevalence has been estimated and fewer still focused on prevention and treatment.

Lameness and injuries represent an important on-farm challenge from a cow welfare and productivity perspective; they also represent key risks to the industry from a customer and consumer perspective. As easy to recognize abnormalities and known welfare concerns, lameness and injuries have become an increasing focus of the dairy industry supply chain. Globally, the dairy industry has developed quality assurance programs to aid in meeting the expectations of the public with respect to how animals are raised. The vast majority of quality assurance programs, including Farmers Assuring Responsible Management (FARM) in the US, proAction in Canada, and Red Tractor in the United Kingdom, have specific requirements for the prevention and treatment of lameness and body injuries; often with on-farm assessments being conducted to estimate the prevalence of these conditions. Farms exceeding these program thresholds are then often required to implement corrective actions to address identified issues.

Despite considerable research and industry emphasis on these conditions over the past several decades, lameness and injuries remain prevalent on the majority of dairy farms in industrialized dairy countries. Furthermore, researchers have demonstrated that lameness is consistently underestimated by farmers; with true prevalence estimates often 2 to 4 times higher than farmer estimates (Cutler et al., 2017; Sadiq et al., 2019). While new technologies are being explored to aid in the automated assessment and identification of lame and injured animals, we would suggest that visual assessment remains the current best practice. Beyond identification of lame and injured cows, our understanding of the key risk factors that are associated with, and may contribute to, these conditions has grown considerably due to a large number of epidemiological studies over the past 25 yr. It is clear that several key management, housing, and cow-level factors contribute to the incidence of these conditions; however, identification of the specific factors contributing to any one issue on a specific farm can remain a challenge due to the interplay between several factors. Informed by these studies, industry has adopted recommendations for best practices around prevention and treatment; though the impact of these efforts is dependent on several factors from severity of cases, to farmer consistency in implementing changes.

The purpose of this narrative review is to provide an overview of the research on lameness and leg injuries in dairy cattle, with a specific focus on reviewing herd-level prevalence estimates, risk factors, strategies for prevention, control, and treatment of these conditions, and barriers to best practice adoption. As a systematic review on such a broad set of objectives would be impractical, we instead showcase the results from other recent syntheses, systematic literature reviews, and meta-analyses, many of which were conducted with a more narrow scope and objective, in addition to numerous primary sources to offer the reader an accessible synthesis of current knowledge to offer evidence-based messages for both academia and industry, and to identify current gaps in our understanding of these conditions.

ASSESSMENT AND PREVALENCE

Lameness

Upon exploring the most recent literature on the prevalence of lameness on dairy farms, it is clear a high prevalence of lameness exists across the global dairy industry. The results from a recent systematic literature review that included lameness prevalence estimates from 53 studies, representing locomotion assessments on 414,950 cows from 3,945 dairy herds, reported a mean prevalence of lameness (defined as a score of 3–5 on a 1–5 scale; see more on methods of assessment below) of 22.8% (Thomsen et al., 2023). Afonso et al. (2020) conducted a meta-analysis to investigate lameness prevalence in British dairy cattle and reported a pooled prevalence of 29.5% (95% CI 26.7–32.4%) and an all-cause lameness incidence rate of 30.9 cases of lameness per 100 cow-years (95% CI 24.5–37.9). There is also merit in distinguishing between causes of lameness; commonly classified as infectious (e.g., digital dermatitis, interdigital dermatitis) and non-infectious (e.g., sole ulceration, white line disease). A recent review from the European Food Safety Authority (EFSA) published a synthesis of the prevalence of claw disorders, suggesting that the cow-level prevalence of infectious claw disorders is generally reported to be lower (0.0–3.1%) than non-infectious claw disorders (15.9–46.6%), with the exception of heel horn erosion (26.9–59.9%) (EFSA AHAW Panel, 2023). Additional North American studies (not included in the synthesis) report that infectious cases are present in 69.7–94% of herds, affecting 9.3–22.9% of cows, while sole ulceration is present in 70.4–92% of herds, and white line disease is present in 50–93% of herds, affecting with

4.7–9.3% and 2–4% of cows, respectively (Cramer et al., 2008; Solano et al., 2016; Cartwright et al., 2017). When exploring cause-specific lameness incidence rates per 100 cow-years, Afonso et al. (2020) reported 66.1 (95% CI 24.1–128.8) for white line disease, 53.2 (95% CI 20.5–101.2) for sole ulcer, 53.6 (95% CI 19.2–105.34) for digital dermatitis, with 51.9 (95% CI 9.3–129.2) attributable to other lameness-related lesions.

Of the studies that have examined lameness prevalence, the majority use a 5-point scale for lameness (gait/locomotion-score) detection in loose housing systems (Flower and Weary, 2006) and in-stall lameness behaviors for detection of lameness in tie-stall barns (Gibbons et al., 2014; Table 1). Using the Flower and Weary (2006) gait scoring method, a score of >2 is considered lame within this 5-point scoring system used in loose housing systems. Using the Gibbons et al. (2014) in-stall assessment method, if 2 or more of the specified behavioral indicators (weight shift, stand on edge, uneven weight, uneven movement) are present, the cow is considered lame. Although the 2 scoring systems are comparable when detecting cows with moderate and severe levels of the lameness, the in-stall lameness scoring system has the potential to underestimate lameness severity as it does not differentiate between levels of severity and may be insufficient to reliably detect mild cases of lameness (Gibbons et al., 2014; Palacio et al., 2017). Although the methods discussed above have been used in many studies, others, particularly in the United Kingdom, used a 4-point scale to identify lameness; cows in those studies were considered lame if they had a score >1 using the 4-point scale (Main et al., 2012).

An additional consideration when using these scoring systems is their subjective nature, which can impact the sensitivity and specificity of detection and reliability between raters (Schlageter-Tello et al., 2015, Gardenier et al., 2021). Low inter- and intra-observer reliability consistency are particularly prevalent when scoring is performed by inexperienced observers (Schlageter-Tello et al., 2015). It has been suggested that observers need to review a large number of cows to improve inter-observer reliability (Channon et al., 2009). Croyle et al. (2018) identified that using a 3-d training workshop, 3 wk of experience, and video training, led to substantial agreement among 18 lameness assessors that were evaluated. This suggests that through appropriate training, a suitable level of agreement with respect to lameness scoring can be achieved.

Hock, Knee, and Neck Injuries

For cows, injuries are prevalent in 3 main areas: 1) hock injuries, which are situated on the tarsus joint; 2) knee injuries, which are situated on the carpus joint; 3) and neck injuries, which are situated on the dorsal portion of the neck (Zaffino Heyerhoff et al., 2014). Similar to lameness, there are many different methods that have been used to classify hock injuries. The most commonly used method is a 4-point scale, where a score of >1 is considered to be a hock injury (Gibbons et al., 2012; Table 2). The scale developed by Gibbons et al. (2012) is also commonly used for detecting knee and neck injuries (Table 2). For knee and neck injuries, a score of >1 is considered to be an injury.

