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The Impact of Lameness on Dairy Cattle Welfare: Growing Need for Objective Methods of Detecting Lame Cows and Assessment of Associated Pain

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Abstract

Dairy cows are the major animals reared for milk production worldwide. Lameness is a manifestation of painful condition due to injury or disease in the foot, regarded as a major welfare problem in dairy cows. An effective lameness management requires prompt identification of lame cows. The objectives of this systematic review were to discuss the various techniques of detecting lameness, assessment of the associated pain, and the impact of lameness on dairy cow welfare. Results from the literature search yielded 534 papers, with 102 papers meeting the inclusion criteria. The eligible studies were discussed in two sections which were; (1) lameness detection systems and their application in pain assessment using four methods: gait and behavioral variables, physiological parameters, pressure nociceptive threshold and blood biomarkers; (2) impact of lameness on animal-based welfare measures. Despite the limitations in the use of automated locomotion scoring systems, results showed the technique remains a promising tool for the prompt detection of lame cows compared with manual systems (MLSS). More investigation of such systems could aid the validation of pain in cows with various degree of lameness. Further studies are required for early lameness detection and minimizing the welfare implications in dairy herds.

Keywords: lameness, locomotion, pain, claw lesions, animal welfare, behavior, dairy cows

1. Introduction

The primary aims of dairy husbandry include efficient productive life cycle and good animal welfare. Nevertheless, the continuous selection of cows for high production under intensively managed systems remains a challenge in achieving optimal animal welfare [1]. Aside from being a production limiting condition, lameness is regarded as one of the most important welfare problems in dairy cows. The five freedoms described as the fundamentals of good welfare requires an animal to be provided with adequate food and water, comfort, environment to express normal behavior, the absence of pain and disease, and freedom from fear and distress [2]. On this note, lameness has been shown to impact negatively either directly or indirectly on the aforementioned basics of animal welfare [3].

The factors contributing to the welfare consequences of lameness are multifaceted. Lameness arising from foot or claw lesions is one of the most painful conditions in dairy cattle [3]. To relieve such pain, alteration in gait and posture is evident during locomotion and standing. These events often affect other behavioral activities including feeding, lying pattern, rumination, and social ranking, thus contributing to why lame cows lag behind their sound herd mates in productivity [3]. These behavioral changes have been reported not only in severely lame cows, but also in moderate lameness events [4]. Another aspect is farmers' perception of the importance of lameness and the expertise required in providing adequate care to lame cows. Farmers have been reported to underestimate the prevalence of lameness in their herds compared to trained personnel [5] while regarding only severely lame cows as those requiring treatment [6]. These events contribute to cows becoming chronically lame and reducing their chance of recovery following treatment [7]. Hence, measures to detect slight changes in locomotion remains pertinent to reduce the welfare implications of lameness.

Currently, the manual locomotion scoring system (MLSS) remains the gold standard for the detection of lameness in dairy herds. Though, simple to use, constraints such as their subjectivity and low sensitivity in detecting cows with claw lesions are key issues [8], thereby limiting the assessment of pain associated with lameness. These constraints supported the development of automated lameness detection systems, where sensors and pressure weighing platforms are employed to monitor locomotion. The validation of both manual and automated locomotion scoring systems (ALSS) has been attempted using pain assessment. Recently, researchers have employed techniques entailing the measure of pressure nociceptive method (PNT), physiological parameters [9, 10], biomarkers and expression of genes associated with inflammation in clinically lame cows or based on the presence of claw lesions [11]. These emerging methods have been shown to be more sensitive in detecting lame cows and for better understanding of the etiology and the related pain.

This review discusses recent findings on the welfare implications of lameness in dairy cows based on the associated pain and vital behaviors. Also, the techniques used in the assessment of pain in lame cows either based on clinical diagnosis or detection of specific claw lesions are highlighted. Particularly, the strength and weakness of the locomotion scoring systems are highlighted with emphasis on objective methods for detecting lameness.

