Prevalence of and factors associated with hock, knee, and neck injuries on dairy cows in freestall housing in Canada

J. C. Zaffino Heyerhoff,^{*1} S. J. LeBlanc,^{*} T. J. DeVries,[†] C. G. R. Nash,^{*} J. Gibbons,[‡] K. Orsel,[§] H. W. Barkema,[§] L. Solano,[§] J. Rushen,[‡] A. M. de Passillé,[‡] and D. B. Haley^{*}

^{*}Department of Population Medicine, and

[†]Department of Animal and Poultry Science, University of Guelph, Guelph, Ontario N1G 2W1, Canada

[‡]Agriculture and Agri-Food Canada, Agassiz, British Columbia V0M 1A2, Canada

[§]Department of Production Animal Health, University of Calgary, Calgary, Alberta T2N 1N4, Canada

ABSTRACT

Injuries are a widespread problem in the dairy industry. The objective of this study was to determine the prevalence of and explore the animal-based and environmental factors associated with hock, knee, and neck injuries on dairy cows in freestall housing in Ontario and Alberta, Canada. Freestall dairy farms in the provinces of Ontario ($n = 40$) and Alberta ($n = 50$) were visited for cross-sectional data collection. A purposive sample of 40 lactating Holstein cows was selected for detailed observation on each farm. Cows were scored for hock, knee, and neck injuries on a 3- or 4-point scale, combining the attributes of hair loss, broken skin, and swelling and with a higher score indicating a more severe injury. The highest hock and highest knee score were used in the analysis. Animal-based and environmental measures were taken to explore which factors were associated with injury. Overall, the prevalence of cows with at least one hock, knee, and neck injury was 47, 24, and 9%, respectively. Lame cows had a greater odds of hock injury [odds ratio (OR) = 1.46] than nonlame cows, whereas cows with fewer days in milk (DIM) had reduced odds of hock injury compared with those >120 DIM (OR = 0.47, 0.64, and 0.81 for <50 , 50–82, and 83–120 DIM, respectively). The odds of hock injury was lower on sand (OR = 0.07) and concrete (OR = 0.44) stall bases in comparison to mattresses. Conversely, the odds of knee injury was greater on concrete (OR = 3.19) stall bases compared with mattresses. Cows in parity 1 (OR = 0.45 and 0.27 for knee and neck injury, respectively) and 2 (OR = 0.49 and 0.40 for knee and neck injury, respectively) had lower odds of knee and neck injury compared with cows in parity 4+. Low feed rail heights increased the odds of neck injury (OR = 76.71 for rails between 128 and 140 cm and OR = 43.82 for rails ≤ 128 cm). The odds of

knee injury was greater on farms where any cows were observed slipping or falling when moving into the holding area for milking (OR = 2.69) and lower on farms with rubber flooring in the alley along the feed bunk compared with bare concrete floors (OR = 0.19). These results demonstrate that individual animal characteristics, as well as barn design and animal management, are associated with hock, knee, and neck injuries. These data can help to guide investigations into causes and prevention of injuries.

Key words: animal welfare, injuries, lameness, stall design

INTRODUCTION

Injuries often occur on the tarsus joint (hock), carpus joint (knee), and neck of dairy cattle (Zurbrigg et al., 2005; Huxley and Whay, 2006a), and are widely accepted as being painful and a welfare concern (Whay et al., 2001; Huxley and Whay, 2006b). Various codes of practice and animal welfare assessment schemes have included recommendations concerning injuries (Main et al., 2007; National Farm Animal Care Council, 2009; von Keyserlingk et al., 2012).

Some animal-based factors have been found to be associated with injuries (Figure 1), including greater age (Weary and Tazskun, 2000; Rutherford et al., 2008; Kielland et al., 2009; Potterton et al., 2011), early lactation (Baggott and Russell, 1981; Busato et al., 2000; Kielland et al., 2009), and BCS (Kielland et al., 2009; Busato et al., 2000; Regula et al., 2004). Swollen hocks have been positively associated with lameness (Klaas et al., 2003), clinical mastitis and teat injury (Sogstad et al., 2006), and, at the herd level, high SCC (Fulwider et al., 2007). Rushen et al. (2007) found a negative correlation between the occurrence of knee swelling and total lying time.

Environmental factors associated with injuries include short stalls (Weary and Tazskun, 2000; Keil et al., 2006; Fulwider et al., 2007) and long stalls (Kielland et

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¹Corresponding author: jessica.heyerhoff@gmail.com

Figure 1. Causal diagram illustrating hypothesized relationships of animal-based and environmental variables with leg injuries.

al., 2009; Potterton et al., 2011), restricted lying space (Regula et al., 2004), small lunging space (Haskell et al., 2006), hard stall base (Livesey et al., 2002; Rushen et al., 2007), and the use of mattresses (Weary and Taszkun, 2000). Little is known of the prevalence or factors associated with injuries on Canadian dairy farms. Estimates of prevalence of hock injuries range from 42 (von Keyserlingk et al., 2012) to 73% (Weary and Taszkun, 2000), but data on the prevalence of knee and neck injuries are sparse. The objective of the current study was to determine the prevalence of and explore the animal-based and environmental factors associated with hock, knee, and neck injuries of Holstein dairy cows on commercial freestall farms in Ontario and Alberta, Canada.

