

# Impact of digital dermatitis on locomotion and gait traits of beef cattle

Anice D. Thomas, Karin Orsel, and Ed A. Pajor<sup>1</sup>

Faculty of Veterinary Medicine, University of Calgary, 3280 Hospital Drive NW, Calgary, AB T2N 4Z6, Canada

<sup>1</sup>Corresponding author: [eapajor@ucalgary.ca](mailto:eapajor@ucalgary.ca)

## Abstract

Digital dermatitis (DD) is an infectious skin disease and a major cause of lameness that significantly impacts cattle productivity and welfare. However, DD does not always result in lameness and lameness scoring systems are not specific to hoof pathologies. Digital dermatitis detection protocols could be improved by including gait traits most related to DD. The aims of this study were to 1) determine the association between DD **M-stage** (“M” for Mortellaro), locomotion, and gait traits: arched back (**AB**), asymmetric gait (**AG**), head bobbing (**HB**), tracking up (**TU**), and reluctance to bear weight (**WB**), and 2) determine which traits are most associated with DD. Cattle ( $n = 480$ ) from three feedlots were enrolled. Locomotion score (**LS**) and gait traits were assessed as cattle walked four strides along a dirt alleyway. Next, cattle were restrained in a chute, each hind foot lifted, and DD **M-stage** (absent, active, or chronic) determined. The association between presence of DD, LS, and gait traits were scored independently ( $n = 291$ ). For both LS and gait the lowest score represents normal and the highest score severely altered. Digital dermatitis presence was associated with higher LS ( $P < 0.001$ ). Odds ratios (**ORs**) for cattle with DD being lame or moderately to severely lame were 8.0 ( $P < 0.001$ ) and 10.1 ( $P < 0.001$ ) times more than cattle without lesions. Cattle with active lesions had the greatest odds of being lame (OR = 9.4;  $P < 0.001$ ). Digital dermatitis presence was associated with all gait traits ( $P < 0.001$ ), where AG (OR = 5.5;  $P < 0.001$ ) and WB (OR = 5.8;  $P < 0.001$ ) had the greatest OR for classifying cattle with DD as having altered gait. The OR for cattle with active lesions having altered gait was greatest for WB which was 6.0 ( $P < 0.001$ ) times greater than cattle without lesions. The OR for cattle with chronic lesions having altered gait was greatest for AG being 6.5 ( $P < 0.001$ ) times more than cattle without lesions. All gait traits had low sensitivity (**Se**) for detecting cattle with DD and varied from 6.7% to 55.8%. Locomotion score (Se 55.8%) and AG (Se 44.2%) were most predictive with positive predictive values of 76.6% and 74.3%, respectively. Specificity for all traits ranged from 94.1% for LS to 98.4% for WB with negative predictive values of 72.1% and 68.9%, respectively. In conclusion, LS, WB, and AG had the strongest association with cattle that had DD. Locomotion scoring that includes a focus on WB and AG is the best tool to detect DD in beef cattle.

## Lay Summary

Digital dermatitis (DD) impacts cattle health, productivity, and welfare; and is an emerging challenge for the beef industry. The most obvious clinical sign associated with DD is lameness; however, not all cattle afflicted with DD will become lame. Typically, locomotion scoring systems are used to assess lameness in cattle. These scoring systems are not specific for hoof pathologies, may not account for subtle changes in gait, and often reflect the needs of dairy cattle. Consequently, nonlame cattle with DD often go undiagnosed. By observing locomotion and other gait traits together we can identify gait traits that are most associated with DD in beef cattle and thereby develop targeted protocols for DD detection. Cattle with DD were consistently more associated with being lame compared to DD-free cattle. The two most important gait traits associated with cattle with DD were reluctance to bear weight (WB) and asymmetric gait (AG); however, their sensitivity to distinguish cattle with DD was low. These findings indicate that locomotion scoring that includes a focus on WB and AG is the best tool to detect DD in beef cattle.

**Key words:** behavior, feedlot cattle, hairy heel warts, hoof lesions, lameness, positive predictive value

**Abbreviations:** AB, arched back; AS, asymmetric gait; BW, body weight; DD, digital dermatitis; DOF, days on feed; HB, head bobbing; LS, locomotion score; M-stage, Mortellaro stage; NPV, negative predictive value; NRS, numerical rating score; OR, odds ratio; PPV, positive predictive value; Se, sensitivity; Sp, specificity; TU, tracking up; WB, reluctance to bear weight;  $\kappa_w$ , weighted kappa.

## Introduction

Digital dermatitis (DD), an infectious skin disease characterized by ulcerative hyperplastic, and hyperkeratotic lesions, was first reported in Italian dairy cattle in 1974 (Cheli and Mortellaro, 1974). Since then, DD has become endemic on dairy farms worldwide (Evans et al., 2016; Orsel et al., 2018) and is increasingly becoming a cause of concern in beef cattle (Sullivan et al., 2013; Kulow et al., 2017). In cattle, lesions typically manifest on the plantar aspect of hind feet and is a significant cause of infectious lameness (Read and

Walker, 1998). Lesions can be classified based on morphological changes over time using the **M-stage** (“M” for Mortellaro) scoring system developed by Döpfer et al. (1997) and modified by Berry et al. (2012). Within cattle operations, the M-stage scoring system is the most common method to classify DD.