When compared with lameness, injuries in cows have not been as intensively investigated. The within herd prevalence of hock injuries is reported to range from 0.0 to 81.2% of cows being affected (Table 3). It is estimated that 2.8–43.0% of cows have knee injuries and 1.0–33.4% of cows have neck injuries; though the prevalence of knee and neck injuries been investigated in considerably fewer studies. Similar to lameness, assessor training is necessary to increase the precision and accuracy of injury scoring to ensure that consistent and valid results are generated across farms (Lievens, 2001). Evidence suggests that substantial agreement between assessors can be produced from a training program that includes classroom instruction, on-farm training, and follow-up after a period of assessment experience (Gibbons et al., 2012; Croyle et al., 2018).

RISK FACTORS.

In several studies different housing, management, and cow-level factors that are associated with prevalence of lameness, hoof and claw lesions, and injuries have been highlighted. Given that most of the studies are observational, we cannot assume that all of these relationships are causal in nature. The body of evidence also lacks sufficient comparability in many areas, with considerable variation in the risk factors identified in some cases. The reported results, therefore, require additional research to further our knowledge of the impact of specific characteristics on lameness and injuries; preferably more prospective cohort studies and randomized clinical trials that will improve the strength of evidence available. These specific risk factors are explored below.

Lameness

The condition of lameness is most often characterized by abnormal gait or abnormal weight bearing across one or more limbs (EFSA AHAW Panel, 2023). The presence of this abnormality is typically considered to be due to pain and discomfort the animal is experiencing in one or more areas of its body. It is however important to note that abnormal locomotion can be caused by a variety of factors, some of which are infectious, while others are non-infectious in nature (Garvey, 2022; EFSA AHAW Panel, 2023), while others occur due to the presence of body injuries (hock, knee, hip, stifle, back), other infectious or metabolic diseases, estrus, genetic disorders, slippery/uneven flooring, and/or cow interactions (EFSA AHAW Panel, 2023). There have been many studies completed highlighting different management practices and demographic factors associated with lameness. A 2019 systematic review and meta-analysis investigated this question, reporting that a body condition score of $\leq 2.5/5$ is associated with increased odds of lameness, while a higher risk of being lame was associated with the presence of claw overgrowth, being in the first 120 DIM, larger herd sizes, and increasing parity (Oehm et al., 2019). These risk factors may, therefore, be considered those with strongest evidence to support them.

The broader body of literature on lameness risk factors, however, suggests that other factors may also play an important role in the incidence of lameness in dairy cattle. It is clear from the literature that housing and its management is critical. Housing type (tie-stall versus loose-housed), access to pasture (access versus zero-grazing), barn flooring characteristics (slats, grooving, slippery), stall design (e.g., lunge space, distance from neck-rail to rear curb, brisket board height), bedding type (e.g., straw versus sand), stall base (e.g., mattresses, concrete), and bedding depth have all been identified as important risk factors (Table 4). More spe-

Table 1. Numerical lameness (gait) scoring in walking dairy cows from Flower and Weary (2006) and in-stall lameness detection behaviors from Gibbons et al. (2014)

Gait Scoring System

Score	Description	Behavioral Criteria
1	Fluid and smooth movement	Flat back Steady head carriage Hind hooves land on or in front of the fore hooves Joints flex freely Symmetrical gait All legs bear weight equally
2	Imperfect locomotion but ability to move freely is not diminished	Flat or mildly arched back Steady head carriage Hind hooves do not track up perfectly Joints slightly stiff Slightly asymmetric gait All legs bear weight equally
3	Capable of locomotion but ability to move freely is compromised	Arched back Steady head carriage Hind hooves do not track up Asymmetric gait Slight limp can be discerned
4	Ability to move is obviously diminished	Obvious arched back Head bobs slightly Hind hooves do not track up Joints are stiff and strides are hesitant Asymmetric gait Reluctant to bear weight on at least one limb but still uses that limb in locomotion
5	Ability to move is severely restricted and must be vigorously encouraged to move	Extremely arched back Obvious head bob Poor tracking up with short strides Obvious joint stiffness characterized by lack of joint flexion with very hesitant and deliberate strides Asymmetric gait Inability to bear weight on one or more limbs

In-Stall Lameness Scoring System

Behavior	**Description**
Weight shift	Regular, repeated shifting of weight from one hoof to another, defined as lifting each hind hoof completely off the ground at least twice. The hoof has to be lifted and returned to the same location and does not include stepping forward or backward
Stand on edge	Cow places one or more hooves on the edge of the stall while standing stationary. This does not include times when both hind hooves were in the gutter or when the cow briefly placed her hoof on the edge during a movement or step
Uneven weight	Repeatedly resting one foot more than the other, indicated by the cow raising a part or the entire hoof off the ground. This does not include raising of the hoof to lick or during kicking
Uneven movement	Uneven weight bearing between feet when the cow is encouraged to move from side to side. This is demonstrated by a more rapid movement by one foot than the other or by an evident reluctance to bear weight on a particular foot

cifically, deep bedding with organic material or sand, rubber flooring in alleyways, and pasture access are consistently associated with lower levels of lameness, whereas the use of mats or mattresses in laying areas is consistently associated with a higher level of lameness. For "deep" bedding, the definition varied depending on the study evaluated. Some researchers reported a dose-dependent relationship, where the deeper the bedding the lower the lameness (Croyle, 2019), while others quantified "deep" as ≥2 cm of bedding on top of the stall base (Solano et al., 2015). Additionally, stall design, specifically small stalls with large cows and higher curb height have been associated with greater lameness (Table 4).

Management has also been identified as being an important factor to consider with respect to lameness, where herd size and biosecurity status (open versus closed herd), frequency of hoof trimming and foot bathing, environmental cleanliness, time out of pens, stocking density, time to treatment, and breed have been identified as important factors (Table 4). Specifically, stalls that were wet or had higher levels of fecal contamination, less preventative hoof trimming or preventative management practices, longer time away from the pen for milking, and higher stocking density have all been associated with higher lameness prevalence.

Lastly, for cow-level factors, lower body condition score (≤2.5), older parity (>1st lactation), past presence of hoof lesions, overgrown claws, injured hocks, previous cases of lameness, and longer days in milk have been associated with a higher prevalence, whereas higher milk production has been associated with a lower amount of lameness (Table 4).

Hoof and Claw Lesions

Though associations between non-specified lameness and various risk factors can be useful in better understanding the etiology of lameness, we must appreciate that to develop effective prevention and treatment strategies, a lesion-specific understanding of risk factors is needed. Many epidemiological studies have been conducted to identify factors that are associated with the occurrence of infectious and non-infectious causes of lameness. If we evaluate the broad category of hoof and claw lesions, higher parity cows, previous history of lameness, and tie-stall housing have been reported to be associated with a higher level of hoof and claw lesions. Table 5 presents study-specific reports of risk factors that have been associated with the occurrence of infectious and non-infectious cases of lameness.

