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A prospective longitudinal study of risk factors associated with cattle lameness in southern Alberta feedlots

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Abstract: The objectives of this study were to determine the incidence proportion of lameness in feedlot cattle and the associated risk factors. Lameness was studied in two southern Alberta feedlots over a 2 yr period. The incidence proportion of lameness was 36.3% for all calves pulled for treatment. Risk factors associated ($P < 0.0001$) with increased lameness included body weight (BW), type of cattle, source, stocking density, percentage of forage in the diet, season, precipitation 1 d before diagnosis, and average temperature range 3 d prior to diagnosis. As BW ($P < 0.001$) increased, the odds of becoming lame also increased. Yearlings and Holsteins had greater ($P < 0.001$) incidence of lameness than respiratory disease. The odds of becoming lame decreased ($P < 0.001$) with increased pen density and percentage of forage in the diet. Lameness was greatest in spring ($P < 0.001$) with the odds of becoming lame being more likely ($P < 0.001$) with increased precipitation and temperature range ($P < 0.001$). Use of a multifactorial approach including animal, managerial, and environmental factors in a single analysis will improve our understanding of the risk of increased lameness and aid in development of strategies to reduce its incidence in feedlots.

Key words: beef, feedlot, lameness, risk factors.

Résumé : Les objectifs de cette étude étaient de déterminer la proportion d'incidence de boiterie dans les bouvillons de parcs d'engraissements et les facteurs de risques qui y sont associés. La boiterie a été étudiée dans 2 parcs d'engraissement du sud de l'Alberta au cours d'une période de 2 ans. La proportion d'incidence de boiterie était de 36,3 % pour tous les veaux tirés pour traitement. Les facteurs de risque associés ($P < 0,0001$) à l'augmentation de boiterie incluaient le poids corporel (BW — « body weight »), le type de bouvillon, la source, la densité du cheptel, le pourcentage de fourrage dans la diète, la saison, la précipitation 1 jour avant diagnostic, et la plage moyenne de températures 3 jours avant le diagnostic. À mesure que le BW augmentait ($P < 0,001$), les risques de boiterie augmentaient aussi. Les bovins âgés d'un an et les holsteins avaient une plus grande ($P < 0,001$) incidence de boiterie que de maladie respiratoire. Les risques de boiterie diminuaient ($P < 0,001$) avec l'augmentation de la densité dans l'enclos et le pourcentage de fourrage dans la diète. L'incidence de boiterie était plus grande ($P < 0,001$) au printemps avec les risques de boiterie plus probable ($P < 0,001$) avec l'augmentation de précipitation et de plage de température ($P < 0,001$). L'utilisation d'une approche multifactorielle, qui inclut les facteurs reliés à l'animal, la gestion, et l'environnement, dans une seule analyse améliorera notre compréhension des risques de boiterie accrue et aidera au développement de stratégies pour réduire son incidence dans les parcs d'engraissement. [Traduit par la Rédaction]

Mots-clés : bœuf, parc d'engraissement, boiterie, facteurs de risque.

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Introduction

Lameness is defined as a deviation in gait resulting from pain or discomfort associated with hoof and leg injuries and disease (Greenough 1997). Given its association with pain, lameness is a significant welfare issue in all livestock. Although lameness has been well documented in dairy cattle (von Keyserlingk et al. 2012; Solano et al. 2015; Westin et al. 2016), there is a lack of peer-reviewed scientific studies evaluating lameness in North American feedlot cattle. An American feedlot study reported that lameness accounted for 16% of all health problems and 70% of all unfit sales cattle (Griffin et al. 1993), and a survey of US feedlot managers and veterinarians estimated that 10% of all mortality was due to lameness for cattle housed in dirt-floored pens (Terrell et al. 2014). With respect to Canadian studies, Tessitore et al. (2011) found the prevalence of lameness in feedlot chronic pens varied between 32.8% and 52.8%, and a study conducted in Alberta feedlots found that lameness accounted for 32.3% of all cattle diagnosed with a disease (Davis-Unger et al. 2019). Given the high prevalence of the disease coupled with the low number of studies, it is not surprising that lameness has been identified as a welfare priority in North American beef cattle and hence requiring additional research (Tucker et al. 2015). Understanding the risk factors and prevalence of lameness is necessary to reduce pain and improve feedlot economics.

Reported risk factors associated with lameness in feedlot cattle include handling events (Green et al. 2012), muddy, frozen or excessively dry pen conditions (Stokka et al. 2001), and animal type or gender (Davis-Unger et al. 2019). However, there are many risk factors associated with lameness in feedlot cattle that have not been studied such as diet composition, stocking density, or changes in ambient temperature. The objectives of this study were to determine the incidence of lameness, and identify risk factors related to animal, feedlot management, and environmental factors in two southern Alberta feedlots.

Material and Methods

All methods were approved by the Lethbridge Research and Development Center Animal Care Committee (protocol No. 1325).