In dairy cattle, among foot lesions, DD is most impactful on welfare because of the high incidence of the painful clinical stage (Bruijnis et al., 2012) and significantly impacts economics and production (Bruijnis et al., 2010; Orsel et al., 2018). A single case of DD in dairy cattle has been estimated to cost

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(US\$) on average between \$64.00 and \$133.00 (Cha et al., 2010; Dolecheck et al., 2019).

Lameness is recognized as the most important clinical sign of DD; cattle adjust their level of mobility and posture to compensate for the discomfort experienced during standing and walking, often having a toe-down stance or lifting and shaking the foot (Blowey and Sharp, 1988; Bassett et al., 1990; Read and Walker, 1998). Assessment for lameness in cattle is generally accomplished by observing cattle for changes in gait, posture, or other behaviors (Van Nuffel et al., 2015a). Subjective scoring systems have been developed to score lameness or locomotion, primarily for dairy cattle, based on defined gait and posture parameters agreed to be indicative of lameness (Manson and Leaver, 1988; Sprecher et al., 1997; Flower and Weary, 2006). The primary goal of dairy producers is long-term production of milk, achieved in part by keeping cows in the herd for an extended period. Good feet and legs, and good locomotion are characteristics of a good herd; therefore, dairy producers use locomotion scoring systems to create standards to track lameness severity over time. By doing this, dairies can reduce culling due to lameness as well as lessen the impact of lameness on milk production and fertility.

Conversely, the goal of feedlot operators is often to determine if cattle are lame or not, and provide treatment, avoiding losses related to lameness or impacting transportation opportunities rather than building a herd. Feedlot cattle spend a relatively short time in the feedlot, typically 60 to 200 d, before being shipped to the abattoir. With increasing farm sizes, subjective scoring systems become laborious, thus creating an opportunity for the development of technologies that can automatically measure locomotion and gait. Technologies such as accelerometers, force platforms, and others (Van Nuffel et al., 2015b) are available to objectively evaluate gait and locomotion. Many of these technologies have been predominantly developed and used within dairy production systems for adult cows. The use of similar technologies for feedlot cattle can be cost-prohibitive, and impractical for feedlot evaluations of beef cattle.

Using dairy scoring systems as templates, two scoring systems have been established for beef cattle, Tunstall et al. (2020) and Larson et al. (2014), the latter being used on commercial farms in North America. The locomotion scoring system (ZINPRO's Step-Up Locomotion Scoring System) by Larson et al. (2014) is a 4-level scoring system for beef cattle and includes four traits: reluctance to bear weight (WB), head bobbing (HB), stride length, and arched back (AB). The difference between levels in the scoring system is not equidistant and all four traits are not represented in all four levels. Within each level, cattle may not always present with a deviation in all the traits identified as important for that level. Locomotion systems like these evaluate lameness in general terms and are not specific to the cause of lameness but are useful and powerful tools to track lameness over time and to identify cattle requiring intervention. Recognizing the limitations of locomotion scoring systems there is value in determining whether specific gait traits, solely or in combination, are more associated with specific foot pathologies such as DD.

Diseases like DD are difficult to detect at disease onset and may not result in lameness. Identifying gait traits most associated with DD would provide producers with additional detection tools and cattle could benefit from earlier identification and treatment of DD. Changes in gait could vary based on type and location of foot lesion and scoring for specific

gait traits could prove more efficient when identifying cattle with DD rather than solely using a locomotion scoring system. Within dairy scoring systems a solid floor is essential where cows are expected to walk normally in a location they are familiar with, typically after milking. Lastly, scoring systems with multiple traits within each category proves more difficult to use on farms (Cramer, 2007) and it is not quite clear which gait traits are most important. This study had two objectives; the first was to determine the association between DD M-stages, locomotion, and gait traits: AB, asymmetric gait (AG), HB, tracking up (TU), and WB, and secondly to determine which traits are most associated with presence of DD in beef cattle.

## Materials and Methods

The University of Calgary Veterinary Services Animal Care Committee (AC17-0224) approved this study in accordance with the ethical principles of the Canadian Council on Animal Care. Written informed consent was obtained from participating feedlot owners.

### Cattle and management

The study was conducted between November 2018 and November 2019 at three commercial feedlots located in Alberta, Canada. On arrival at the feedlot, cattle (auction-derived) were enrolled in the study by way of stratified random sampling. In total, 480 cattle, comprised of heifers ( $n = 320$ ) and steers ( $n = 160$ ) with an initial mean body weight (BW) of  $279 \pm 67$  kg and  $340 \pm 77$  kg (BW  $\pm$  SD), respectively, were enrolled. Cattle were housed outside in 13 hay- or straw-bedded dirt pens, protected by windbreakers. Pen capacity typically ranged from 200 to 280 cattle per pen and stocking densities ranged from 25 to 35 m<sup>2</sup>. Cattle were fed a grain-based ration appropriate for their days on feed (DOF) twice per day. Cattle were observed for DD throughout the feeding cycle and were managed in accordance with the feedlot's management protocol.