Hock Injuries

Similar to lameness, in a large number of studies housing, management, and cow-level factors have been identified that are associated with hock injuries. A 2014 descriptive review concluded that the presence of hock lesions is strongly related to time spent lying on abrasive surfaces, collisions of the hock with stall fittings, and prolonged high local pressure or friction on hard surfaces (Kester et al., 2014). When breaking risk factors down across different levels, housing factors that were commonly associated with reduced hock injuries included deep bedding, access to pasture, and the use of sand as bedding, whereas herringbone parlors, stalls with mattresses, and short length of stalls have been associated with an increased level of hock injuries (Table 6). In terms of housing management, the most critical practice associated with lower prevalence was to ensure that stalls were kept clean and dry. Cows that are in a

Table 2. Hock, knee, and neck injury scoring systems from Gibbons et al. (2012)

Hock Scoring System	
Score	**Description**
0	No swelling. No hair is missing. Thinning of hair or broken hair
1	No swelling or minor swelling (<1 cm). Bald area on the hock
2	Medium swelling (1–2.5 cm) and/or lesion on bald area
3	Major swelling (>2.5 cm). May have bald area/lesion
Knee Scoring System	
Score	**Description**
0	No skin change
1	Hairless patch
2	Lesion/scab with or without medium swelling (<2.5 cm). May have a hairless patch
3	Major swelling (>2.5 cm) with or without lesion or hairless patch
Neck Scoring System	
Score	**Description**
0	No swelling. No hair is missing. Some hair loss or broken hair
1	No swelling. Bald area is visible
2	Broken skin or scab and/or swelling. May have bald area

Table 3. Descriptive summary and prevalence estimates of injuries from 9 peer-reviewed studies

Study	Year of completion	Geographical location	Housing type	Method used	Number of herds assessed	Number of cows assessed	Mean (Range) within herd prevalence of hock injuries	Mean (Range) within herd prevalence of knee injuries	Mean (Range) within herd prevalence of neck injuries
Weary and Taszkun, 2000	1999	British Columbia, Canada	Free-stall	Severity of lesions as either 1 (area of hair loss less than 10 cm2 with no evidence of skin breakage) or 2 (broken skin, dark scab, or area of hair loss greater than 10 cm2).	20	1,752	73% (NR)	N/A	N/A
Chapinal et al., 2014b	2012	China	Free-stall	1 = healthy hock without alopecia, 2 = bald area on the hock without evident swelling, and 3 = evidently swollen or severe injury	34	NR	40% overall (6% to 95% and 5% severe (0% - 50%)	N/A	N/A
Ekman et al., 2018	2014 to 2015	Sweden	Free-stall	Mild hock injury (loss of hair) and severe hock injury (evident swelling or ulceration, with or without hair loss)	99	3,217	74% (68% mild [23 to 100%] and 6% severe [0 to 32%])	N/A	N/A
Zaffino-Heyerhoff et al., 2014	2011	Alberta and Ontario	Free-stall	Gibbons et al., 2012	90	2,304	47% (NR)	24% (NR)	9% (NR)
Jewell et al., 2019b	2015 to 2016	New Brunswick, Nova Scotia, PEI	Free-stall	Gibbons et al., 2012	40	3,129	39% (0 to 83%)	14% (0 to 60%)	1% (0 to 21%)
			Tie-stall	Gibbons et al., 2012	33	1,523	39% (12 to 75%)	17% (2 to 78%)	5% (0 to 31%)
Nash et al., 2016; Bouffard et al., 2017	2011	Ontario and Quebec	Tie-stall	Gibbons et al., 2012	100	3,868	56% (NR)	43% (NR)	33.4% (NR)
Cook et al., 2016	2012	Wisconsin, USA	Free-stall	Similar scales to Gibbons et al., 2012	66	9,690	12.2% (0 to 81%)	6.2% (0 to 35%)	2.0% (0 to 19%)
Croyle, 2019	2015	Across Canada	Free-stall and Tie-stall	Gibbons et al., 2012	374	NR	27.0% (0 to 100%)	N/A	N/A
Crossley et al., 2021	2019 to 2020	Ireland	Pasture	Gibbons et al., 2012	82	NR	6.2%	2.8%	N/A
Rutherford et al., 2008	2007	United Kingdom	Housed and pasture	Dichotomous (sound or damaged)	80	NR	21.6% (pasture); 59.9% (indoor housing)	N/A	N/A
Beggs et al., 2019	2017	Australia	Pasture	Similar scales to Welfare Quality (2009)	50	25,055	NR (0 to 6%)	N/A	N/A
von Keyserlingk et al., 2012	2007 to 2008	British Columbia	Free-stall	Similar scales to Gibbons et al., 2012	42	3,948	42.3% (0 to 82%)	N/A	N/A
		California	Free-stall	Similar scales to Gibbons et al., 2012	39	8,112	56.2% (0 to 100%)	N/A	N/A
		North East USA	Free-stall	Similar scales to Gibbons et al., 2012	40	6,000	81.2% (18 to 100%)	N/A	N/A

NR = Not reported.

Table 4. Housing, management, and cow-level risk factors associated with lower and higher prevalence of lameness

	Lower prevalence of lameness	Higher prevalence of lameness
Housing factors	Kept cows on pasture (Adams et al., 2017; Hernandez-Mendo et al., 2007b; Olmos et al., 2009) Access to pasture (Chapinal et al., 2013; de Vries et al., 2015) Use of sand bedding (Adams et al., 2017; Chapinal et al., 2013; Salfer et al., 2018; Solano et al., 2015) Rubber flooring when compared with concrete (Bergsten et al., 2015; Chapinal et al., 2013) Use of deep bedding (Chapinal et al., 2013; de Vries et al., 2015; Dippel et al., 2009b; Griffiths et al., 2018; Jewell et al., 2019a; Rouha-Mulleder et al., 2009; Salfer et al., 2018; Solano et al., 2015; Croyle, 2019) Use of soft mattress when compared with concrete (de Vries et al., 2015) Distance of neck-rail from the rear curb (Chapinal et al., 2013) Neck-rail diagonal >1.94 m (Rouha-Mulleder et al., 2009) Rubber flooring when compared with concrete (Bergsten et al., 2015; Chapinal et al., 2013)	Tie-stall without exercise (Bielfeldt et al., 2005) No access to pasture (de Vries et al., 2015) Zero-grazing farm (Haskell et al., 2006) Mats or mattresses when compared with sand (Dippel et al., 2009b; Salfer et al., 2018) Presence of head lunge impediments (Chapinal et al., 2013) Obstructed lunge space (Westin et al., 2016) Neck-rail to curb diagonals too short (Dippel et al., 2009b) Concrete for lying area when compared with soft mats or mattresses (de Vries et al., 2015) Presence of damaged concrete (Barker et al., 2010) Presence of area behind the brisket board filled with concrete (Espejo & Endres, 2007) Brisket board height more than 15.24 cm (Espejo & Endres, 2007) Less than 2 cm groove spacing width (Griffiths et al., 2018) Small free-stalls and large cows (Haskell et al., 2006; Westin et al., 2016) Narrower stalls, lower and less forward tie-rails (Bouffard et al., 2017) Curb height of stalls (King et al., 2016, 5 cm increase in curb height over 20.9 cm, increased risk of severe lameness; Rouha-Mulleder et al., 2009, lower prevalence of lameness when curb height <0.22m) Slatted flooring (Rouha-Mulleder et al., 2009) Slippery floors (Solano et al., 2015) Narrow feed alley (Westin et al., 2016)
Management factors	Larger operations (Adams et al., 2017) Lower herd size (Chapinal et al., 2013) Herd consisting of breeds other than Holsteins (Barker et al., 2010) Closed herd status (de Vries et al., 2015) Feet of all cows trimmed on a maintenance schedule once or twice annually (Espejo & Endres, 2007) Preventative hoof trimming in early lactation (Griffiths et al., 2018) Examining and picking up cows' feet within 48 h of detecting lameness (Croyle, 2019) More frequent footbathing (at least once a week; Griffiths et al., 2018) More frequent scraping of manure alleys (King et al., 2016)	Higher stocking density (King et al., 2016; Rouha-Mulleder et al., 2009) Not treating lame cows within 48 h of detection (Barker et al., 2010) Increased percentage of stalls with fecal contamination (Chapinal et al., 2013) Wet stalls (Jewell et al., 2019a) Increased time away from the pen for milking (Espejo & Endres, 2007; Jewell et al.l., 2019a) Use of automatic scrapers (Barker et al., 2010)
Cow-level factors	Higher BCS (Foditsch et al., 2016) High milk yield in previous lactation (Foditsch et al., 2016) Higher milk production (Jewell et al., 2019a; Solano et al., 2015) First lactation (Jewell et al., 2019a; Solano et al., 2015)	Low BCS ($\leq$2.5) (Dippel et al., 2009b; Green et al., 2014; Jewell et al., 2019a; King et al., 2017; Lim et al., 2015; Solano et al., 2015) Lame previously (Green et al., 2014) Larger width of cow (Jewell et al., 2019a) Higher DIM (Jewell et al., 2019a; Lim et al., 2015) Greater parity (King et al., 2017; Lim et al., 2015) Cows pushing each other or turning sharply to enter parlor (Barker et al., 2010) Incidence of claw horn disruption lesions in subsequent lactation (Foditsch et al., 2016) Overgrown claws (Solano et al., 2015) Sires predicted transmitting ability for strength (Foditsch et al., 2016) Injured hocks (Solano et al., 2015; Westin et al., 2016; Croyle, 2019)