Cattle lameness was studied in two large (>10 000 head capacity) feedlots located in southern Alberta over a 2 year period (June 2013 to May 2015). Both feedlots consisted of open dirt pens with 20% porosity wind break fencing to the west, a feed bunk in front facing a feed truck alley and one water trough. Average pen size was 2000 m^2, and the average number of calves per pen was 190. During winter months, straw bedding was added at the back of the pens as needed following snow or rain. Southern Alberta has a semi-arid, temperate climate with hot, dry summers and cold, sunny, dry winters. However, chinook winds during the winter months can increase ambient temperature from well below 0 °C to above freezing in a few hours causing wet and muddy pen conditions.

Animal and health records obtained from the database (feedlot 1: Medlogic, Veterinary Agri-Health Services, Airdrie, AB, Canada; feedlot 2: Fusion, SSG Fusion Ltd, Picture Butte, AB, Canada) were used to document risk factors associated with lameness as described below.

Animal and health factors

Animal and health data included gender (steers or heifers), source (ranch or auction), type of cattle (fall placed calves, winter placed, yearling, or Holstein), body weight (BW) at the time of diagnosis classified into one of three categories (130–325 kg, 326–499 kg, or >500 kg), days on feed (DOF), and cause of morbidity.

Feedlot management factors

Feedlot management data included feedlot identification, diet composition (% forage and % grain), use of a beta-agonist (zilpaterol chlorhydrate, ractopamine hydrochloride, or none), and bunk (cm·head^{-1}) and pen density (m^2·head^{-1}).

Environmental factors

Data for environmental factors included average ambient temperature range (°C), temperature humidity index (THI), and precipitation (mm). Each measurement was obtained 7, 3, and 1 d prior to the day lame cattle were pulled for assessment and possible treatment. Data loggers (HOBO U23 Prov2, Onset, Bourne, MA, USA) with the ability to measure temperature and relative humidity were used to calculate average temperature range as well as a THI value, and the closest weather station to each feedlot was used to record precipitation. Season was recorded as spring (20 Mar.–20 June), summer (21 June–21 Sept.), fall (22 Sept.–21 Dec.), or winter (22 Dec.–19 Mar.).

Cause of lameness was determined by two researchers from the Agriculture and Agri-Food Canada Lethbridge Research and Development Centre (LRDC, Lethbridge, AB, Canada) experienced in conducting visual assessments of lesions on lame cattle. Once weekly, the two trained researchers visited each feedlot to assess the legs and feet of individual cattle identified in healthy pens for treatment by the feedlot staff, and corroborate agreement regarding the cause of lameness. Cattle in the hospital pens were not evaluated. On the morning of the visit, feedlot staff placed all lame cattle (pulled that day) into a holding pen next to a handling facility until the assessments could be done. All lame cattle were moved calmly to facilitate assessment of lameness according to a five-point gait scale modified from Sprecher et al. (1996), where they walked at a normal pace along a clean flat-surfaced dirt alley (approximately

Table 1. Description of the feedlot morbidity included within the eight morbidity types for analysis.

Category	Causes of morbidity included in each category	Incidence (% per year)
Musculoskeletal/ lameness	Foot rot, digital dermatitis, injury, joint infection, toe tip necrosis, laminitis, lame no swelling	36.3
Respiratory	AIP, BRD, diphtheria, and honker[a]	57.7
Digestive tract	Bloat, bloat surgery, and grain overload	1.9
Nervous	Nervous disease	0.2
Reproductive	Calving, metritis, retained placenta, buller, castration, and prolapse	3.2
Other	Abscess, drug reaction, ear infection, pink eye, diarrhea, water belly, and others	0.7

Note: AIP, acute interstitial pneumonia; BRD, bovine respiratory disease.
[a]Honker: Cattle that have tracheal edema and hemorrhage causing coughing, dyspnea, and respiratory stertor.

17.5 m in length) leading to the handling facility. Each lame animal was then moved to the handling facility and restrained in a squeeze chute where its affected limb was lifted (with the exception of problems in the upper leg or joint infection), and the claw was cleaned with a brush and disinfectant (Prepodyne Gen, West Penetone, Edmonton, AB, Canada) to facilitate identification of the cause of lameness. Causes of lameness were classified as joint infection (lower limb), injury (lower limb), upper limb lameness, laminitis (observed as slipper foot), toe tip necrosis, foot rot (FR), digital dermatitis (DD), or unknown. Multiple causes of lameness in a single animal were also recorded. All assessed cattle were placed back into their home pens or hospital pens following the evaluation of their legs and feet and treatment if needed.