### Cattle selection for assessment

Every 2 wk, by completing pen walks, while cattle walked in their pens, cattle were observed by three trained observers for the presence or absence of DD. Level of agreement between observers was assessed throughout the study and found to be good. Details on the DD training program employed, and level of agreement parameters are described in Thomas et al. (2021). The skin above the coronary band, between the heel bulbs on both hind feet, was assigned a DD M-stage score. The M-stage lesion scoring system classifies DD lesions into six stages: M0—normal skin; M1—ulcerative lesions < 2 cm; M2—ulcerative lesions > 2 cm; M3—healed lesions; M4—chronic lesions; and M4.1—chronic lesions with an M1 focus (Döpfer et al., 1997; Berry et al., 2012). Next, locomotion was observed, and a locomotion score (LS) assigned using ZINPRO's Step-Up Locomotion Scoring System (ZINPRO, 2013). The locomotion scoring system classifies locomotion on a 4-level numerical rating score (NRS) to determine lameness. The lowest score of 0 represents normal locomotion and the highest score of 3 represents severe lameness (Table 1). Throughout the feeding period, cattle suspected of having DD (DD lesion present or LS greater than 0 with DD lesion present) were selected for detailed locomotion and gait scoring in an alleyway. In total, 194 cattle were selected during pen

**Table 1.** Description of the numerical rating score used to score locomotion in beef cattle

| LS <sup>1</sup> | Clinical description | Description                                                                                                                                                                                                                                             |
|-----------------|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0               | Normal               | <ul style="list-style-type: none"> <li>• Animals walk normally</li> <li>• Hind feet land in a similar location to front feet</li> <li>• No apparent lameness or change in gait</li> </ul>                                                               |
| 1               | Mild lameness        | <ul style="list-style-type: none"> <li>• Animal exhibits shortened stride, dropping the head slightly</li> <li>• Does not exhibit a limp when walking</li> </ul>                                                                                        |
| 2               | Moderate lameness    | <ul style="list-style-type: none"> <li>• Animal exhibits obvious limp, favoring affected limb(s)</li> <li>• Limb(s) still bears weight</li> <li>• Slight head bob when walking</li> </ul>                                                               |
| 3               | Severe lameness      | <ul style="list-style-type: none"> <li>• Animal applies little or no weight to affected limb</li> <li>• Reluctant or unable to move</li> <li>• While walking, animal's head will be dropped and back arched, with head bob and limp detected</li> </ul> |

<sup>1</sup>LS, locomotion score; Step-Up Beef Cattle Locomotion Scoring System (ZINPRO, 2013).

walks for alleyway locomotion and gait scoring. At minimum, six cattle per pen were selected to represent all DD M-stages. Further, during routine rehandling events, another 116 cattle were selected from study pens for detailed locomotion and gait scoring in the alleyway. Rehandling events were in accordance with feedlot's processing schedule.

### Alleyway locomotion and gait assessment

Cattle locomotion and five gait characteristics were scored using videos of cattle walking through an alleyway, immediately before examination of feet in a squeeze chute. Cattle were moved individually through a dirt alleyway for a minimum of four complete strides. To encourage cattle to walk, feedlot personnel walked immediately behind cattle. The alleyway was fitted with video cameras to capture locomotion from the rear (Sony NEX-VG10, Sony, Tokyo, Japan) and sides (GoPro Hero 3+, GoPro, San Mateo, CA).

Cattle-specific identifiers were removed from the videos and replaced with a random number generated in Microsoft Excel (v16.0; Microsoft Corporation, Redmond, WA). An experienced observer (observer 1) watched the videos and scored each video separately for locomotion and gait characteristics. Each video was observed six times; once to score locomotion and the five gait traits individually. Locomotion was scored in accordance with the Step-Up Locomotion Scoring System previously described. Gait characteristics, AB, AG, HB, TU, and WB, were scored using the 5-level NRS described by Flower and Weary (2006). Level 1 is indicative of normal (unaltered) gait characteristic and level 5 indicative of extremely altered gait characteristic. Score characteristics are presented in Table 2. Three hundred and ten cattle were video recorded, three were not scored for locomotion, and 18 not scored for gait characteristics because of cattle running, stumbling, slipping, or stopping, resulting in a total of 291 cattle used for the final video analysis.