higher lactation and DIM have a higher prevalence of hock injuries, as do cows that are lame or have a low body condition score.

Knee and Neck Injuries

Fewer studies have been completed to determine risk factors that were associated with knee and neck injuries. For knee injuries, older cows have been associated with a higher prevalence of injury (Table 6), whereas for neck injuries, low neck-rails (<140 cm in height) have been associated with a higher prevalence of injuries (Table 6).

PREVENTION

Given current global prevalence estimates, it is not unreasonable to suggest that current approaches to prevent and treat lameness and injuries have largely been ineffective at the population level. Though evidence exists to support many of the current best practices, given the lack of progress, one might infer that our current practices simply allow us to prevent the issue from getting worse, rather than truly reducing incidence in the first place. The global dairy industry's inability to meaningfully lower and maintain herd-level prevalence of these conditions suggests our current best practices need to be re-evaluated and more than likely supplemented; truly affecting change will require broader systems thinking and an openness to challenge current husbandry and housing practices. As discussed above, the current body of scientific evidence largely points to associations between the aforementioned risk factors and lameness and/or injuries. There is a clear need for intervention studies that expressly seek to investigate whether or not a causal relationship exists between these animal outcomes and changes in on or more of the risk factors identified above. The use of cohort studies and randomized controlled trials in particular would significantly strengthen the quality of evidence available today and guide recommendations for evidence-based prevention strategies.

Lameness

When considering the lameness risk factors mentioned above, it is clear that implementing sound management practices and making targeted changes in housing design has the potential to reduce the risk of lameness. Specifically, in a study by Morabito et al. (2017) this was exemplified, where farmers that had increased bedding quantity, changed the stall base, and grooved crossover alleys had a lower prevalence of lameness and longer lying times than producers that made no changes.

One of the major strategies for the control of lameness is routine hoof trimming, with the goal of maintaining correct weight bearing and minimizing and preventing the development of claw-horn disruption lesions (CHDL) (Manske et al., 2002; Sadiq et al., 2020); however, few studies have been conducted to quantify the impact of hoof trimming on lameness score (Stoddard and Cramer, 2017; Sadiq et al., 2020). In a 2020 systematic literature review by Sadiq et al. (2020), the authors reported a scarce amount of data on the efficacy of claw trimming in lameness management; however, what was reviewed showcases positive associations between the occurrence of trimming and claw health. Preventive trimming has been reported to reduce the incidence of CDHL (Thomsen et al., 2019); though the methodology used limits the ability to reliably conclude a causal link back to the act of preventive trimming (Sadiq et al., 2020). Sadiq et al. (2020) concluded that the ability of hoof trimmers to effectively manage sole thickness and presentations, and the literature findings available to date, suggest that claw trimming is important for the prevention of claw lesions.

Claw horn disruption lesions, such as sole ulcers and white line disease, may be prevented through improvements to housing systems to enhance cow comfort and through management strategies to reduce total standing time and increased resting time (Bicalho and Oikonomou, 2013). Concrete walking surfaces are a major risk factor for lesions and allowing pasture access has been reported to have an impact on reducing CHDL (Hernandez-Mendo et al., 2007b). Rubber flooring has been reported to have inconsistent effects on CHDL, with some researchers identifying positive effects (Vanegas et al., 2006; Ouweltjes et al., 2011) and others reporting negative effects (Vokey et al., 2001; O'Driscoll et al., 2009; Fjeldaas et al., 2011) related to claw growth and wear and overall incidence of CHDL. It is possible that some of the benefit of improved cushioning and traction is neutralized by additional standing time and claw overgrowth. Improved resting time achieved through deep-bedded stalls (Andreasen and Forkman, 2012), sand bedding, prevention of overcrowding, proper stall design, and reduced time standing waiting to be milked (Main et al., 2010) are each thought to reduce the levels of CHDL. Therefore, ensuring that resting time is maximized can aid in preventing lesions of the claw.

Further, genetic selection could play a role in controlling CHDL. Variable levels of heritability estimates have been reported for certain foot lesions (van der Waaij et al., 2005; Laursen et al., 2009; van der Linde et al., 2010). Oberbauer et al. (2012) reported heritability for risk of digital dermatitis of 0.4 (95% CI: 0.20–0.67)

Table 5. Housing, management, and cow-level risk factors associated with lower and higher prevalence of infectious hoof lesions and non-infectious claw lesions