Data management and statistical analysis

The database contained 9719 calves that were treated for disease or injury (musculoskeletal/lameness, respiratory, digestive, nervous, reproductive, and other diagnosis; Table 1). However, each time, the calf was pulled a new entry was made resulting in a total of 18 096 entries or records. The number of entries per calf (times they were pulled) varied between 1 (7117 calves) and 8 (1 calf) with a median and average entry per calf of 1 and 1.3, respectively. Records of animals pulled with the same disease (Table 1) within 7 d of the initial entry as well those with missing identification or values that were considered out of normal range (error values or outliers) were removed from the database. The final database contained a total of 11 374 entries of calves that were pulled and treated for disease or injury.

Descriptive statistics were calculated using Proc Tabulate within SAS version 9.4 (SAS Institute Inc., Cary, NC, USA) to describe all the variables for each factor (animal, managerial, and environmental). The incidence proportion of lameness was determined for each categorical variable, whereas descriptive statistics (N, mean, standard deviation, minimum, $Q1$, median, $Q3$, maximum, and number of observations with missing value) were calculated for continuous variables within each category. Categorical variables were gender, source, type of cattle, BW category, use of beta-agonist, and season. Continuous variables were DOF, diet composition, bunk density, pen density, ambient temperature range, THI, and precipitation.

A collinearity test using a Pearson's correlation and a Spearman's correlation was performed to identify the variables with high correlation ($r \geq 0.8$) such as BW category and DOF, average ambient temperature range, and temperature humidity index obtained 7, 3, and 1 d prior to cattle when pulled, and % of grain and % of forage.

Logistic regression (Proc Logistic, SAS Institute Inc., Cary, NC, USA) was used to identify the association between lameness and risk factors compared with respiratory disease because disease associated with digestive, nervous, reproductive, and other diagnosis causes only accounted for 6% of all pulled cattle; animals with those diagnoses were excluded from the analysis. The selection of significant variables for all models was carried out by backward selection using the type III analysis of effects. Three logistic regressions were performed independently for variables related to animal characteristics, feedlot management, and environmental factors. Interaction terms between variables were introduced into the model for each group of variables and were eliminated if not significant. Predictors with a univariate association of $P \leq 0.05$ for each factor analysis were retained in the final model. The final model was used to determine the factors associated with diagnosis: lameness versus respiratory. Significance was established at $P \leq 0.0001$. For each variable, the estimated parameters and odds ratios were reported. Estimated least square means and the estimated odds ratios were determined for each pair of categorical data, whereas the odds ratios for continuous data was determined using the estimated increase (× units) for each variable. The fit of the final model was assessed based on the receiver operating characteristic curve associated with the model and the lowest Akaike information criterion value.

Results and Discussion

Incidence proportion of lameness and characterization

In the present study, lameness accounted for 36.3% of all treated calves over the 2 year study (30.3% of lameness year 1 and 42.2% of lameness year 2) making it the second most recognized disease in both feedlots after respiratory disease (57.7%; Table 1). Feedlot A accounted for 35.1% of lameness and 19.7% of lameness in years 1 and 2, respectively, whereas feedlot B accounted for 64.9% and 80.3% of lameness in years 1 and 2, respectively. An earlier (1993) study assessing lameness in five large western Nebraska feedlots reported that lameness only accounted for 16% of all health problems (Griffin et al. 1993); roughly half of the proportion observed in the present study. A more recent study assessing lameness in 28 Southern Alberta feedlots over a 10 year period found 32.3% of all health problems were due to lameness (Davis-Unger et al. 2019) which is in agreement with the findings of the present study. Possible reasons for the substantial increase in the proportion of lameness observed between the older and more recent studies may be explained by steadily increasing carcass weights over the last 20 years. For example, beef carcass weights at Canadian abattoirs increased by 76 kg between 1993 and 2018 (Statistics Canada 2019), and Wells et al. (1993) observed a 1.9-fold increase in the odds of clinical lameness for each 100 kg increase in BW in dairy cows. This relationship between BW and lameness was also observed in the present study and is described below. In addition, a growing number of feedlots finish dairy steers, which may increase the risk of lameness associated with digital dermatitis in all feedlot cattle; it is possible that dairy origin calves bring DD into a feedlot as DD has been commonly reported in dairy herds compared with beef cattle (Sullivan et al. 2013). Other factors related to production intensification such as high pen density, pen condition or feedlot management may also play a role in increased lameness between studies. However, further research could elucidate if these differences reflect true trends in the incidence proportion of lameness or are related to factors such as the ability of feedlot staff to properly identify and diagnose the disease playing a key role in documenting the proportion of animals suffering lameness.