MATERIALS AND METHODS

Study Design

All methods were approved by the Animal Care Committees and Research Ethics Boards at the University of Guelph and the University of Calgary. The data collected were part of a larger cross-sectional study on dairy cattle housing, management, and welfare in Canada. Freestall farms were visited in Ontario ($n = 40$) from January to November 2011 and in Alberta ($n = 50$) from March to December 2011, which together make up 57% of the freestall farms in Canada (Canadian Dairy Information Centre, 2012).

Herd Selection

To be eligible for participation in this study, farms had to be enrolled with CanWest DHI (Guelph, Canada). Farms were only included in the study if they had ≥ 40 Holstein milking cows and if their milking cows had been housed in their current housing system for at least 1 y. To ensure study farms were representative of the majority of Canadian dairy farms, farms were excluded from the study if the milking cows had outdoor access for more than 2 h/d. In Ontario, farms were randomly selected from all those with mean milk production $\geq 7,000$ L/cow per year and within 4-h driving distance from the provincial research group (Guelph or Kemptville, Canada; $n = 3,052$). Farms were invited by mail to participate in the study. The number of letters sent out was based on an expected positive response rate of 20% and a target sample size of 40 freestall farms in Ontario. Due to a lower-than-expected response, an additional random selection phase was included, and 316 letters were sent out in total. In Alberta, a letter of invitation to participate was sent to all freestall farms ($n = 130$) that were participants of The Alberta Hoof Health Project. These farms were proven to be representative of the average Alberta dairy farm in terms of herd size (provincial average = 120 cows, study farm average = 175), longevity (median percent of cows in third lactation or higher: entire province = 37%, study herds = 38%), breed (chose only Holstein study cows), and herd management (sampled only freestall farms,

which are the majority in Alberta). When letters were returned indicating the willingness of the producer to participate, they were interviewed by telephone to determine if they met the additional study inclusion criteria.

Cow Selection

The outcome was cow-level prevalence of injuries (i.e., the number of injured cows divided by the total cows assessed). To estimate an expected prevalence of 40% with an acceptable difference of 2% with 95% confidence requires 2,305 cows (Abramson, 2011). However, based on the size of freestall herds in Canada, our target cow-level inclusion criteria (below), and increasing the external validity of the estimates, we collected cow-level outcomes from many herds. Specifically, based on the availability of equipment and time constraints, as well as previous work on representative sample sizes for lying time (Ito et al., 2009) from each herd, 40 focal cows were purposively selected for detailed observations. Considering the average freestall herd size in Alberta and Ontario (Canadian Dairy Information Centre, 2012), this would allow us to sample an average of 29% of each herd. As often as possible, focal cows were between 10 and 120 DIM because this period has been shown to be associated with increased odds

of hock and knee injury (Kielland et al., 2009). Cows <10 DIM were not selected to allow for habituation to their present environment. If the milking herd had less than 40 Holstein cows between 10 and 120 DIM, the selection criterion was increased above 120 DIM until a sample of 40 cows was obtained. If the milking herd had more than 40 Holstein cows between 10 and 120 DIM, the sample of focal cows was balanced to reflect the proportion of primiparous cows in the herd (e.g., if 45% of the milking herd was primiparous, then the sample of 40 cows would include 18 animals in first lactation). Treating each herd as a cluster of 40 sampled cows and allowing for a design effect of 1.4 (i.e., inflation of the sample size due to lack of independence of cows in a herd) required 81 herds to be sampled to provide data from >3,202 cows (Abramson, 2011).

Animal-Based Measures

Based on previous literature and biological plausibility, causal diagrams were drawn for leg injuries (Figure 1) and neck injuries (Figure 2). These diagrams were used to determine what variables to measure on farms and also what variables to include in analyses.

Data collection teams in both provinces underwent an intensive 2-wk training program; the repeatability for each trainee was assessed as described in Gibbons

Figure 2. Causal diagram illustrating hypothesized relationships of animal-based and environmental variables with neck injuries.

et al. (2012) throughout the data collection period. The only observers who went on to score injuries on the farm were those who attained the target $Kw \geq 0.6$ during training (Gibbons et al., 2012). As data collection teams were located in different provinces, observer repeatability was assessed using a gold standard, which has been demonstrated in other work (Mullan et al., 2011)

Data were collected during a single visit. Cows were scored for hock, knee, and neck injuries according to the criteria in Table 1 (Gibbons et al., 2012) at the anatomical locations shown in Figure 3. Injuries were scored in the area of each farm that enabled the best view of the cow, which varied by farm. Hock injuries were most commonly scored in the milking parlor, whereas knee and neck injuries were commonly scored in the freestall area, where cows were free to move about. Both the left and right limbs were scored for hock and knee injuries. No more than 2 injury observers were active per farm, and each observer would assess the same injury type on all cows on a farm.