	Lower prevalence	Higher prevalence
Infectious Hoof Lesions (Digital Dermatitis, Interdigital Dermatitis, Heel Horn Erosion)	Use of rubber mats (Haggman & Juga, 2015) Use of a TMR (Haggman & Juga, 2015) Pasture access (Somers et al., 2005, Read and Walker, 1998; Wells et al., 1999; Onyiro et al., 2008; Olmos et al., 2009) Housed on slatted concrete flooring (Fjeldaas et al., 2011; Somers et al., 2005; Haufe et al., 2012) Dry cows (Sommers et al., 2005; Holzhauer et al., 2006; Corlevic and Beggs, 2022) Cows with a high antibody mediated immune response (Cartwright et al., 2017; Palmer & O'Connell, 2015)	Observed to be lame (Foditsch et al., 2016) Old cows (Foditsch et al., 2016; Haggman & Juga, 2015) Multiparous cows (Chapinal et al., 2010a) First lactation cows (Somers et al., 2005; Read and Walker, 1998; Rodriguez-Lainz et al., 1999; Corlevic and Beggs, 2022) Cows with lesions in previous lactation (Foditsch et al., 2016) High milk yield in previous lactation (Foditsch et al., 2016) Cows in early and mid-lactation (Haggman & Juga, 2015) Increased DIM (Chapinal et al., 2010a) Cows always kept indoors had higher odds of non-infectious claw disorders than cows with access to outdoors during summer, whereas cows with access to summer pasture and winter exercise yard were the most likely to have infectious claw disorders (Haggman & Juga, 2015) Tie-stall housing (Bielfeldt et al., 2005) Hgher level of dirty legs (Relun et al., 2013) Solid grooved flooring compared with solid non-grooved concrete (Barker et al., 2009) Textured concrete flooring (Wells et al., 1999) Higher moisture level in the environment (Rodriguez-Lainz et al., 1996; Read and Walker, 1998) Introduction of new animals into the herd (Rodriguez-Lainz et al., 1996, 1999; Wells et al., 1999) Improper disinfection of hoof trimming equipment (Wells et al., 1999)
Non-Infectious Claw Lesions (Solce Ulceration, White Line Disease)	Rubber flooring (Bergsten et al., 2015) Trimming heifers before calving (Cramer et al., 2009) Rubber flooring (Fjeldaas et al., 2011)	Tie-stall with exercise compared with tie-stalls with no exercise (Bielfeldt et al., 2005) Higher parity (Holzhauer et al., 2008) Parity of 4 or greater (Barker et al., 2009) Increasing herd size (Barker et al., 2009) Use of roads or concrete cow tracks between parlor and grazing (Barker et al., 2009) Cows at pasture by day and housed at night (Barker et al., 2009) Higher DIM (Holzhauer et al., 2008) Use of lime on free-stalls (Barker et al., 2009) Housing in free-stalls with sparse bedding (Barker et al., 2009) Increased frequency of alley scraping (Cramer et al., 2009) Year-round outdoor access from tie-stalls compared with seasonal and no access (Cramer et al., 2009) Low BCS (Green et al., 2014) Lame previously (Green et al., 2014)

Table 6. Housing, management, and cow-level risk factors associated with lower and higher prevalence of hock, knee, and neck injuries

	Lower prevalence of hock injuries	Higher prevalence of hock injuries
Housing factors	Open/dry lot (Adams et al., 2017) Deep bedding (Barrientos et al., 2013; de Vries et al., 2015; van Gastelen et al., 2011) Use of sand as bedding (Barrientos et al., 2013; Zaffino-Heyerhoff et al., 2014; Jewell et al., 2019b; van Gastelen et al., 2011) Access to pasture in dry cow period (Barrientos et al., 2013) Soft mattress compared with rubber mats or concrete (de Vries et al., 2015; Ekman et al., 2018) Peat moss bedding when compared with sawdust and straw (Ekman et al., 2018) Appropriate stall width (Ekman et al., 2018) Use of straw or hay bedding (Jewell et al., 2019b; Keil et al., 2006) Manger wall height <10 cm or >20 cm (Jewell et al., 2019b) Chain length <50 cm (Jewell et al., 2019b) Longer duration of outdoor access (Keil et al., 2006) (50 h min outside spent outdoors over 4-week period in tie-stall)	Use of automatic scrapers (Barrientos et al., 2013) Concrete for lying area when compared with soft mats or mattresses (de Vries et al., 2015) Herringbone parlors compared with tandem parlors (Ekman et al., 2018) and parallel parlors (Jewell et al., 2019b) Increasing stall gradient (Haskell et al., 2006) Use of sawdust for bedding when compared with sand (Barrientos et al., 2013) Stalls with mattresses when compared with concrete and sand (Zaffino-Heyerhoff et al., 2014; Jewell et al., 2019b; Nash et al., 2016; Salfer et al., 2018) Stall length <165 cm (TS) or <182 cm (FS) (Jewell et al., 2019b; Nash et al., 2016) Narrower stall width (Nash et al., 2016) Further forward tie-rail position (Nash et al., 2016) Shorter chain length (Nash et al., 2016) Presence of an electric trainer (Zurbrigg et al., 2005)
Management factors	Bedding dry matter ≥83.9% (Barrientos et al., 2013)	Increased percentage of stalls with fecal contamination (Barrientos et al., 2013) Increased stocking density (Barrientos et al., 2013) Poor bedding management (Barrientos et al., 2013) Cleaner cows (Ekman et al., 2018) Wet bedding (Jewell et al., 2019b)
Cow-level factors	First lactation cows (Jewell et al., 2019b) Presence of dirty flank (Jewell et al., 2019b)	Holsteins (Ekman et al., 2018) Higher DIM (Ekman et al., 2018; Zaffino-Heyerhoff et al., 2014; Jewell et al., 2019; Nash et al., 2016) Older cows (Ekman et al., 2018; Nash et al., 2016) Lame cows (Zaffino-Heyerhoff et al., 2014; Nash et al., 2016) Low BCS (Nash et al., 2016; Jewell et al., 2019b) Increased cow width (Nash et al., 2016)
	Lower prevalence of knee injuries	**Higher prevalence of knee injuries**
All risk factors	Rubber flooring when compared with concrete (Zaffino-Heyerhoff et al., 2014) Manger height 10 to 19 cm (Jewell et al., 2019b) Higher DIM (Nash et al., 2016) Higher BCS (Nash et al., 2016) Increased stall width (Nash et al., 2016)	Concrete stall bases compared with mattresses (Zaffino-Heyerhoff et al., 2014) Older cows (Zaffino-Heyerhoff et al., 2014; Jewell et al., 2019b) Slip or fall when moving into holding area (Zaffino-Heyerhoff et al., 2014) Stall width <120 cm (Jewell et al., 2019b) Dirty flank (Jewell et al., 2019) Recycled construction bedding (Jewell et al., 2019b) Decreased chain length (Nash et al., 2016) Decreased bed length (Nash et al., 2016)
	Higher prevalence of neck injuries	
All risk factors	Older cows (Zaffino-Heyerhoff et al., 2014; Jewell et al., 2019b) Low feed/tie-rails (<140 cm) (Zaffino-Heyerhoff et al., 2014; Zurbrigg et al., 2005) and higher tie-rail and less forward tie-rails (Bouffard et al., 2017) Manger height <10 cm in tie-stalls (Jewell et al., 2019b) Tie-rail to curb distance <180 cm or 200 to 209 cm (Jewell et al., 2019b) Cow height 146 to 149 cm or >153 cm (Jewell et al., 2019b) Post and rail feed-rail (Jewell et al., 2019b) Shorter chains (Bouffard et al., 2017) Narrower stalls (Bouffard et al., 2017)	

and sole ulcer of 0.30 (95% CI: 0.08–0.63). Barden et al. (2022) reported similar estimates and further demonstrated that sole lesion recovery might be heritable, but largely independent of genetic background of susceptibility. Therefore, there is potential for selective breeding to reduce the frequency of chronically lame cows, with a focus on selecting for recovery instead of solely focusing on reduced susceptibility. Focusing on conformational traits, such as higher foot angle (Oikonomou et al., 2013), rear legs rear view (Boettcher et al., 1998), thurl width (Boettcher et al., 1998), and mammary composite traits (Onyiro et al., 2008), has also been reported as potentially meaningful in reducing CHDL; though many countries (e.g., Canada; Malchiodi et al., 2020) have developed specific foot lesion indexes to aid in direct selection for reduced CHDL.