A total of 4395 calves were diagnosed with lameness. The most common cause of lameness was FR (41.8%; $n = 1837$) followed by DD (25.5%; $n = 1121$). Lameness was also associated with problems in the upper limb (5.9%; $n = 259$), and lower limb [joint infection (5.5%; $n = 242$), injury (4.9%; $n = 215$)], toe tip necrosis (3.9%; $n = 171$), and laminitis (1.5%; $n = 66$). However, 8% ($n = 352$) of the cattle had unknown causes of lameness, whereas 3% ($n = 132$) had more than one cause of lameness (86% FR and DD on the same foot). Similar findings were reported by Currin et al. (2005) and Step et al. (2015), who found FR to be the most commonly diagnosed cause of lameness within feedlots. Davis-Unger et al. (2019) also observed FR as the main cause of feedlot lameness followed by joint infections; however, only four causes of lameness were documented in their study that used feedlot records where the diagnosis was performed by feedlot staff that may or may not have been trained to identify causes of lameness observed in the present study. In a study conducted in Kansas and Nebraska where feedlot staff had been trained to identify different causes of lameness based on a diagnostic algorithm, the most common cause reported was upper limb lameness followed by septic joints (Terrell et al. 2017). The authors attributed the low incidence of FR to lesion misclassification by the feedlot staff. Differences observed in the cause of lameness between Terrell's and the present study may also be explained by weather, type of cattle, or feedlot management.

Risk factors associated with lameness prevalence

Lameness in dairy cattle is well known to be a multifactorial disease (Faye and Lescourret 1989; Chapinal et al. 2013; Solano et al. 2015). To date, only one published study has assessed risk factors associated with lameness in feedlot cattle under the North American production system (Davis-Unger et al. 2019) where both cattle type and gender effects were considered. The present study is the first to evaluate lameness using a multifactorial approach including animal, managerial, and environmental factors in a single analysis.

When all the significant factors for animal, management, and environment were combined, BW, type of cattle, source, pen density, percentage of forage in the diet, season, precipitation 1 d before diagnosis and average temperature range 3 d before diagnosis were found to be statistically significant ($P < 0.001$; Table 2). No interactions among factors were included in the model because the best receiver operating characteristic curve associated with the model (AUC of 0.88) indicated the accuracy of the model was greatest when the interactions were not included.

The estimated percentage of lame cattle pulled for treatment for BW categories 130–325 kg, 326–499 kg, and >500 kg was 17.46% [$IC_{95\%} = (14.94, 20.29)$], 52.77% [$IC_{95\%} = (49.03, 56.47)$], and 85.90% [$IC_{95\%} = (83.33, 88.13)$], respectively. Body weight was a significant factor (Wald $\chi^2 = 886.52$; $P < 0.001$) in the model where lame cattle were found to be heavier ($P < 0.0001$) than those diagnosed with respiratory disease (Table 2). These results may be explained by the fact that the incidence of BRD is greatest within the first 30 d after arrival to the feedlot when lighter weight receiving calves are exposed to many pathogens due to commingling in combination with the stressors such as of shipping, weaning, the vaccination, which are known to compromise the immune system (Babcock et al. 2010; Taylor et al. 2010). The odds of cattle weighing 326–499 kg and >500 kg becoming lame were 5.26 and 33.33 times greater than the calves

Table 2. Analysis of maximum likelihood estimates for risk of becoming lame according to animal, managerial, and environmental factors in two southern Alberta feedlots over a 2 year period.

Parameter	Estimate	Standard error	Wald χ^2	Pr > χ^2
Intercept	2.2923	0.1943	139.2083	<0.001
Body weight category				
130–325 kg	−3.3603	0.1143	864.1684	<0.001
326–499 kg	−1.6959	0.0791	459.1978	<0.001
>500 kg	referent	—	—	—
Type of cattle				
Fall placed calves	−1.0098	0.0870	134.6747	<0.001
Holstein	−0.4829	0.1099	19.2950	<0.001
Winter placed calves	−0.7907	0.0945	69.9451	<0.001
Yearlings	referent	—	—	—
Source				
Auction	−1.1842	0.1327	79.5978	<0.001
Ranch	referent	—	—	—
Pen density ($m^2 \cdot calf^{-1}$)	−0.00337	0.000404	69.5560	<0.001
Forage in diet (%)	−0.00190	0.00151	159.4357	<0.001
Season				
Spring	1.3773	0.0818	283.2837	<0.001
Summer	0.6278	0.0954	43.3465	<0.001
Fall	−0.2469	0.0837	8.7079	0.0032
Winter	referent	—	—	—
Precipitation (mm)[a]	0.436	0.0107	16.4547	<0.001
Average temperature range (°C)[b]	0.0734	0.0691	112.8834	<0.001

[a]Total precipitation collected 1 d prior to cattle being pulled for assessment and possible treatment.
[b]Average ambient temperature rage 3 d prior to cattle being pulled for assessment and possible treatment.

weighing 130–325 kg and 5.55 times greater in calves >500 kg than those that were 326–499 kg (Table 3). Lameness caused by injury, swollen joints, or problems of the upper limb have been associated with handling. For example, Green et al. (2012) observed an increase in lameness after processing at arrival, indicating it was more prevalent in younger, lighter weight cattle after they enter the feedlot in the fall. The predominant causes of lameness in the present study were FR and DD, which occurred primarily in the spring when the cattle were heavier, and pen conditions would be favorable to those types of lameness. These findings are in agreement with another Alberta study conducted by Davis-Unger et al. (2019).