Based on a power calculation with the R package "irr" (R for Windows, R Foundation for Statistical Computing), the sample size required to determine intra- and interobserver agreement when assessing locomotion and gait was calculated. Sample size calculation was dependent on number of outcome categories and proportions per category; thus, sample size varied by gait trait and ranged from 10% to 20% of total video recordings. To estimate intraobserver reliability, observer 1 rescored video recordings selected randomly from the video data set at least 7 d after the last scoring session. To

estimate interobserver reliability, a second trained observer (observer 2) scored and rescored this same sample of recordings. Intra- and interobserver reliability was calculated using weighted kappa,  $\kappa_w$  (Cohen, 1968) with linear weights (Cicchetti and Allison, 1971). This measure of reliability is best suited for variables measured on an ordinal scale. Weighted kappa ( $\kappa_w$ ) can range from 0 (no agreement) to 1 (perfect agreement). Using the classification scale developed by Altman (1991), adopted from Landis and Koch (1977), a  $\kappa_w > 0.60$  indicates good agreement. Overall intra- and interobserver agreement for locomotion and gait traits are reported in Table 3. The strength of agreement was good to very good between observers for all traits.

### Clinical examination of feet

Immediately after walking through the alleyway, cattle were moved into a squeeze chute and feet lifted to confirm DD M-stage. Individually, hind feet were secured with a rope, lifted, and washed using water and a brush, to remove any dirt that was present, and then dried with paper towel. Observer 1 and observer 2 scored all hind feet for the presence or absence of DD lesions using the M-stage scoring system. Cattle were then assigned a DD status on the animal level; cattle that had a DD lesion on at least one hind foot were recorded as DD present ( $n = 104$ ) and cattle with no lesions on either hind foot were recorded as DD absent ( $n = 206$ ). Further, DD present cattle were subdivided in cattle that had active ( $n = 69$ ) or chronic ( $n = 35$ ) DD lesions. Cattle with active DD lesions presented with an ulcerative lesion (M1, M2, or M4.1) on one or both hind feet. Cattle with chronic DD lesions presented with a chronic lesion (M3 or M4) on one or both hind feet, with no hind foot presenting with an active lesion.

### Data analysis

All statistical analyses were conducted using IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, NY) and a  $P < 0.05$  was considered statistically significant. In cases of multiple comparisons, a Bonferroni correction was applied. The experimental unit was animal.

To determine the relation between DD and locomotion and gait traits, six cumulative odds ordinal logistic regression models were developed. These models calculated the probability of cattle with DD having a greater locomotion and gait score. The following covariates: feedlot, arrival BW, DOF, BW at assessment, average daily gain, and placement season were

**Table 2.** Numerical rating score used to score gait characteristics in beef cattle

| Gait <sup>1,2</sup> | Level | Description                                                                                                          |
|---------------------|-------|----------------------------------------------------------------------------------------------------------------------|
| AB                  | 1     | Flat back                                                                                                            |
|                     | 2     | Mildly arched back                                                                                                   |
|                     | 3     | Arched back                                                                                                          |
|                     | 4     | Obvious arched back                                                                                                  |
|                     | 5     | Exaggerated arched back                                                                                              |
| AG                  | 1     | Long and confident stride or step (symmetrical gait)                                                                 |
|                     | 2     | Slightly asymmetric gait                                                                                             |
|                     | 3     | Short strides or step (asymmetric gait)                                                                              |
|                     | 4     | Short and hesitant strides or step                                                                                   |
|                     | 5     | Very short, hesitant, and deliberate strides or step                                                                 |
| HB                  | 1     | Steady head carriage                                                                                                 |
|                     | 2     | Slight head bobbing                                                                                                  |
|                     | 3     | Head bobbing                                                                                                         |
|                     | 4     | Obvious head bobbing                                                                                                 |
|                     | 5     | Exaggerated head bobbing                                                                                             |
| TU                  | 1     | Hind hooves land on or in front of fore hooves                                                                       |
|                     | 2     | Hind hooves and front hooves do not track up (approximately 1 hoof distance between track of front and hind hooves)  |
|                     | 3     | Hind hooves do not track up (approximately 2 hooves distance between track of front and hind hooves)                 |
|                     | 4     | Hind hooves do not track up (approximately 3 hooves distance between track of front and hind hooves)                 |
|                     | 5     | Poor tracking up with short strides (approximately 4 or more hooves distance between track of front and hind hooves) |
| WB                  | 1     | All legs bear weight equally                                                                                         |
|                     | 2     | Slight limp can be discerned                                                                                         |
|                     | 3     | Limp can be discerned                                                                                                |
|                     | 4     | Reluctant to bear weight on at least one limb but uses that limb in locomotion                                       |
|                     | 5     | Inability to bear weight on the limb or more than one limb clearly affected                                          |

<sup>1</sup>Based on Flower and Weary (2006).

<sup>2</sup>AB, arched back; AG, asymmetric gait; HB, head bobbing; TU, tracking up; WB, reluctance to bear weight.