2. Materials and methods

This review covers peer reviewed articles, published in English between 2005 and 2017, reporting on the detection of lameness and assessment of the related pain, and their impact on dairy cow welfare. To achieve our stated objective, a narrative integrative review was carried out from October, 2017 to February, 2018 and bias was attempted to be reduced by exploring aspects of systematic review. Three databases namely PubMed, Google scholar and Web of Science were used for the literature search. Where relevant, publications cited in the retrieved articles were also reviewed. The search terms used included "Lameness", "Locomotion", "Claw lesions", "Behavior", "Dairy cows", "Pain", "Welfare", and "Body condition". A total of 576 and 37 records were retrieved from database and other sources respectively. For the study selection process, the PRISMA checklist was employed (**Figure 1**).
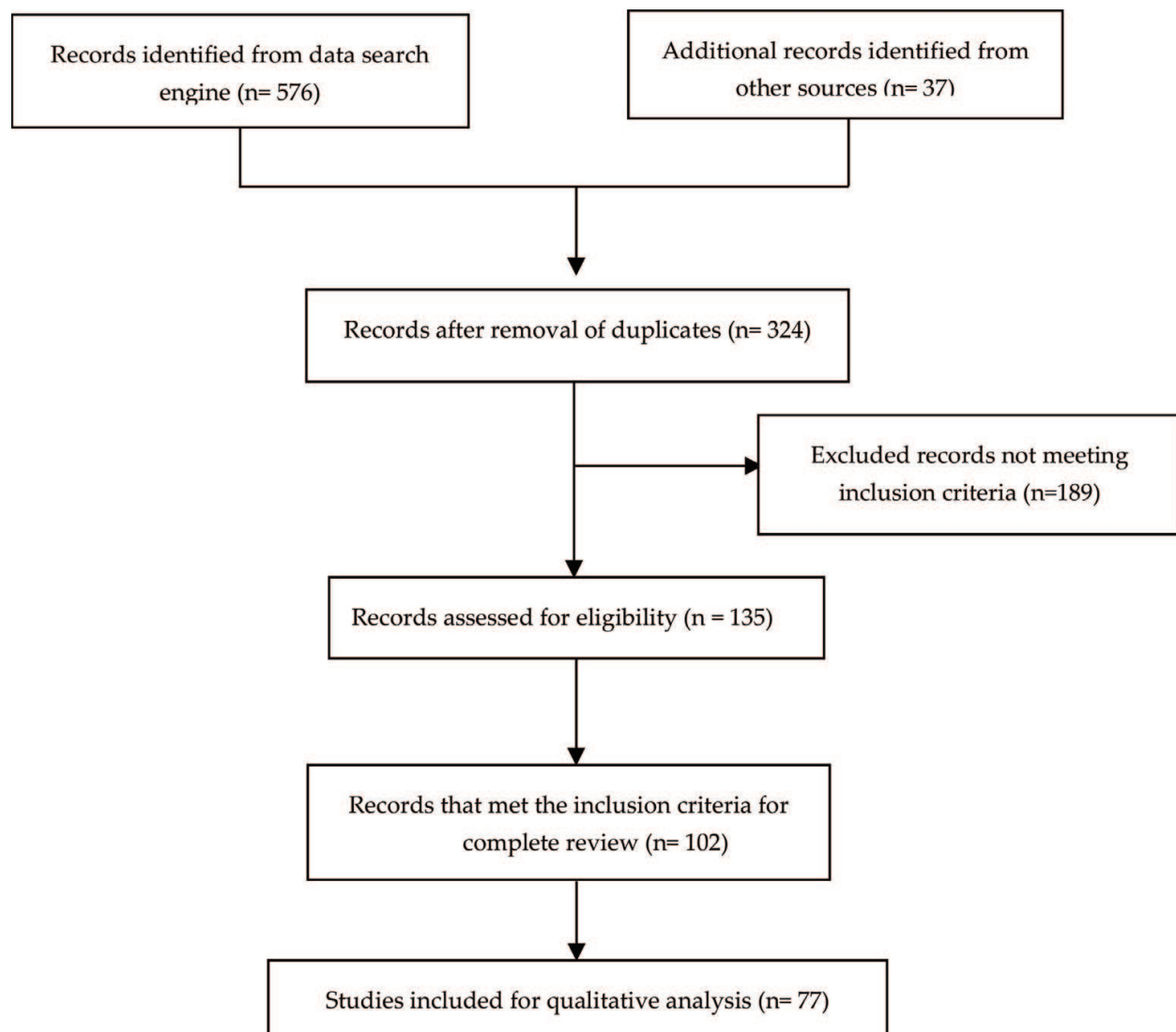

Figure 1. Flow diagram of study selection process using PRISMA procedure.