Cattle type was also associated (Wald $\chi^2 = 137.99$; $P < 0.001$) with lameness (Table 2). Yearlings and Holstein cattle had greater incidence of lameness than respiratory disease (Table 2). The estimated percentage of lameness for fall placed, winter placed, yearling, and Holstein cattle was 42.13% [$IC_{95\%}$ = (38.73, 45.60)], 47.54% [$IC_{95\%}$ = (43.22, 51.89)], 66.64% [$IC_{95\%}$ = (62.25, 70.77)], and 55.21% [$IC_{95\%}$ = (49.64, 60.66)], respectively. Yearlings had 2.77, 2.22, and 1.62 greater odds of becoming lame than fall placed, winter placed, and Holstein calves, respectively. We speculate that these differences may be due to previous handling experience and or temperament of the cattle. For example, yearlings are typically housed on pasture for a longer period of time before being placed into the feedlot (compared with calves) and are generally more reactive as they are usually handled infrequently. Handling increases the prevalence of lameness as observed by Green et al. (2012) in a large commercial feedlot after processing. Additionally, stressed cattle that are more temperamental tend to congregate in a chosen corner of their new pen, having larger flight zones, and therefore, the risk of becoming lame may increase in these cattle as they may be more likely than calm cattle to slip and fall or hit gates and (or) fences (Noffsinger et al. 2015). In addition, fractious behaviour would increase the risk of injury to the interdigital space whereby pathogens associated with the lesions could enter. Furthermore, yearling calves are heavier than the other type of cattle when pen conditions are favorable to infectious disease such as FR and DD, and as described above, heavier calves had greater odds of becoming lame. Holstein calves had 1.36 and 1.69 greater odds of becoming lame than fall and winter placed calves, respectively (Table 3). A significant proportion (42.32%) of Holstein calves were diagnosed with DD, the second most common type of lameness in feedlot cattle

Table 3. Analysis of odds ratio estimates for risk of becoming lame according to animal, managerial, and environmental factors in two southern Alberta feedlots over a 2 year period.

Parameter	Odds ratio	95% Wald confidence limits
Intercept		
Body weight category		
326–499 kg vs. 130–325 kg	5.26	4.34–6.66
>500 kg vs. 130–325 kg	33.33	20.00–33.33
326–499 kg vs. >500 kg	0.18	0.15–0.22
Type of cattle		
Holstein vs. fall placed calves	1.69	1.28–2.22
Holstein vs. winter placed calves	1.36	1.02–1.81
Holstein vs. yearlings	1.62	1.22–2.13
Fall placed calves vs. winter placed calves	0.80	0.65–0.99
Fall placed calves vs. yearlings	0.36	0.29–0.46
Winter placed calves vs. yearlings	0.45	0.36–0.58
Source		
Auction vs. Ranch	3.22	2.50–4.16
Pen density ($m^2 \cdot calf^{-1}$)	0.997	0.996–0.997
Forage in diet (%)	0.981	0.978–0.984
Season		
Spring vs. summer	2.12	1.67–2.69
Spring vs. fall	5.07	4.00–6.44
Spring vs. winter	3.96	3.21–4.89
Summer vs. fall	2.40	1.87–3.07
Summer vs. winter	1.87	1.47–2.39
Winter vs. fall	1.28	1.03–1.58
Precipitation (mm)[a]	1.045	1.023–1.067
Average temperature range (°C)[b]	1.076	1.062–1.091

[a]Total precipitation collected 1 d prior to cattle being pulled for assessment and possible treatment.
[b]Average ambient temperature rage 3 d prior to cattle being pulled for assessment and possible treatment.

compared with fall placed calves (6.42%), winter placed calves (17.91%), and yearlings (13.71%). The lower incidence of respiratory disease in Holstein calves (10.68%) and yearlings (16.45%) may explain the greater odds of becoming lame compared with fall and winter placed calves. Winter placed calves had 1.25 greater odds of becoming lame than fall placed calves (Table 3).

Cattle source was a predictor of lameness (Wald $\chi^2 = 79.59$; $P < 0.001$) (Table 2). The estimated percentage of lame cattle coming from a ranch was 67.12% [$IC_{95\%} = (61.14, 72.58)$] compared with 38.44% from an auction [$IC_{95\%} = (38.44, 40.34)$]. The odds of becoming lame when calves were sourced from a ranch were 3.22 times more likely than when they were sourced from an auction (Table 3). These results were unexpected as the number of risk factors is greater in auction market cattle (time at the auction, time in transit, loading and unloading, and walking on abrasive surfaces) which may also increase the incidence of lameness. However, it is well documented that the risk of respiratory disease is greater in auction market than ranch-derived calves (Gummow and Mapham 2000; Step et al. 2008) as a result of the increased stress associated with multiple transportations, handling, and commingling that can increase exposure to pathogens (Taylor et al. 2010). Factors at the auction market may have a greater impact on respiratory disease than lameness. Consequently, further research is needed to understand the role of those additional factors.