**Table 3.** Overall intra- and interobserver reliability, expressed as weighted kappa ( $\kappa_w$ ) for locomotion score (LS) and gait traits: arched back (AB), asymmetric gait (AG), head bobbing (HB), tracking up (TU), and reluctance to bear weight (WB) scored by two observers

| Trait | Intraobserver reliability |             |         | Interobserver reliability |             |         |
|-------|---------------------------|-------------|---------|---------------------------|-------------|---------|
|       | $\kappa_w$                | 95% CI      | P-value | $\kappa_w$                | 95% CI      | P-value |
| LS    | 0.876                     | 0.742–1.010 | <0.001  | 0.752                     | 0.549–0.955 | <0.001  |
| AB    | 0.828                     | 0.580–1.075 | <0.001  | 0.698                     | 0.462–0.935 | <0.001  |
| AG    | 0.871                     | 0.719–1.022 | <0.001  | 0.700                     | 0.525–0.875 | <0.001  |
| HB    | 0.909                     | 0.787–1.031 | <0.001  | 0.732                     | 0.572–0.892 | <0.001  |
| TU    | 0.797                     | 0.622–0.971 | <0.001  | 0.622                     | 0.403–0.841 | <0.001  |
| WB    | 0.928                     | 0.829–1.027 | <0.001  | 0.755                     | 0.545–0.965 | <0.001  |

offered to the model and through backward elimination, only significant covariates were considered for the final model. Feedlot and DOF were the only significant covariates that remained in the final logistic regression models. There were no problems with multicollinearity as assessed by inspection of correlation coefficients and Tolerance/Variance Inflation Factor values. The assumption of proportional odds was met, as assessed by a full likelihood ratio test comparing the fit of the proportional odds model to a model with varying location parameters.

To determine the probability of cattle with DD falling into one of two locomotion or gait categories, 12 binomial logistic regression models were developed. All covariates offered to the previous model were offered to these models and through backward elimination, only significant covariates remained. Continuous independent variables were found to be linearly related to the logit of the dependent variable as assessed by the Box–Tidwell procedure. Again, there were no problems with multicollinearity. Overall agreement was estimated by comparing locomotion and gait trait scores to DD M-stage (absence or presence). Sensitivity (Se), specificity (Sp), positive predictive value (PPV), negative predictive value (NPV), and overall accuracy were calculated.

## Results

### Distribution of locomotion and gait scores

Cattle distribution by DD M-stages and locomotion and gait scores are presented in Table 4. In total, 291 cattle were assigned both LS and gait scores. Among cattle with DD, 56% were classified as lame (LS  $\geq$  1) at time of assessment. In addition, cattle with DD were distributed across all five levels of most gait traits (except for AB), but only a few in level 5. Among cattle with DD, AG had the least number of cattle scored at level 1 and greatest number of cattle scored at level 5.

### Association between DD M-stage and LS

The results of the models used to estimate 1) the probability of cattle with DD having a greater LS, 2) the probability of classifying cattle with DD as lame, and 3) the probability of classifying cattle with DD as severely lame are presented in Table 5. DD M-stage had a significant association with LS in all models. Covariates, feedlot, and DOF remained in the final model; there were no significant 2-way interactions or confounding variables. The odds of cattle being lame (LS  $\geq$  1) was greatest for cattle with active DD lesions compared to cattle without lesions. Further, the odds ratio (OR) for cattle with active DD lesions increased when the LS threshold was changed to LS  $\geq$  2 (moderately to severely lame). The odds of being lame ( $P = 0.431$ ) or severely lame ( $P = 0.084$ ) was not different between cattle with active or chronic DD lesions. An increase in DOF was associated with an increase in odds of having a greater LS ( $P = 0.001$ ).

### Association between DD M-stage and gait traits

The association between DD M-stage and gait traits are presented in Table 6. The DD M-stage of cattle was significantly associated with gait scores in all models that estimated the probability of cattle with DD having a greater gait trait score or cattle having altered gait. Compared to other traits, AG (OR = 5.5) and WB (OR = 5.8) had the greatest OR for the



**Table 4.** Distribution of cattle scored in each level of locomotion score and gait score: arched back (AB), asymmetric gait (AG), head bobbing (HB), tracking up (TU), and reluctance to bear weight (WB), based on digital dermatitis (DD) M-stage: absence ( $n = 187$ ), active DD ( $n = 69$ ), and chronic DD ( $n = 35$ ) lesion

| Item | N   | LS <sup>1</sup> and gait <sup>2</sup> |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
|------|-----|---------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|      |     | Level 1                               |                 |                 | Level 2         |                 |                 | Level 3         |                 |                 | Level 4         |                 |                 | Level 5         |                 |                 |
|      |     | ND <sup>3</sup>                       | AD <sup>3</sup> | CD <sup>3</sup> | ND <sup>3</sup> | AD <sup>3</sup> | CD <sup>3</sup> | ND <sup>3</sup> | AD <sup>3</sup> | CD <sup>3</sup> | ND <sup>3</sup> | AD <sup>3</sup> | CD <sup>3</sup> | ND <sup>3</sup> | AD <sup>3</sup> | CD <sup>3</sup> |
| LS   | 291 | 162                                   | 32              | 14              | 14              | 11              | 11              | 11              | 20              | 8               | 0               | 6               | 2               |                 |                 |                 |
| AB   | 291 | 168                                   | 48              | 22              | 16              | 17              | 10              | 3               | 3               | 3               | 0               | 1               | 0               | 0               | 0               | 0               |
| AG   | 291 | 141                                   | 27              | 8               | 24              | 14              | 9               | 13              | 10              | 10              | 5               | 13              | 5               | 4               | 5               | 3               |
| HB   | 291 | 164                                   | 45              | 21              | 10              | 10              | 7               | 9               | 8               | 6               | 4               | 4               | 1               | 0               | 2               | 0               |
| TU   | 291 | 147                                   | 36              | 14              | 23              | 13              | 12              | 13              | 13              | 4               | 3               | 4               | 3               | 2               | 3               | 2               |
| WB   | 291 | 160                                   | 34              | 14              | 13              | 9               | 9               | 11              | 11              | 6               | 3               | 13              | 6               | 0               | 2               | 0               |