3. Claw lesions causing lameness

About 90% of lameness disorders in dairy cows are attributed to claw lesions [12]. Claw lesions have been broadly categorized into infectious and non-infectious causes [13]. Non-infectious causes also described as claw horn disruptive lesions (CHDLs), are pathological alterations arising from the internal capsule or claw horn tissues. Sole ulcers (SU), sole hemorrhages (SH) and white line disease (WLD) are the major lesions in this category (**Figure 2**). These conditions are multifactorial, as supporting evidence suggest the interplay between rumen acidosis laminitis complex, prepartum metabolic, and hormonal changes affecting the stability of the pedal bone and suspensory apparatus [14, 15], as well as biomechanical reaction at the claw-floor interface [16]. In addition, animal-based measures such as body condition loss, reduced thickness of the digital cushion (DC) [17], injured hock, and overgrown claw have been associated with increased odds of CHDLs [18, 19].
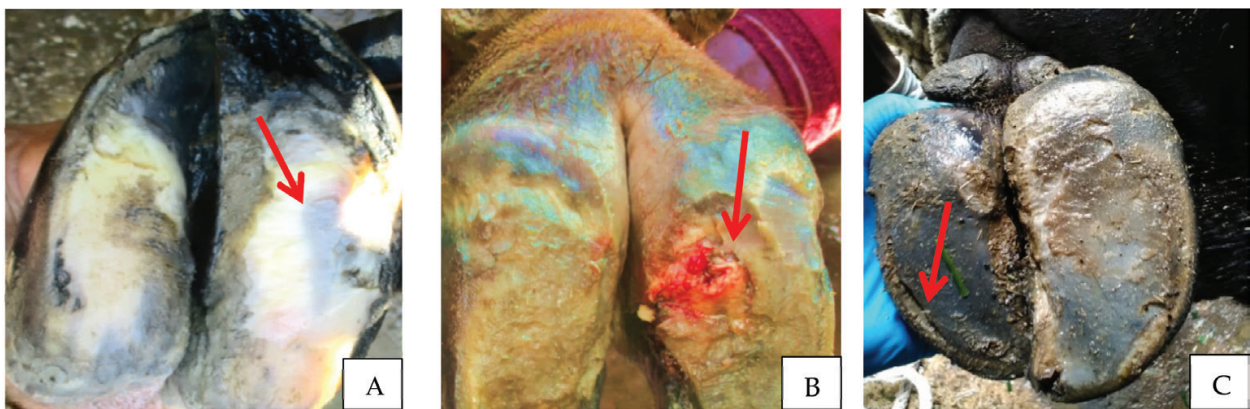

Figure 2. (A) Severe sole hemorrhage (red arrow) and toe necrosis (B) sole ulcer (red arrow lateral claw) (C) white line fissure (red arrow medial claw).
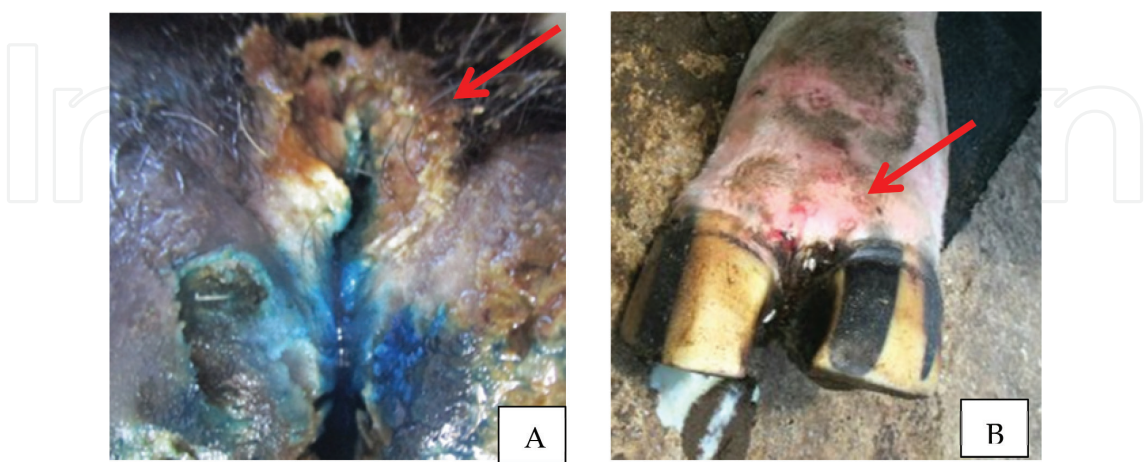

Figure 3. (A) Digital dermatitis at plantar surface of the foot (red arrow) (B) suspected case of foot rot with characteristic swollen coronet, interdigital lesion and purulent discharge.

Digital dermatitis (DD) and foot rot are important claw diseases classified under the infectious etiology. DD lesion is manifested as a circumscribed moist ulcerative mass on the plantar surface of the foot and may extend to the interdigital space [20]. They often result from bacterial pathogens capable of invading a broken digital skin and presence of infected cows in a herd is a vital risk factor [20]. Foot rot is a sub-acute or acute necrotic (decaying) infectious disease of cattle, causing swelling (especially around the coronary band) and lameness in at least one foot (**Figure 3**). The bacterium often isolated is *Fusobacterium necrophorum.* The infectious agents normally gain entry through mechanical injury and softening of the interdigital skin due to prolonged standing, exposure to contaminated manure, and walking on abrasive and rough surfaces. Also, environmental conditions such as high temperature and humidity could affect the integrity of the digital skin [21].