With respect to digital dermatitis, several control strategies have been recommended for digital dermatitis, including maintaining a clean, dry environment, individual topical treatment of affected cows, and footbathing (Laven and Logue, 2006; Nuss, 2006; Döpfer et al., 2012). Footbaths have been demonstrated to be effective in controlling digital dermatitis, with copper sulfate being effective in reducing prevalence (Speijers et al., 2010; Fjeldaas et al., 2014; Solano et al., 2017). A 2019 systematic review and network meta-analysis investigated the current evidence on the effect of footbath protocols for prevention and treatment of digital dermatitis in cattle (Jacobs et al., 2019); those researchers concluded that only 5% copper sulfate used at least 4 times/wk was superior to no footbath and a water placebo. They further concluded that despite the limited strength of evidence, the use of footbaths is quite common in industry and there is a need for more research to support the standardization and adoption evidence-based protocols for lameness treatment (Jacobs et al., 2019). To maximize the effectiveness of the footbaths, it is important to fully submerge each foot in the bath in an effort to achieve contact time between hoof and product. The probability of each rear foot getting at least 2 immersions was 95% at a footbath length of 3.0 m and a significant increase in the frequency of 3 and 4 immersions per foot at a footbath length between 3.0 to 3.7 m long (Cook et al., 2012). This suggests that footbaths should be at least 3.0 m long to get ample submersion of the cows' feet.

Early intervention in identified cases could also be considered a meaningful form of preventing more severe cases (Groenevelt et al., 2014; Wilson et al., 2022). Leach et al. (2012) demonstrated that early intervention resulted in less severe foot lesions and reduced the prevalence of lameness. However, given that 40% of cows were treated for lameness by farmers more than 3 wk after being identified as lame by researchers (Alawneh et al., 2012), there is clearly a need to improve timely detection. It has been suggested that combining lameness scoring on a bi-weekly basis and appropriate treatment (i.e., therapeutic foot trimming) leads to higher cure rates of lameness and an increased number of sound cows (Groenevelt et al., 2014).

Hock, Knee, and Neck Injuries.

Very little research has been completed regarding preventative strategies to reduce the incidence of injuries. From the risk factors associated with the prevalence of injuries, it is clear that a variety of housing, management, and cow-level factors are involved. Based on previous studies, proper housing design and use of deep bedding appear to be the most consistently identified factors that can help to reduce the prevalence of injuries (Table 4).

TREATMENT

Lameness

Few studies have been completed regarding the most appropriate treatment of lameness. Of the studies that have been completed, most of the literature evaluates the treatment of digital dermatitis (Potterton et al., 2012). The application of antibiotics including a copper-containing preparation (Hernandez et al., 1999), oxytetracycline (Hernandez et al., 1999; Berry et al., 2012), lincomycin (Moore et al., 2001; Berry et al., 2012), and topical tetracycline (Cutler et al., 2013), were reported to be effective in improving resolution of digital dermatitis. However, a recent meta-analysis identified that the effectiveness of these treatments remains unclear, as the body of knowledge and current quality of evidence is low (Ariza et al., 2017).

The effect of intervening with therapeutic trimming for CHDL has also been studied. Therapeutic trimming consists of the removal of all necrotic and loose or undermined horn to create an aerobic environment and minimize the possibility of abscess formation. This is followed by adjusting weight bearing on diseased or damaged claws (Shearer et al., 2013). A 2020 systematic review of the effect of hoof trimming on lameness highlighted an important trade-off between the short and long-term impacts of claw trimming, reporting that claw trimming often induces immediate pain sensations, stress, changes in lying behavior, and reduction in milk yield, but improvements in locomotion score have been observed later in lactation (Sadiq et al., 2020). Those researchers concluded that claw trimming is both beneficial for lameness management and improves the welfare and production of dairy cows. Therapeutic trimming of cows identified with CHDL can lead to recovery from lameness, but is dependent on a variety of factors, including case severity (Miguel-Pacheco et al., 2017), presence of bandaging (Klawitter et al., 2019), parity (Klawitter et al., 2019), application of a hoof block and administration of pain relief (as reviewed by Sadiq et al., 2022). Another important consideration with therapy is whether the case is chronic or has been occurring for a long duration of time, as it is likely that the success of therapy will be lower (Thomas et al., 2016).

Another important component to treatment, commonly applied during therapeutic trimming, is the application of a hoof block on the healthy claw to relieve pressure on the affected claw. A few researchers have investigated the impacts of treatment of CHDL with a combination of therapeutic trimming, application of a hoof block, and administration of a non-steroidal anti-inflammatory drug (NSAID) and reported promising results (Thomas et al., 2015; Garcia-Muñoz et al., 2017). In a 2022 randomized clinical trial, Sadiq et al. (2022) randomly allocated first parity cows with CHDL on a single foot to one of 5 treatments. In that work, cows receiving a therapeutic trim, administration of ketoprofen for 3 d, and hoof block on the healthy claw had significantly better recovery and reduced pain sensitivity compared with those that only received therapeutic trimming. Crucially, while these studies demonstrate the benefit of a combination of therapies, there remains little evidence that the application of a block on its own improves lameness outcomes; further highlighting the need for additional research in this area.

Pain Management.

Lameness is a painful condition that results in cows changing their gait due to pain resulting from infections and lesions that are primarily in their hooves (Whay et al., 1998; O'Callaghan et al., 2003). In addition to managing pain through corrective trimming and hoof blocks, the use of analgesics has been demonstrated to aid in recovery of lameness; however, a small number of controlled studies have been completed on this topic (Coetzee et al., 2017). Multiple field trials have been conducted using ketoprofen, often in combination with a corrective trim and application of a hoof block, reporting improvements ranging from: more even weight distribution seen in all 4 limbs (Flower et al., 2008), a reduced variation in weight distribution (Chapinal et al., 2010c), a mild improvement in lameness score (Flower et al., 2008), an improved cure of lameness 35 d after treatment (Thomas et al., 2015), a lower risk of being culled (Wilson et al., 2022), and a lower odds of remaining lame and increased milk production (Kasiora et al., 2021). Wilson et al. (2022) demonstrated that administration of a 3-d dose of ketoprofen, starting 24–36 h after calving, led to a reduced odds of becoming lame. The use of other NSAIDs, flunixin meglumine (Schulz et al., 2011), and oral meloxicam, (Offinger et al., 2013; Coetzee et al., 2014; Nagel et al., 2016) have also been reported to have positive impacts on lameness outcomes. It is important to note, however, that several researchers have also reported no positive associations with the use of NSAIDs in this context (Laven et al., 2008; Thomas et al., 2016; Wilson et al., 2022), pointing to a clear need for more research to investigate the true relationships and impacts of pain mitigation. Furthermore, in a recent systematic review by Mason et al. (2022), following the initial screening over 229 studies investigating associations between NSAID use and claw horn lameness, only 6 studies were deemed suitable for inclusion based on their reporting of impacts in locomotion score, nociceptive threshold, and lying times. Though animals in NSAID intervention groups from these papers yielded lower point estimate lameness risk and greater nociceptor threshold point estimates compared with control groups, no differences were detected between the groups; similar to the effect of NSAID application on lying times (Mason et al., 2022). Their critical review of the literature demonstrates a varying degree of risk of bias and quality of evidence, with a high degree of heterogeneity across studies, which limits comparability. Generally, the current evidence suggests that best practice is to intervene with a combination of therapeutic trim, hoof block, and use of an NSAID (Thomas et al., 2015; Sadiq et al., 2022) (a protocol particularly effective for acute cases); while this strategy is generally supported by most scientists as well, more research is needed to develop a truly evidence-based protocol.