<sup>1</sup>LS, locomotion score; LS = 0 (normal), LS = 1 (mild lameness), LS = 2 (moderate lameness), LS = 3 (severe lameness).

<sup>2</sup>Gait, gait score; 1 = normal gait, 2 = mildly altered gait, 3 = altered gait, 4 = very altered gait, 5 = severely altered gait.

<sup>3</sup>ND, DD absent—no lesion present (M0); AD, active DD—ulcerative DD lesions (M1–M2–M4.1); CD, chronic DD—hyperkeratotic or proliferative DD lesions (M3–M4); based on Döpfer et al. (1997) modified by Berry et al. (2012).

**Table 5.** Odds ratio for the probability of classifying beef cattle with digital dermatitis (DD) as lame,  $n = 291$ 

| DD stage <sup>2</sup> | 4-level LS <sup>1</sup>  |         | LS $\geq 1$ or LS = 0    |         | LS $\geq 2$ or LS = 0    |         |
|-----------------------|--------------------------|---------|--------------------------|---------|--------------------------|---------|
|                       | OR <sup>3</sup> (95% CI) | P-value | OR <sup>4</sup> (95% CI) | P-value | OR <sup>5</sup> (95% CI) | P-value |
| DD present            | 7.6 (4.1–14.3)           | <0.001  | 8.0 (4.1–15.6)           | <0.001  | 10.1 (4.4–23.2)          | <0.001  |
| Active DD             | 9.5 (4.7–19.5)           | <0.001  | 9.4 (4.3–20.8)           | <0.001  | 14.9 (5.7–39.1)          | <0.001  |
| Chronic DD            | 5.6 (2.6–12.5)           | <0.001  | 6.4 (2.7–15.2)           | <0.001  | 5.5 (1.9–16.3)           | 0.002   |

<sup>1</sup>LS, locomotion score; LS = 0 (normal), LS = 1 (mild lameness), LS = 2 (moderate lameness), LS = 3 (severe lameness).

<sup>2</sup>DD present—DD lesion present; active DD—ulcerative DD lesions (M1–M2–M4.1); chronic DD—hyperkeratotic or proliferative DD lesions (M3–M4); based on Döpfer et al. (1997) modified by Berry et al. (2012); referent group = DD absent—no lesion (M0).

<sup>3</sup>OR, odds ratios for the probability of cattle with DD having a greater LS compared to cattle without DD.

<sup>4</sup>OR, odds ratios for the probability of classifying cattle with DD as lame (LS  $\geq 1$ ).

<sup>5</sup>OR, odds ratios for the probability of classifying cattle with DD as moderate to severely lame (LS  $\geq 2$ ).

probability of classifying cattle as having altered gait. Likewise, the OR for classifying cattle with DD as having severely altered gait was greatest for AG (OR = 8.2) and WB (OR = 17.9), compared to other gait traits. The OR for cattle with active DD lesions increased when the threshold for AG, HB, and WB was changed from gait level  $\geq 1$  to  $\geq 4$ , whereas no difference was observed for TU, and no cattle scored a level  $\geq 4$  for AB.

### Using LS and gait to identify cattle with DD

Using LS as a means of identifying presence of DD lesions had a Se of 55.8% and Sp of 86.6%, with PPV and NPV of 69.9% and 77.9%, respectively (Table 7). Sample prevalence was 35.7%. All gait traits had low Se for detecting cattle with DD and Se varied greatly from 36.5% to 6.7% for WB and AB, respectively.

## Discussion

To our knowledge, this is the first study to estimate the association between DD M-stages, LS, and gait traits in beef cattle. Cattle presenting with DD had greater odds of having a greater LS and gait score. This finding is similar to those of Thomsen et al. (2012) who reported the odds of finding DD in Danish dairy cattle increased with increasing LS. That

study did not however examine the impact of individual gait measurements. In our study, the traits most associated with beef cattle with DD being lame were, in order, LS, WB, AG, HB, TU, and AB. The top three order of importance did not change when cattle had active or chronic lesions. LS is multivariate and considering that all gait traits in our study were shown to be significantly associated with DD, this might explain why LS was most important and should continually be used by beef producers. In dairy cattle, gait traits have been shown to be correlated with LS (Chapinal et al., 2009; Schlageter-Tello et al., 2015). When looking specifically on dairy cattle with DD, Chapinal et al. (2009) reported no difference in gait traits among multiparous dairy cows in an early stage of DD and those without lesions using both an NRS and visual analog scales. Sample size was small for their study, which could explain why they were not able to distinguish between populations. Our results are not directly comparable to their study due to differences in scoring methodology, DD classification, and breed.