4. Pain associated with lameness

Lameness is a welfare problem manifested in response to pain and discomfort. Specifically, painful sensations from CHDLs are presumably due to the inflammation and compression of the corium in the affected area [21, 22], whereas infectious claw lesions such as DD could be painful both at active and healing stages [23]. According to the International Association for the Study of Pain, pain is defined as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage" [24]. The definition highlighted two major components comprising of nociception and experiencing pain. Nevertheless, in animals, the concept of the emotional experience of pain is often excluded as described by Zimmerman [25], "it is an aversive sensory experience caused by actual or potential injury that elicits protective motor and vegetative reactions, results in learned avoidance and may modify species-specific behaviors including social behavior." Such protective and modified behaviors were suggested as requirements for an animal in pain to reduce and prevent the relapse of injury, stimulate healing and enhance their survival in various habitats [26]. An aspect of this concept was suggested in dairy cattle as they could hide signs of noxious stimuli, perceived as an adaptive behavior to evade predators. Such event might contribute to the presence of painful claw lesions in cows without eliciting clinical lameness [27].

Another aspect is the significance of acute and chronic pain in lame cows. Generally, chronic pain is perceived as a sensation different from acute pain in animals. It is believed that certain stimuli or unceasing nociceptive events enhance the development of chronic pain [28]. Lameness is often categorized as acute or chronic based on the duration of the insult. Chronic cases were defined by higher locomotion score (LS) persisting for more than two weeks [7]. Nevertheless, prompt detection of lame cows is often lacking and contributes to chronic lameness events and hyperalgesia (abnormal increased sensitivity to pain). This is suggestive that such cases either cause more pain or cattle find it difficult to conceal them. Hence, an effective pain management during therapeutic claw trimming (CT) is vital [29].

5. Pain assessment in lame cows

In humans, pain can be directly assessed by a rating scale scored by a patient. However, the situation is different in animals, where physiological and behavioral alterations need to be gleaned for the same purpose [30]. Since pain is the cause of the altered gait in lame cows, the assessment of gait variables is considered as an indicator of the severity using locomotion scoring systems.

5.1. Manual or visual locomotion scoring systems (MLSS)

Locomotion scoring systems (LSS) are widely used for the detection of lame cows and monitoring lameness prevalence in dairy herds [31]. This system entails trained personnel scoring the cow on a numerical scale by observing certain gait and postural variables during locomotion. A nine-point scoring scale described by Manson and Leaver [32] was one of the first detailed LSS where parameters such as asymmetric gait, abduction, and reluctance to bear weight, and difficulty in turning and rising were used in categorizing lame cows. Thereafter, postural traits including arched back, head bobs, and stride length (gait measure) were introduced in classifying cows into five categories ranging from sound to severe lameness [33]. The five scale LS developed by Sprecher [33], which remains the most widely used in lameness related research [8]. Later, head bobs as a postural indicator of lameness using a four-level scoring scale was introduced [34], whereas tracking up and joint flexion was included by Flower and Weary [35]. Attempts to design standardized MLSS include the system developed by the Welfare Quality® Assessment Protocol for Cattle [36] and DairyCo. [37]. The presence of numerous MLSS depicts the lack of consensus and constraints on standardized measures of classifying lameness. The constraints in the application of MLSS include subjectivity and low inter-rater agreement [8], low sensitivity in detecting claw lesions as found during CT [38], influence of animal-based measures and environmental factors [39], and need for training and expertise [8].

5.2. Automated lameness detection methods

Based on the limitations in the use of MLSS, advances have been made in developing automated lameness detection systems or locomotion scoring systems (ALSS). The analysis of gait and postural pattern in ALSS is based on either one or combination of kinematic, kinetic, and indirect approaches. Kinematic principle involves the assessment of changes in specific body segment at a given time interval using automated systems such as accelerometers and image processing techniques [40, 41]. Parameters such as step length, step height and back curvature are measured in such systems to detect the degree of impaired locomotion. Also, techniques involving the attachment of accelerometers to the limbs to measure the accelerations during locomotion [42] and sensitive walkways containing pressure sensors [43] are related to kinematic principle.

On the other hand, kinetic gait analysis deduces information from the force applied to the limbs as seen in ground reaction force systems such as force plates or weight recording platforms [43]. Impaired locomotion is evaluated by measuring the force exerted on the floor by the hooves

when a cow walks on the force plates, or the weight distributed when standing on the platform [44]. Behavioral and production variables are used as indicators in the indirect approach. The alterations in daily lying behavior (duration and bouts) and standing time monitored by accelerometers were used in detecting lame cows [45] and specifically, those likely to develop claw horn lesions [22]. Likewise, live weight gain and milk meters were measured as production indicators of impaired locomotion using combined sensors [46]. A non-invasive tool for prompt diagnosis of claw lesions using infra-red thermography has also been demonstrated in few studies [47, 48]. Although the technique was not used in categorizing lame cows, increase in the surface temperature of the lame hind limb was consistent with the presence of claw lesion.