Hock, Knee, and Neck Injuries

Virtually no published studies have been completed on how to appropriately treat or manage cows with hock and knee injuries. Armstrong (2020) followed 598 cows from 14 commercial herds with hock and knee injuries for 14 wk following a single transition to a new "cow friendly" facility (offering resting areas with mattresses, sand, pack, and/or pasture) and identified that 100% of cows with moderate knee injuries healed once transitioned, and 77% and 36% of cows with moderate and severe hock injuries healed once they had moved. In that study, compared with mattresses, cows with moderate hock injures healed 7.2, 3.0, 2.2 times faster when transitioned to pasture, sand, and bedded packs, respectively. Armstrong et al. (2019) reported that moving cows to sand bedding, bedded packs, or pasture led to faster resolution of healing for both types of injuries; with healing times often taking close to 60 d. Based on the previously presented risk factors and the limited research available, it is expected that improving the cushioning of cows' lying surface and bedding may aid in recovery. However, more research is needed to explore the recovery and remediation time associated with different treatment methods to manage injuries.

FARM LEVEL BARRIERS

The multifactorial nature of lameness (Solano et al., 2015; Cook et al., 2016) makes its prevention and control a challenge. However, simply understanding the root causes of lameness, and the necessary farm-specific changes that are required to reduce its occurrence, is only one aspect to its prevention and control. Reducing lameness in dairy herds requires farmers to adapt or change existing practices, which often requires investment (time and money) and a change in behavior. To improve the levels of lameness and injuries on Canadian dairy farms, it is therefore important to account for producers' attitudes and intention to take action (Bruijnis et al., 2013).

Numerous researchers have concluded that both extrinsic (e.g., time, money, space) and intrinsic (e.g., farmer attitude, perception, priorities, and mindset) barriers exist to addressing lameness on dairy farms. A 2019 systematic review on dairy farmers' perceptions of and actions in relation to lameness management demonstrated that, among extrinsic factors, research suggests that producers view a shortage of time and labor as important barriers to lameness control (Sadiq et al., 2019). Leach et al. (2010a) reported that time and skilled labor were important limiting factors for lameness control activities and that financial constraints prevented farmers from taking action on advice in 30% of cases in the UK; similar findings were reported in Canada (Cutler et al., 2017). Sadiq et al. (2019) also highlighted that farmers' understanding of the implications of lameness on the farm business is limited. One strategy to address these barriers has been to try to understand the economic costs and returns of different interventions for lameness (Bruijnis et al., 2012; Dolecheck et al., 2019). Bruijnis et al. (2012) suggest that providing information about the correlation between welfare and economics could motivate producers to follow through with change. It may also support decisions on which measures to prioritize. On-farm assessment programs where producers are provided with feedback on animal-based measures may also help to motivate producers to improve lameness on their farms. Simply making producers aware of the scale of the problem on their farm was enough to motivate changes in management on their farm and improve the levels of both lameness and hock injuries (Chapinal et al., 2014a). Additional motivation for changes in facility design and management can be attained through providing reports to producers highlighting the prevalence of animal-based measures compared with other herds in the same region (Chapinal et al., 2014a). The use of these benchmarked reports has also been shown to be successful in motivating other on-farm changes, such as changing colostrum management (Sumner et al., 2018).

The review by Sadiq et al. (2019) highlights that the provision of information and advice alone, however, seldom produces lasting on-farm change. Though the extrinsic characteristics noted above (e.g., time, money, space) represent important barriers, there are also several important intrinsic barriers to lameness control. The decision to invest time and resources is ultimately determined by the level of importance and priority that one places on that issue (Bruijnis et al., 2012). It has been suggested in previous research (Leach et al., 2010a, 2013) and a systematic review (Sadiq et al., 2019) that incomplete detection, a high tolerance of lameness, lack of awareness of the welfare impact of lameness, and other herd health issues being given high priority, are also important barriers to reducing lameness in dairy herds.

Researchers have demonstrated that farmers substantially underestimate lameness in their herds when compared with researchers, veterinarians, and other on-farm advisors (Whay et al., 2002; Espejo and Endres, 2007; Šárová et al., 2011; Leach et al., 2010a, 2013). For example, the prevalence estimate from a study of 50 Minnesota free-stall herds was 3 times greater than the estimates given by herd managers (Espejo et al., 2006). In other studies comparing the level of self-assessed lameness by a farmer and independent researchers, it has been demonstrated that farmers missed roughly 2-thirds of lame cows (Cutler et al., 2017; Croyle et al., 2018). Croyle et al. (2019) suggested that this may be due to a phenomenon called "barn blindness," which they defined as a lack of perception of welfare problems in one's own barn. It is estimated that the true prevalence of lameness is between 2 and 4 times greater than the producer-perceived level of lameness, respectively (Fabian et al., 2014; Cutler et al., 2017; Sadiq et al., 2019). Importantly, while the average prevalence of lameness differs across different housing systems (e.g., free-stall versus tie-stall versus pasture-based), the proportion of cows identified as lame by the farmer, relative to the true number of lame cattle in their herd, remains consistent. This highlights that consistent and accurate detection likely has less to do with housing system and more to do with the lack of a consistent process for detection (Fabian et al., 2014). The discrepancy in the identification of lameness is mostly observed in mild lameness cases (score of 3 out of 5) and could be due to many producers (42% of respondents in a survey of over 1,000 producers across Canada from the National Dairy Study; a nationally representative benchmarking survey completed in 2015 [www.nationaldairystudy.ca]) never formally assessing cows for lameness other than during casual observations (Croyle, 2019). However, it is likely that the largest reason for discrepancy is that when compared with researchers, producers may have substantially different definitions of what they classify as being lame. To rectify this difference, further education and extension strategies are needed to provide producers with training to better identify lameness.