Gait traits WB and AG likely emerged as the most important traits due to the location of DD lesions and cattle trying to avoid the discomfort felt when the lesion touches the surface. Although WB and AG were most associated with cattle with DD, the Se of identifying cattle with DD using these traits was low. Using WB and AG solely to identify cattle with DD would therefore not be recommended and best

**Table 6.** Odds ratio for the probability of classifying beef cattle with digital dermatitis (DD) as having an altered gait: arched back (AB), asymmetric gait (AG), head bobbing (HB), tracking up (TU), and reluctance to bear weight (WB),  $n = 291$ 

| Gait | DD stage <sup>2</sup> | 5-level gait <sup>1</sup> |         | Gait $\geq 2$ or gait = 1 |         | Gait $\geq 4$ or gait = 1 |         |
|------|-----------------------|---------------------------|---------|---------------------------|---------|---------------------------|---------|
|      |                       | OR <sup>3</sup> (95% CI)  | P-value | OR <sup>4</sup> (95% CI)  | P-value | OR <sup>5</sup> (95% CI)  | P-value |
| AB   | Present               | 3.3 (1.7–6.4)             | <0.001  | 3.3 (1.7–6.4)             | <0.001  |                           |         |
|      | Active                | 3.2 (1.5–6.7)             | 0.002   | 3.2 (1.5–6.8)             | 0.002   |                           |         |
|      | Chronic               | 3.5 (1.5–8.1)             | 0.004   | 3.4 (1.4–8.1)             | 0.005   |                           |         |
| AG   | Present               | 5.1 (2.9–8.8)             | <0.001  | 5.5 (2.9–10.7)            | <0.001  | 8.2 (3.0–22.2)            | <0.001  |
|      | Active                | 5.5 (2.9–10.3)            | <0.001  | 5.1 (2.4–10.7)            | <0.001  | 8.9 (2.9–26.9)            | <0.001  |
|      | Chronic               | 4.6 (2.2–9.5)             | <0.001  | 6.5 (2.5–17.0)            | <0.001  | 6.8 (1.6–27.9)            | 0.008   |
| HB   | Present               | 3.1 (1.6–5.8)             | <0.001  | 3.3 (1.8–6.3)             | <0.001  | 3.3 (0.9–12.5)            | 0.075   |
|      | Active                | 3.3 (1.6–6.8)             | 0.001   | 3.6 (1.7–7.5)             | 0.001   | 4.4 (1.1–18.0)            | 0.036   |
|      | Chronic               | 2.7 (1.2–6.2)             | 0.018   | 3.0 (1.3–7.0)             | 0.012   | 1.4 (0.2–13.8)            | 0.757   |
| TU   | Present               | 3.0 (1.7–5.1)             | <0.001  | 3.0 (1.6–5.2)             | <0.001  | 3.8 (1.1–12.5)            | 0.031   |
|      | Active                | 3.1 (1.6–5.7)             | <0.001  | 2.7 (1.4–5.2)             | 0.004   | 3.2 (0.8–12.2)            | 0.091   |
|      | Chronic               | 2.8 (1.3–5.8)             | 0.007   | 3.4 (1.5–7.7)             | 0.004   | 4.9 (1.1–21.6)            | 0.038   |
| WB   | Present               | 5.8 (3.2–10.6)            | <0.001  | 5.8 (3.1–10.9)            | <0.001  | 17.9 (4.8–65.6)           | <0.001  |
|      | Active                | 6.4 (3.2–12.5)            | <0.001  | 6.0 (2.9–12.4)            | <0.001  | 25.2 (6.3–101.2)          | <0.001  |
|      | Chronic               | 5.1 (2.4–11.0)            | <0.001  | 5.5 (2.4–12.7)            | <0.001  | 9.6 (2.0–46.7)            | 0.005   |

<sup>1</sup>Gait, gait score; 1 = normal gait, 2 = mildly altered gait, 3 = altered gait, 4 = very altered gait, 5 = severely altered gait.

<sup>2</sup>DD present—DD lesion present; active DD—ulcerative DD lesions (M1–M2–M4.1); chronic DD—hyperkeratotic or proliferative DD lesions (M3–M4); based on Döpfer et al. (1997) modified by Berry et al. (2012); referent group = DD absent—no lesion (M0).

<sup>3</sup>OR, odds ratios for the probability of cattle with DD having a greater altered gait score compared to cattle without DD.

<sup>4</sup>OR, odds ratios for the probability of classifying cattle with DD as having altered gait (gait score  $\geq 2$ ).

<sup>5</sup>OR, odds ratios for the probability of classifying cattle with DD as having very altered or severely altered gait (gait score  $\geq 4$ ).