Pen density was another factor that influenced the odds of becoming lame (Wald $\chi^2 = 69.55$; $P < 0.001$) (Table 2). When the number of cattle within a pen increased by 10, the odds of becoming lame were 0.96 times greater than that of the original pen density, indicating that increased pen density did not increase lameness (Table 3). These results were not expected as greater pen densities may reduce lying due to limited lying space as observed in Fregonesi et al. (2007) in dairy cattle. Limited lying space was highly correlated with reduced lying time, and reduced lying time was correlated with increased claw lesions (Leonard et al. 1996), which may be related to the amount of time the claws are exposed to damaging mechanical forces or prolonged contact with wet conditions (Geenough 1997), as well as increased aggressive interactions (Fregonesi and Leaver 2002). However, as we are comparing the odds of becoming lame with the odds of having respiratory disease in a population of calves pulled for treatment, the results observed herein may indicate that pen density is more crucial for developing respiratory disease than lameness, as the addition of 10 more animals per pen would still allow the calves to lie down.

Percentage of forage in the diet was found to be a significant risk factor for lameness (Wald $\chi^2 = 159.43$; $P < 0.001$) (Table 2). When the percentage of forage decreased by 10%, the odds of becoming lame were 1.21 times greater compared with the original percentage of forage (Table 3). It is well known that the inclusion of long fiber in diets is important for the health of ruminants, including foot health based on its association with laminitis, although in our study, the incidence of laminitis/slipper foot was very low. For example, Groehn et al. (1992) found that the exclusion of dry hay from the diet increased the risk of lameness in dairy cattle, whereas Amstutz (1985) associated high-grain diets with laminitis in dairy cattle. Including greater amounts of fiber in feedlot diets may reduce the probability of becoming lame, although at this time, we do not know the true relationship between the amount of fiber and causes of lameness other than laminitis, or the optimal amount according to cattle and forage type.

Season was a significant risk factor for lameness (Wald $\chi^2 = 387.15$; $P < 0.001$) (Table 2). The estimated percentage of lame cattle in spring, summer, fall, and winter were 74.25% [$IC_{95\%} = (70.43, 77.74)$], 57.68% [$IC_{95\%} = (53.08, 62.14)$], 36.24% [$IC_{95\%} = (32.54, 40.10)$], and 42.11% [$IC_{95\%} = (37.97, 46.36)$], respectively. The odds of becoming lame in the spring were 2.12, 5.07, and 3.96 times greater than becoming lame in the summer, fall, and winter, respectively (Table 3). The odds of becoming lame in the summer were 2.40 and 1.87 times greater than in fall and winter, and cattle in winter had 1.28 greater odds of becoming lame than in fall (Table 3). This may be explained by the fact that FR (41.8%) and DD (25.5%) were the most common causes of lameness identified in our study. Both conditions are well known to be associated with wet/muddy pen conditions (Stokka et al. 2001) often occurring during the spring and winter months in Southern Alberta when warm winds (chinooks) melt snow and ice quickly. Moreover, lying space may be reduced when the pens are wet and muddy (Mader et al. 2014) which may also have an impact on the incidence of lameness (Greenough 1997). Furthermore, cattle are heaviest in the spring and summer months as they near market weight and have greater odds of becoming lame than light-weight cattle as described above. The fact that the odds of becoming lame in the fall were lower than in other seasons might be explained by failure to identify cases of lameness during the fall when cattle are entering the feedlot and more likely to be diagnosed with respiratory disease. Groehen et al. (1992) observed increased lameness with larger dairy herd size as managers have fewer opportunities to observe each individual animal to detect lameness, and we speculate that this may also happen in feedlots with high stocking density (between 200 and 300 head per pen).

Precipitation 1 d prior to (Wald $\chi^2 = 11.35$; $P = 0.0008$), and average temperature range 3 d prior to pulling for treatment (Wald $\chi^2 = 108.2$; $P < 0.001$) were significant risk factors for lameness (Table 2). A 10-unit increase in precipitation (10 mm) 1 d prior to pulling for treatment increased the odds of becoming lame 1.4 times, whereas a 5.0-unit increase in the average temperature range (5 °C) 3 d prior to treatment increased the odds of becoming lame 1.4 times (Table 3). Rain during spring, summer, and fall can exacerbate muddy pen conditions, whereas thawing snow during winter may also contribute to muddy pen conditions. As described previously, wet and muddy pens may increase the incidence of lameness by increasing the number of slips. In addition, wet environmental conditions are believed to soften and thin the interdigital skin making it more susceptible to the invasion of infectious agents (Stokka et al. 2001; Step et al. 2015).