This underestimation of the true level of lameness on-farm may ultimately contribute to the belief that lameness is not a significant problem and is, therefore, not a priority. In a survey of 222 UK dairy farms, Leach et al. (2010a) reported that 90% of farmers did not perceive lameness to be a major problem on their farm, although the average prevalence of lameness was 36%. They further described that for 62% of the sample farmers, lameness was not the top priority for efforts made to improve herd health. Given these attitudes, it would therefore, not be surprising to see that these producers tend to prioritize other diseases on the farm (Leach et al., 2010b; Cutler et al., 2017). Bruijnis et al. (2013) demonstrated that most producers in their study of 152 Dutch dairy farmers were satisfied with the hoof health of their cows and were, thus, unlikely to take any related action to mitigate lameness in their herds. These researchers further reported that producers did not consider subclinical foot disorders, where the cow was not visibly lame, as important with respect to animal welfare (Bruijnis et al., 2013).

Another important component contributing to how producers view lameness relates to their awareness of its impact on animal welfare. Researchers have suggested that lameness is not universally viewed by all farmers as a painful and economically impactful condition in dairy cattle. For example, Bruijnis et al. (2013) reported that 25% of producers surveyed thought that lame cows do not suffer pain. Further, Becker et al. (2013) reported that 52% of Swiss producers interviewed would not consult a veterinarian or provide pain management for common painful hoof health interventions. Although, it is notable that those researchers reported only 11% of farmers agreeing with the statement that the cost of pain management was a major concern for farmers (compared with 47% of veterinarians and 33% hoof trimmers interviewed). These results suggest that while economic aspects impact decision-making, the producer's understanding of the condition and its impacts are most influential over their determination of whether to intervene or not. In several studies it has been demonstrated that producers consider pain and suffering and reduced performance by lame cows as motivating factors for making on-farm changes (Leach et al., 2010b; Croyle et al., 2019). Although, interestingly, Cutler et al. (2017) reported that producer perception of lameness as a painful condition and the economic costs of lameness were not related to success in controlling lameness on-farm. More work is needed to better understand the motivations and priorities of producers with respect to the prevention and control of lameness.

The Role of Advisors

There are many diverse stakeholders involved in lameness and injury management including the farmer, farm staff, veterinarian, hoof trimmer, nutritionist, and other farm advisors. Addressing dairy cattle lameness and injuries must, therefore, consider the people involved, as it is the people who are influencing and implementing on-farm decisions related to lameness prevention, treatment, and control. To date, no research has been conducted on how advisors play a role in the management of injures; hence, the remainder of this section reviews studies around how advisors play a role in lameness management.

Researchers have previously investigated the importance of involving advisors in lameness decisions, with a particular focus on the role of the veterinarian (Main et al., 2012; Whay et al., 2012; Leach et al., 2013; Croyle et al., 2019; Wynands et al., 2021, 2022). This focus is primarily taken as veterinarians are in an ideal position to advise and motivate farmers to improve welfare-related practices (Lam et al., 2011). While evaluating the UK-based Healthy Feet project (https://ahdb.org.uk/healthy-feet), Whay et al. (2012) reported that farmers implemented more changes that were likely to positively impact lameness when the ideas were generated with the direction of a veterinarian, rather than on their own. Main et al. (2012) concluded that the reduction of lameness observed over time by Whay et al. (2012) was greater on farms that were monitored and offered additional support (from veterinarians and/or other producers) compared with farms that only received monitoring. Further, Croyle et al. (2019) conducted a qualitative focus group study with Canadian producers and concluded that veterinarians were trusted and most commonly viewed as the most important partner in animal welfare. However, a Canadian study by Cutler et al. (2017) reported that only 8% of farmers surveyed called the veterinarian or hoof trimmer after they detected a lame cow.

Veterinarians represent one of many relevant advisors to the farmer, particularly when addressing a multifactorial disease such as lameness. Nutritionists, hoof trimmers, and other farm advisors also commonly work with farmers on the development and evaluation of health management programs. Hoof trimmers are a source of information and they work directly with the cows' hooves; however, little information exists about hoof trimmers and their impact on lameness decisions. Recent work by Wynands et al. (2021) focused on understanding dairy farmer, hoof trimmer and veterinarian perceptions of lameness, noting that despite a shared concern about lameness, there was a lack of communication between these important actors; though there was an expressed desire to work together more productively. In a recent review of dairy farmers' perceptions of and actions related to lameness, Sadiq et al. (2019) suggested that tensions between farm advisors can be an important barrier to change and that the lower-cost of services provided by nutritionists and trimmers over veterinarians, may result in less consideration being given to pain management of lame animals. Becker et al. (2013) compared the perceptions of Swiss farmers, hoof trimmers, and veterinarians, concluding that there was a lack of awareness among farmers and trimmers of the obligation to carry out painful therapeutic trimming under analgesia (a regulatory requirement in the country). Those researchers further reported that while most veterinarians (79%) viewed local anesthesia during the trimming of sole ulcers as reasonable, significantly fewer farmers (42%) and trimmers (47%) felt the same (Becker et al., 2013). In addition, research conducted in the United States demonstrated that veterinarians were more likely to provide a foot block when treating sole ulcers when compared with hoof trimmers; however, a low percentage of veterinarians (26%) recommended the use of analgesics for treatment of sole ulcer lesions (Kleinhenz et al., 2014). A recent study by Wynands et al. (2022) used a participatory approach to bring veterinarians, hoof trimmers, and nutritionists together with individual farmers to establish advisory teams. Participants reported improved communication, stronger relationships, and increased confidence in reaching out to one another; this type of approach may offer a promising avenue for facilitating advisor engagement on farm to work toward lameness reduction (Wynands et al., 2022).

Ultimately, advisors play an important role in guiding and influencing on-farm decision-making related to lameness. Farmers particularly value the pre-established relationship they have with these advisors, their expertise in dairy care/welfare, the opportunity for a fresh, outside perspective, the ability to compare and contrast with other clients' farms (a form of benchmarking), and the ability to advise and offer corrective recommendations (Croyle et al., 2019).

CONCLUSIONS

Lameness and injuries are prevalent across the dairy industry and are both considered to be significant welfare concerns. Dairy farmers consistently underestimate the true level of lameness in their herds, often due to failure to recognize mild cases of lameness. Digital dermatitis represents the most common source of infectious lesions, while sole ulcers and white line disease are the most prominent non-infectious causes of lameness. Numerous risk factors have been associated with the incidence of lameness and injuries, notably housing, management, and cow-level factors. Key preventative approaches for lameness include routine preventative and corrective hoof trimming, improving cushioning and traction through access to pasture or adding rubber flooring, deep bedded stalls, sand bedding, and frequent use of foot baths; very little research has been conducted on prevention of injuries. The global dairy industry's inability to meaningfully lower and maintain herd-level prevalence of these conditions suggests our current best practices need to be re-evaluated and more than likely supplemented. Future research must aim to improve the quality of evidence available today, and challenge current husbandry and housing practices to truly tackle the burden of lameness and injuries. Numerous researchers have concluded that both extrinsic (e.g., time, money, space) and intrinsic (e.g., farmer attitude, perception, priorities, and mindset) barriers exist to addressing lameness and injuries on dairy farms. There are many diverse stakeholders in lameness and injury management including the farmer, farm staff, veterinarian, hoof trimmer, nutritionist, and other advisors. Addressing dairy cattle lameness and injuries must, therefore, consider the people involved, as it is these people who are influencing and implementing on-farm decisions related to lameness prevention, treatment, and control.

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