**Table 7.** Test characteristics<sup>1</sup> for locomotion and gait traits in differentiating beef cattle with digital dermatitis (DD,  $n = 104$ ) from cattle without visible foot lesions ( $n = 187$ )

| Trait <sup>2</sup> | Threshold <sup>3</sup> | Se (%) | Sp (%) | PPV  | NPV  | Accuracy |
|--------------------|------------------------|--------|--------|------|------|----------|
| LS                 | 1                      | 55.8   | 86.6   | 69.9 | 77.9 | 75.6%    |
| LS                 | 2                      | 34.6   | 94.1   | 76.6 | 72.1 | 72.9%    |
| AB                 | 3                      | 6.7    | 98.4   | 70.0 | 65.5 | 65.6%    |
| AG                 | 3                      | 44.2   | 88.2   | 67.6 | 74.0 | 69.1%    |
| AG                 | 4                      | 25.0   | 95.2   | 74.3 | 69.5 | 70.1%    |
| HB                 | 3                      | 20.2   | 93.0   | 61.8 | 67.7 | 67.0%    |
| HB                 | 4                      | 6.7    | 97.9   | 63.6 | 65.4 | 65.3%    |
| TU                 | 3                      | 27.9   | 90.9   | 63.0 | 69.4 | 68.4%    |
| TU                 | 4                      | 11.5   | 97.3   | 70.6 | 66.4 | 66.7%    |
| WB                 | 3                      | 36.5   | 92.5   | 73.1 | 72.4 | 72.5%    |
| WB                 | 4                      | 20.2   | 98.4   | 87.5 | 68.9 | 70.4%    |

<sup>1</sup>Sensitivity (Se), likelihood that cattle with DD scored equal or higher than the threshold; specificity (Sp), likelihood that cattle without DD scored lower than the threshold; positive predictive value (PPV), probability that cattle with altered locomotion and gait have DD; negative predictive value (NPV), probability that cattle with normal locomotion and gait do not have DD; accuracy, the ratio of correct results to all the results of a test.

<sup>2</sup>LS, locomotion score; AB, arched back; AG, asymmetric gait; HB, head bobbing; TU, tracking up; WB, reluctance to bear weight.

<sup>3</sup>Threshold = 1, LS  $\geq 1$ ; threshold = 2, LS  $\geq 2$ ; threshold = 3, gait score  $\geq 3$ ; threshold = 4, gait score  $\geq 4$ ; LS based on 4-level numerical rating score: LS = 0 (normal), LS = 1 (mild lameness), LS = 2 (moderate lameness), LS = 3 (severe lameness); gait score based on 5-level numerical rating score: 1 = normal gait, 2 = mildly altered gait, 3 = altered gait, 4 = very altered gait, 5 = severely altered gait.

practices should include using the LS to identify cattle that require close foot inspection. WB was reported by Chapinal et al. (2009) as a significant predictor of sole ulcers suggesting that WB as a standalone may not allow for discrimination between disease types. Se to identify cattle with DD was also low for all the other traits TU, HB, and AB. We did not evaluate all possible gait traits in this study and there are other gait traits such as joint flexion or stride length

that may be associated with cattle with DD and therefore an area for further exploration. Additionally, gait traits may be affected by DOF, and BW, and subjective, visual measures may not be sensitive enough to discern changes in locomotion and gait resulting from DD. This might be an area for exploration into using technologies (Van Nuffel et al., 2015b) or using other behaviors to identify cattle with DD (Thomas et al., 2021).

Cattle with DD were most associated with gait traits WB, and AG. Within our study only one animal had an AB score greater than level 3 indicating this trait may not add additional value when included in scoring systems for early detection of DD in beef cattle. In our study, AB was scored while cattle were walking, early LS systems for dairy cattle (Sprecher et al., 1997) included AB while standing and walking. Having not assessed our cattle for AB while standing we can't completely discount the value of measuring this trait and would suggest further investigation. The multitrait locomotion scoring system used in our study was developed for beef cattle. Although AB is included in that system, it is only included as a trait when cattle are severely lame implying that this trait may only be important in severely lame cattle. When assessing AB in dairy cattle O'Callaghan et al. (2003) reported that cows with DD and foot rot when compared to cows with sole ulcers and white line disease were more likely to be associated with lower AB scores, and cows with severe hoof lesions had increased AB severity when compared to mildly lame cows. Within our population only eight cattle were assigned an LS-3 which might explain why our animals did not show severely altered AB. Severely altered HB was also not associated with cattle with DD. These results are again similar to findings reported by O'Callaghan et al. (2003) who reported that foot lesions (sole ulcer and white line disease) were more likely to be associated with higher head carriage scores than DD and foot rot. Again, severe lameness was shown to be more associated with altered head carriage compared to mild lameness.

In conclusion, DD changes the gait pattern of beef cattle. Consistent with previous studies not all cases of DD result in lameness. Increased LS and gait traits scores were associated with an increased odds of cattle having DD lesions. LS is most predictive of cattle with DD and among gait traits WB and AG are most important for detection of cattle with DD. These results suggest that the most practical approach to identifying cattle with DD is to select cattle for close foot inspection based on an LS that includes a focus on WB and AG.

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## Conflict of Interest Statement

The authors declare no real or perceived conflicts of interest.

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