Overall, ALSS that present results positively correlated with MLSS are beneficial in prompt detection of lameness. For instance, the gait variables in the Gaitwise system [43] and improved images processing using 3D cameras [49] when compared to MLSS could detect mildly lame cows. Garcia et al. [50] also reported Sp and Se above 80% using milking robot and leg-mounted accelerometers. Recently, the extracted gait cycle variables (cow pedo-gram data) using high-frequency accelerometers were able to accurately detect hind limb lameness and foot pathologies [51]. The latter technique has practical advantage based on the little space required for their set-up and data availability. Nevertheless, there are certain constraints in application of ALSS. This include the use of MLSS as gold standard in validating various ALSS, high cost of installations [8], on-farm practical usage [43], and recently, farmers' preference or perception for lameness detection systems [52]. Additionally, there is need for improved methods of securing the cows' hoof on weight measuring platforms and capacity of detecting mild and severe claw lesions.

5.3. Assessing pain in lame cows using MLSS and ALSS

Researchers have considered the validation of pain in lame cows by investigating their response to various management protocols and comparing the findings between MLSS and ALSS.

5.3.1. Gait and behavioral variables

Gait attributes such as the use of visual LS and weight shifting between rear legs has been reported in studies relating to pain assessment in lame dairy cows. Clinically lame cows that were treated by the application of foot blocks and CT showed significant improvement in mean LS [53]. Similar results were reported following oligofructose induction of lameness [54] and lame cows injected with ketoprofen [55]. The administration of flunixin meglumine produced significantly less weight shifting between the rear limbs in lame cows indicative of pain relief [56], whereas combining the same drug with CT showed no improvement in LS [44]. Again, the weight borne on the rear limbs in lame cows improved following ketoprofen injection [57].

Regarding specific claw lesions, a positive association was reported between higher LS and increasing severity of SH [11]. In another study, a mean reduction of LS (1.5 points on 5 point scoring scale) was recorded in dairy cows affected with CHLs and infectious claw lesions one week after CT [10]. By using a pain scoring scale, DD affected cows that were treated

with salicylic acid had significantly lower pain score after 2 weeks compared with the control group [58]. These findings indicate management routine targeted at reducing pain in lame cows could be assessed by their response to gait variables.

Certain behavioral alterations have been investigated as measures of pain and stress in lame cows. In a clinical trial, an equal number (n = 42) of acutely lame cows with or without CHLs were observed during CT [59]. Lame cows showed significantly higher leg movement than the sound cows, indicating a greater response to pain. Similarly, rumination, self-grooming and feeding time were observed in 16 dairy cows divided into two equal groups (lame and non-lame) [60]. Results showed that all the behaviors were significantly less displayed in lame cows compared to non-lame herd mates. However, despite the improvement in weight distribution amongst the rear limbs in lame cows after CT, lying duration was not different between lame and sound cows [57].

5.3.2. Pressure or mechanical nociceptive threshold (MNT)

Primary nociceptors are stimulated in the manifestation of pain in lame cows. For instance, tissue damage at the site of injury results in impulse transmission to the central nervous system and subsequently interpreted as pain. The higher sensation to pain in lame cows is the mechanism interpreted in pain assessment when measuring the pressure or mechanical nociceptive threshold (MNT). Claw or foot pain is assumed to have a strong impact on limb locomotion. To objectively determine the associated pain, the amount of pressure required to initiate the withdrawal of the limb upon compression with hoof tester or algometer was proposed by Dyer et al. [61]. Less pressure was required for cows with higher LS to induce such limb retraction. As such, cows with higher LS could be experiencing more pain compared to those with lower LS. Also, by pressing the metatarsus (dorsal area) with a mechanical pin, the pressure at which the cow reacts is a good estimate of the threshold for pain sensation [62].

By comparing the association between MNT and LS, a lower MNT was found in cows with moderate to severe lameness (LS ≥3) compared with sound cows [63].

Leg withdrawal time has been employed as a parameter for MNT in lameness detection. For instance, hyperalgesia persisted in lame cows despite treatment with a non-steroidal and anti-inflammatory drug [53]. Another study reported no significant difference in the MNT of cows affected with active and healing DD lesions, which was suggestive of painful sensations at both stages [23]. Recently, MNT was measured after CT of cows affected with claw lesions [10]. The result showed that the MNT of cows with CHDLs increased significantly after trimming, but only tended in those with DD. The finding supports the use of CT in the management of pain associated with CHDLs. Also, the overall outcomes are signs of the multimodal approach required in addressing specific causes of lameness and the associated pain.