Conclusions

The current study confirms that lameness is an important disease in Canadian feedlots with significant potential to reduce cattle welfare and feedlot profitability, and it is the first to evaluate lameness using a multifactorial approach including animal, managerial, and environmental factors in a single analysis. Foot rot and digital dermatitis were the two most common causes of lameness. The most important risk factors associated with increased lameness included BW, type of cattle, source, pen density, percentage of forage in the diet, season, precipitation 1 d and average temperature range 3 d prior to treatment for lameness. Consequently, strategies such as increasing the percentage of forage in the diet, maintaining clean, dry pens by routinely scraping or bedding, reducing slaughter weights, and reducing handling frequency may help to reduce the incidence of lameness in feedlot cattle. Future studies should include assessing specific risk factors for the different causes of lameness, and mitigation strategies based on the risk factors listed above.

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References

Amstutz, H.E. 1985. Symposium on bovine lameness and orthopedics. Prevention and control of lameness in dairy cattle.

Vet. Clin. Food Anim. Pract. **1**: 25–38. doi:10.1016/S0749-0720(15)31348-7.

Babcock, A.H., Renter, D.G., White, B.J., Dubnicka, S.R., and Scott, H.M. 2010. Temporal distribution of respiratory disease events within cohorts of feedlot cattle and associations with cattle health and performance indices. Prev. Vet. Med. **97**: 198–219. doi:10.1016/j.prevetmed.2010.09.003. PMID:20947196.

Chapinal, N., Barrientos, A.K., von Keyserlingk, M.A.G., Galo, E., and Weary, D.M. 2013. Herd-level risk factors for lameness in freestall farms in the northeastern United States and California. J. Dairy Sci. **96**: 318–328. doi:10.3168/jds.2012-5940. PMID:23141819.

Currin, J.F., Dee Whittier, W., and Currin, N. 2005. Foot rot in beef cattle. [Online]. Available from https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/400/400-310/400-310_pdf.pdf [9 Dec. 2019].

Davis-Unger, J., Schwartzkopf-Genswein, K.S., Pajor, E.A., Hendrick, S., Marti, S., Dorin, C., and Orsel, K. 2019. Prevalence and lameness-associated risk factors in Alberta feedlot cattle. Transl. Anim. Sci. **3**: 595–606. doi:10.1093/tas/txz008.

Faye, B., and Lescourret, F. 1989. Environmental factors associated with lameness in dairy cattle. Prev. Vet. Med. **7**: 267–287. doi:10.1016/0167-5877(89)90011-1.

Fregonesi, J.A., and Leaver, J.D. 2002. Influence of space allowance and milk yield level on behaviour, performance, and health of dairy cows housed in straw yard and cubicle system. Livest. Prod. Sci. **78**: 245–257. doi:10.1016/S0301-6226(02)00097-0.

Fregonesi, J.A., Tucker, C.B., and Weary, D.M. 2007. Overstocking reduces lying time in dairy cows. J. Dairy Sci. **90**: 3349–3354. doi:10.3168/jds.2006-794. PMID:17582120.

Green, T.M., Thomson, D.U., Wileman, B.W., Guichon, P.T., and Reinhardt, C.D. 2012. Time of onset, location, and duration of lameness in beef cattle in a commercial feedyard. Kansas State University. [Online]. Available from http://krex.k-state.edu/dspace/handle/2097/13556 [9 Dec. 2019].

Greenough, P.R. 1997. Lameness in cattle, 3rd ed. W.B. Saunders Company. Philadelphia, PA, USA.

Griffin, D., Perino, L., and Hudson, D. 1993. Feedlot lameness. Historical Materials form University of Nebraska-Lincoln Extension. Paper 196.

Groehn, J.A., Kaneene, J.B., and Foster, D. 1992. Risk factors associated with lameness in lactating dairy cattle in Michigan. Prev. Vet. Med. **14**: 77–85. doi:10.1016/0167-5877(92)90086-U.

Gummow, B., and Mapham, P.H. 2000. A stochastic partial-budget analysis of an experimental Pasteurella haemolytica feedlot vaccine trial. Prev. Vet. Med. **43**: 29–42. doi:10.1016/S0167-5877(99)00071-9. PMID:10665949.

Leonard, F.C., O'Connell, J.M., and O'Farrell, K.J. 1996. Effect of overcrowding on claw health in first-calved Friesian heifers. Br. Vet. J. **152**: 459–472. doi:10.1016/S0007-1935(96)80040-6. PMID:8791854.

Mader, T.L. 2014. Bill E. Kunkle interdisciplinary beef symposium: animal welfare concerns for cattle exposed to adverse environmental conditions. J. Anim. Sci. **92**: 5319–5324. doi:10.2527/jas.2014-7950. PMID:25414102.