5.3.3. Physiological parameters and biomarkers

In response to pain, the physiological activity of the hypothalamus-pituitary–adrenal axis and the autonomous nervous system is activated resulting in the release of cortisol; the main glucocorticoid hormone [64]. Accordingly, a significant increase in the plasma concentration

of cortisol was reported in clinically lame cows compared to non-lame groups [65, 66]. Similar results were observed in lame cows compared to the untreated group after inducing lameness using oligofructose approach [54] and evaluation of cortisol level in the milk of lame cows [66]. However, in the assessment of cows affected with various degree of SH (mild, moderate, and severe), plasma cortisol level was not significantly different [11]. More research is needed to assess the pain associated with specific claw lesions causing lameness.

Based on the rumen acidosis laminitis complex in the development of CHLs, recent studies have investigated the role of haptoglobin (an acute phase protein elevated in response to inflammation) in lameness events. As such, increased concentration of haptoglobin was found in clinically lame cows and those affected with sole ulcers [54, 66], but only tended to occur in cows (not clinically lame) with severe SH compared with mild and moderate cases [11]. This shows that cows with claw lesions experience pain and discomfort even without being clinically lame.

Chronic pain and stress is another important aspect in lameness. Clinical parameters relating to cardiovascular function such as heart rate (HR) and variability parameters were reportedly increased in chronically lame cows [9]. Contrarily, the increment in measures such as HR, respiratory rate, and rectal temperature occurred only in severely lame cows, whereas mildly lame cows had significantly increased plasma level of cortisol and Hp [63]. One could infer that the latter biomarkers (Hp and cortisol) as more sensitive indicators of pain compared with clinical parameters. However, other conditions not associated with pain and periodic fluctuations might influence plasma cortisol concentrations [67]. Also, reliable changes in plasma cortisol level can only be ascertained following series of measurements before and after treatment. Factors such as behavioral changes, animal restraint, and tissue sampling might initiate stress and pain, thereby affecting the results.

Measurement of the coronary band temperature (CBT) and skin temperature (ST) around the limb using infrared thermography (IT) in lame cows has also been reported [47, 48]. Although significantly higher CBT was observed in cows with CHLs and DD compared with healthy cows, increased LS was only recorded in those with SU [47]. The authors concluded that CBT was a promising tool for the detection of SU. In addition, the higher lameness prevalence obtained using digital IT compared with MLSS was suggestive of better objective quality.

5.3.4. Blood biomarkers and gene expression

Recently, gene expression profiling relating to hematological parameters and physiological responses have been attempted for a better understanding of the mechanisms and associated pain in lameness events [11, 68]. Pro-inflammatory cytokines and acute-phase proteins (APPs) have been shown as potential biomarkers of bovine lameness [69]. A major function of pro-inflammatory cytokines (interleukins) is to stimulate the productions of APPs such as Hp and serum amyloid A (SAA) [69]. In a randomized control trial, gene expression coding for peripheral blood mononuclear cells (PBMCs), glucocorticoid receptor (GR-a), interleukin (IL-1B), and metalloproteinase (MMP-9) were not significantly different between lame and non-lame cows, despite indication of pain and stress by higher plasma cortisol in the former group [60]. In another study, a fold increase in the gene coding for interleukin (IL-2 and IL-10), MMP-13, and chemokine C-C motif receptor-5 (CCR5) were observed in lame cows

compared with non-lame herd mates [70]. In order to identify potential diagnostic biomarkers in transition dairy cows with the likelihood of developing lameness, Zhang et al. [62] found significant changes in serum concentrations of certain metabolites, pro-inflammatory cytokines and APPs in several weeks prior to when the cows became lame. Most importantly, in lame cows, serum lactate concentrations increased from 8 to 4 weeks prepartum and became more evident the week clinical lameness ensued.

Based on specific claw lesions, despite higher concentration of Hp was found in cows with severe SH compared with mild and moderate cases, no difference was recorded in the expression of genes associated with lameness amongst the various categories [59]. However, lame cows affected with sole ulcers compared to sound cows had higher or tendency of relative expression of the gene coding for cytokines (IL-1α, IL-1β, IL-10), MMP-13, GR-α, and Hp [11].

6. Impact of lameness on animal-based welfare measures

6.1. Feeding behavior and rumination

Feeding pattern is an essential behavior that influences the nutrition and welfare of the cow. The measures for feeding behavior are related to the duration and frequency expended in eating at feed bunk and number of visits after feed delivery. Cows with higher LS [71] or clinically lame [42] had significantly reduced feeding time, feeding frequency, and higher feeding rate compared with sound cows. Another study indicated that lower silage intake and less time spent feeding occurred in cows with mild gait alterations prior to when they became severely lame [72]. The prolonged lying duration in lame cows after feed delivery was suggestive of lower time spent standing to eat compared to sound cows [73]. These events could be more evident during peak production level when there is higher risk of lameness incidence. As shown by Palmer et al. [71], the significant reduction in feed intake (dry matter) was only present at early days in milk in cows with higher LS. These findings support the aftereffects of lameness on body condition loss. Nevertheless, periparturient feeding behaviors could influence the rate of body condition loss at early lactation, thus supporting the development of CHDLs from the negative impact on the digital cushion. This process could be triggered around calving as changes in standing duration could increase the pressure of the pedal bone on the corium.

Rumination is an innate behavioral need in cattle and, therefore, considered as a vital measure in evaluating their well-being [74]. Cows spend an average of 8 hours daily ruminating with the physiological benefits similar to sleep in humans [75]. Few studies have indicated negative associations between lameness and rumination [60, 76], whereas the results of other authors [51, 77] depicted no relationship. Recently, Beer et al. [78] developed a model for automated lameness detection via data obtained from leg-mounted accelerometers and nose-banded sensors. Although the best predictor for lameness was the model comprising of number of standing bouts and walking speed, significantly lower eating and ruminating time was observed in lame cows compared with non-lame group. More importantly, lame cows had fewer ruminating chews and boluses. Weigele et al. [4] using the same ALSS found similar outcomes in feeding behavior (eating time and jaw movements) between non-lame and moderately lame cows after corrective CT. These findings suggest that the impact of lameness on rumination could be dependent on the specific foot pathologies causing lameness.

However, two studies investigated the impact of specific claw lesions on feeding and postural behavior after CT [79, 80]. DD-affected cows ruminated more when standing, whereas such behavior only tended in those with SU compared with the healthy group [79]. Cows affected with infectious claw lesions spent less and more time in lying down and standing up, respectively and higher feeding rate compared to those with CHDLs [80]. Additionally, lying duration and LS decreased significantly after CT with no difference in ingestive behavior. Therefore, changes in postural and feeding behavior in lame cows could vary depending on the specific claw lesion and degree of severity. More research is required to quantify rumination efficiency and feeding behavior as related to claw lesions causing lameness.

6.2. Lying behavior

Lying behavior is an important activity in dairy cows with benefits such as conditions to rest after milking, effective rumination, greater space for other herd mates' movement, and increased perfusion of the mammary gland [81]. Conditions influencing the lying down duration could affect the budgeted time for other activities [82]. For instance, prolonged standing on hard floors and unhygienic resting surfaces could affect claw health and subsequent development of claw lesions. Evidence has shown that lame cows lie down for longer durations compared to healthy herd mates [22]. They also display frequent lying bouts as signs of the on-going discomfort [22].

The impact of specific claw lesions on lying behavior has been demonstrated in few studies. Cows affected with DD were found to have spent longer time lying down on concrete and abrasive floors [83]. Another author reported higher lying down duration in cows affected with DD compared to those with sole ulcers [84]. Lame cows with one or more CHDLs laid down significantly longer than sound herd mates [22]. Overall, the direction of the association between lameness and lying behavior requires more investigation as such changes might be consequences of lameness, or the other way around. Also, since other conditions aside lameness might affect lying behavior, the assessment of the behavior could proffer the need for further examination of the limb.

6.3. Social interaction with herd mates and estrus behavior

One natural herd interaction is social activity manifested in form of self-grooming and caudal licking. Since lame cows are in pain and distress, they are less likely to express such behavior compared to non-lame herd mates. Almeida et al. [60] in a randomized control trial reported significant reduction in self-grooming in lame cows compared to sound herd mates. Other researchers investigated the impact of flooring systems (rubber mats and concrete floors) on the aforementioned behaviors in lame and non-lame cows [85, 86]. Overall, self-grooming and caudal licking were displayed effectively in non-lame cows and preferably on soft cushioning floors than concrete floors. Cows find it easier to groom and lick other herd mates on rubberized floorings due to better comfort and greater slip resistance.

Estrus behavior is another important trait affected in lame cows. Events such as delayed cyclicity and low oestrus expression arising from the disturbance in hormonal function and follicular development were reported in lame cows compared to sound herd mates [87]. Claw lesions cause pain, increased plasma concentration of cortisol, and delayed activity of the

luteinizing hormone, thereby leading to impaired follicular growth [88]. Such disturbance in ovarian activity might delay estrus expression and detection necessary for successful inseminations. Other authors have linked the reduced conception rates in lame cows to lower standing duration to be mounted [88]. However, production losses in lame dairy cows are interlinked as feeding behaviors might lead to reduced intake of dry matter vital and energy balance needed for folliculogenesis and ovulation.