Noffsinger, T., Lukasiewicz, K., and Hyder, L. 2015. Feedlot processing and arrival cattle management. Vet. Clin. Food Anim. **31**: 323–340. doi:10.1016/j.cvfa.2015.06.002.

Solano, L., Barkema, H.W., Pajor, E.A., Mason, S., LeBlanc, S.J., Zaffino Heyerhoff, J.C., et al. 2015. Prevalence of lameness and associated risk factors in Canadian Holstein-Friesian cows housed in freestall barns. J. Dairy Sci. **98**: 6978–6991. doi:10.3168/jds.2015-9652. PMID:26254526.

Sprecher, D.J., Hostetler, D.E., and Kaneene, J.B. 1996. A lameness scoring system that uses posture and gait to predict reproductive performance. Theriogenology, **47**: 1187–11679. doi:10.1016/s0093-691x(97)00098-8.

Statistics Canada. 2019. Table 32-10-0125-01 Cattle and calves, farm and meat production. Available from: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=321001250 [1 Dec. 2019].

Step, D.L., Krehbiel, C.R., DePra, H.A., Cranston, J.J., Fulton, R.W., Kirkpatrick, J.G., et al. 2008. Effects of commingling beef calves from different sources and weaning protocols during a forty-two-day receiving period on performance and bovine respiratory disease. J. Anim. Sci. **86**: 3146–3158. doi:10.2527/jas.2008-0883. PMID:18567723.

Step, D.L., Whitworth, B., Giedt, E.J., and Lalman, D. 2015. Foot rot in cattle. Oklahoma Cooperative Extension Service. ANSI-3355.

Stokka, G.L., Lechtenberg, K., Edwards, T., MacGregor, S., Voss, K., Griffin, D., et al. 2001. Lameness in feedlot cattle. Vet. Clin. North Am. Food Anim. Pract. **17**: 189–207. doi:10.1016/S0749-0720(15)30062-1. PMID:11320695.

Sullivan, L.E., Carter, S.D., Blowey, R., Duncan, J.S., Grove-White, D., and Evans, N.J. 2013. Digital dermatitis in beef cattle. Vet. Rec. **173**: 582. doi:10.1136/vr.101802. PMID:24106250.

Taylor, J.D., Fulton, R.W, Lehenbauer, T.W., Step, D.L., and Confer, A.W. 2010. The epidemiology of bovine respiratory disease: what is the evidence for predisposing factors? Can. Vet. J. **51**: 1095–1102. PMID:21197200.

Tessitore, E., Schwartzkopf-Genswein, K.S., Cozzi, G., Pajor, E., Goldhawk, C., Brown, F., et al. 2011. Prevalence of lameness within hospital and chronic pens of three southern Alberta feedlots during summer months. Can. J. Anim. Sci. **91**: 508–509.

Terrell, S.P., Thomson, D.U., Reinhardt, C.D., Apley, M.D., Larson, C.K., and Stackhouse-Lawson, K.R. 2014. Perception of lameness management, education, and effects on animal welfare of feedlot cattle by consulting nutritionists, veterinarians, and feedlot managers. AABP Proc. **48**: 53–50.

Terrell, S.P., Reinhardt, C.D., Larson, C.K., Vahl, C.I., and Thomson, D.U. 2017. Incidence of lameness and association of cause and severity of lameness on the outcome for cattle on six commercial beef feedlots. J. Am. Vet. Med. Assoc. **250**: 437–445. doi:10.2460/javma.250.4.437. PMID:28165312.

Tucker, C.B., Coetzee, J.F., Stookey, J.M., Thomson, D.U., Grandin, T., and Schwartzkopf-Genswein, K.S. 2015. Beef cattle welfare in the USA: identification of priorities for future research. Anim. Health Res. Rev. **16**: 107–124. doi:10.1017/S1466252315000171. PMID:26459152.

von Keyserlingk, M.A.G., Barrientos, A., Ito, K., Galo, E., and Weary, D.M. 2012. Benchmarking cow comfort on North American free stall dairies: Lameness, leg injuries, lying time, facility design, and management for high-producing Holstein dairy cows. J. Dairy Sci. **95**: 7399–7408. doi:10.3168/jds.2012-5807. PMID:23063152.

Wells, S.J., Trent, A.M., Marsh, W.E., McGovern, P.G., and Robinson, R.A. 1993. Individual cow risk factors for clinical lameness in lactating dairy cows. Prev. Vet. Med. **17**: 95–109. doi:10.1016/0167-5877(93)90059-3.

Westin, R., Vaughan, A., de Pasillé, A.M., DeVries, T.J., Pajor, E.A., Pellerin, D., et al. 2016. Cow- and farm-level risk factors for lameness on dairy farms with automated milking systems. J. Dairy Sci. **99**: 3732–3743. doi:10.3168/jds.2015-10414. PMID:26923045.