6.4. Hock condition

Hock conditions have been increasingly assessed as an indicator of dairy cattle welfare. Most especially, the lateral aspect of the hock is composed of little fatty tissues and muscles, thus making the area prone to traumatic injuries. Such injuries are generally referred to as "hock lesions" and they appear in form of hair loss, broken skin, visible wounds, localized or extensive swelling [89]. The hock condition score (HCS) is used in grading the severity of hock lesions. An example is the 4 point scoring scale developed by Gibbons et al. [90], which simplifies the manifestation of poor hock condition by measuring the area affected by hair loss, swelling or ulceration. Hock lesions have been reported as important causes of lameness in dairy herds [91]. As reviewed by Sadiq et al. [92], positive associations were reported between lameness and hock injuries in several cross-sectional studies. Cows with injured hocks were more likely (OR = 1.4) to be lame in a large Canadian study [18], while significant correlation was reported between lameness and hock lesions prevalence at animal and herd level [93]. The study designs presumed that lameness and hock injuries occur within the same time frame and the direction of the events need to be elucidated. However, monitoring the prevalence of both conditions could enhance the provision of better welfare, since factors influencing their occurrence are similar [94]. For instance, the severity of hock lesions and the risk of lameness might be related to the comfort of the lying surface. The increased lying duration in lame cows on hard and abrasive surfaces or beddings might precipitate hock injuries. Lameness could also result from severe hock injuries, possibly connected to slips and falls when cows are housed on highly slippery floors. Hence, preventive measures for hock lesions could potentially reduce lameness occurrence, thus improving dairy cow welfare.

6.5. Leg hygiene

Good animal welfare requires freedom from discomfort and disease. Maintaining herd cleanliness is a key approach to ensure adequate animal health. However, such practice remains a major challenge in intensively managed dairy facilities due to persistent contamination of stalls and resting surfaces with manure and urine. At cow level, leg hygiene is used as an estimate to overall herd cleanliness. Cook [95] developed a subjective leg hygiene scoring system by measuring the level of manure contamination of the lateral aspect of the rear limbs. The scoring system has been used to assess the relationship between leg hygiene and lameness occurrence. Accordingly, increased odds of clinical lameness [18] and prevalence of DD [96, 97] were reported in cows with poor leg hygiene. The study designs implied that dirty legs could either be a factor for lameness, or the other way round. Mechanical injury or softening of the digital skin and other sensitive areas of the claw might occur in conditions where the foot is exposed to manure slurry, thus aiding the occurrence of DD and other claw lesions.

Factors suggestive to influence such poor leg hygiene include inappropriate concrete floor designs for efficient drainage [98], usage of rubber mats [99], and cleaning frequency [97]. Nevertheless, changes in the budgeted time for essential activities in lame cows could be a factor. For instance, the prolonged lying down time, less activity and self-grooming in lame cows compared to sound herd mates could increase the exposure of the udder and limbs to manure contamination. Farmers might also accord little importance to lame cows, thus limiting the care for affected cows during routine cleaning.

6.6. Body condition score

Based on the manifested pain, reduced frequency of visits to feed bunk, lower feeding duration, and reduced capacity to compete for feeding space, it is expected for lame cows to lose body condition score (BCS). Nevertheless, the event could be the other way round, with cows in low BCS likely to develop CHDLs causing lameness [100]. The relationship between BCS and CHDLs stemmed from understanding the composition of the digital cushion (fatty pad) as an adipose tissue that annuls the contusive forces directed unto the pedal bone [101]. Hence, thinning of the DC from the mobilization of fats during negative energy balance could predispose to CHDLs incidence [102]. Recently, the reduced thickness of the DC and body condition loss was described as mechanisms for the development of CHDLs [15]. This complex relationship further depicts the multifactorial nature of lameness. Other theorized mechanisms such as ruminal acidosis laminitis complex, activation of metalloproteinase, and periparturient hormonal changes might come into play within the same time frame.

Considering the welfare implications of lameness, the freedom from hunger and thirst is one of the fundamental provisions of good animal welfare [2]. According to Whay and Shearer [3], BCS could be seen as an alternative indicator of hunger and body condition loss through reduced feeding duration, lowered competitiveness for feed, and negative energy balance as defensive mechanisms against on-going clinical lameness. If these events could precipitate suboptimal nutrition, then an association is present between hunger and lameness. Whilst there are sparse studies investigating the impact of lameness on drinking behavior, the alterations in budgeted time seen in lame cows could affect such behavior.

7. Conclusion

Lameness remains a condition with significant impact and burden to optimal welfare in dairy cows. With the majority of lameness events attributed to foot or claw lesions, assessment of the painful condition necessitates objective techniques for early detection of cows in discomfort prior to the development of obvious signs of lameness. ALSS are promising tools for the detection of lame cows. However, there applications in the assessment of pain associated with lameness require further evaluation. As such, the validation of various lameness detection systems could be more explored through the assessment of gait and behavioral variables, nociceptive threshold, physiological parameters, and blood biomarkers. In addition, consideration of specific claw lesions causing lameness is important to further understand the association between variables assessed in various lameness detection systems and validation

of the associated pain. Further works are needed to investigate the impact of specific claw lesions on dairy cow welfare. Such result could enhance the adoption of definite preventive measures and management practices to reduce the occurrence of lameness in dairy herds.

Acknowledgements

Conflict of interest

The authors declare no conflict of interest.

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