To record lying time, an electronic data logger (HOBO Pendant G Acceleration Data Logger, Onset Computer Corporation, Pocasset, MA) was attached to one hind leg on the lateral side of the metatarsus using Co-Flex vet wrap (Andover Healthcare, Inc., Salisbury, MA) while cows were in the milking parlor. The loggers were set to record at 1-min intervals and began recording at midnight on the day of farm visit. Lying time (min/d), number of lying bouts, lying bout duration, and standard deviation of lying bout duration were averaged over 4 consecutive 24-h periods (Ito et al., 2009; Vasseur et al., 2012).

Cows were video recorded while walking back from the milking parlor and categorized as lame or not lame based on the presence of a limp defined as uneven weight bearing of one or more limbs (Flower and Weary, 2006). Cows were scored for body condition on a 5-point scale in 0.25-increments (Ferguson et al., 1994). Information on parity and DIM of study cows on the day of the farm visit was obtained from DHI records.

Figure 3. (A) Location of hock scoring: lateral surface of the tarsal joint. (B) Location of knee scoring: cranial surface of the carpal joint. (C) Location of neck scoring: dorsal surface of the middle of the neck.

Environmental Measures

Measures of the cows' environment were taken from all pens containing focal cows on the day of farm visit. Stall dimensions were measured on the end stalls of 3 representative rows in each pen according to Figure 4. Lunge space was labeled adequate if no obstruction was present 76 cm forward from the center of the top of the brisket board and to a 45° angle to the left and right, and inadequate if an obstruction was in this space. If no brisket board was present, this measure was taken from the point of the neck rail and 10 cm above the stall surface (National Farm Animal Care Council, 2009).

Table 1. Description of injuries assessed on lactating dairy cattle (Gibbons et al., 2012)¹

Area of interest	Score 0	Score 1	Score 2	Score 3
Hock (tarsus)	No swelling. No hair is missing or broken hair.	Bald area on hock with no swelling or swelling <1 cm high.	Swelling 1–2.5 cm high, or broken skin or scab on bald area.	Swelling >2.5 cm high. May have bald area, broken skin, or scab.
Knee (carpus)	No swelling. No hair is missing or slight hair loss or broken hair.	No swelling. Bald area.	Broken skin, scab, or swelling (<2.5 cm high). May have bald area.	Swelling ≥2.5 cm high. May have bald area or lesion.
Neck	No swelling. No hair is missing, slight hair loss or broken hair.	No swelling. Bald area visible.	Broken skin, scab, or swelling. May have bald area.	Not applicable.

¹For analysis, scores of 2 and 3 were combined as 2+.

Figure 4. Description of the stall dimensions measured on the end stalls of at least 3 representative rows in each pen. (a) Stall length (includes forward lunge space); (b) bed length: distance from brisket board to rear point of stall curb, if no brisket board, distance from neck rail to rear point of stall curb; (c) brisket board height: height of brisket board above bedding surface; (d) height of bottom divider rail: distance from upper edge of bottom divider rail to bedding surface; (e) neck rail height: height below neck rail to bedding surface; (f) neck rail distance: distance between rear point of neck rail and rear point of stall curb; and (g) curb height: distance from top of curb to flooring surface. Adapted from Cook (2005).

Stall width was measured as an average of 3 consecutive stalls on either side of the center stall in each row that was measured. A minimum of 6 stalls per farm were evaluated for bedding depth and cleanliness. Stalls next to the center stall in each measured row were selected. Bedding depth was evaluated as none (unable to rake bedding), ≤ 2 cm (when raked evenly for organic bedding, or below the curb for sand bedding), or ≥ 2 cm (when raked evenly for organic bedding, or even with or above the curb for sand bedding). Previous work has shown increased lying times for every additional 1 cm or 1 kg of bedding (Tucker and Weary, 2004; Drissler et al., 2005; Tucker et al., 2009), and 2 cm would be the minimum required to completely cover the stall base so as not to have bare spots. Stall cleanliness was evaluated qualitatively on the back 25% of the stall after the cleaning routine to get an indication of how well cleaning was being done. Stalls were considered clean if they had little or no manure or wet spots. Stall base and bedding type were recorded. Sand stall bases were those where the concrete was not exposed by digging 10 cm into the sand (Barrientos et al., 2013).

For each pen, the stocking density was calculated as the number of cows divided by the number of lying stalls. The length of the available feeding space was measured to determine space at the feed bunk. The total feed bunk length was divided by 60 cm (the standard width of headlocks) and then by the total number of cows, to get the variable spaces per cow. The type of feed barrier and flooring type in the cow alley adjacent to the feed bunk was recorded. The height of the feed rail was measured from the cow standing floor surface to the underside of the rail or headlock top bar.

The total daily time spent outside of the home pen for milking was calculated per pen as the time between the first cow leaving the home pen and the last cow returning back to the home pen multiplied by the milking frequency per day. Cows' slips and falls were observed for up to 30 min while they were being moved to the holding area for milking, or, alternatively, in the pen on the way back from milking if observation in the holding area was not possible. Slips and falls were categorized as 1 (any number of cows slipped or fell) or 0 (none of the cows slipped or fell).

Data Handling

The data were entered into a relational database (Microsoft Access 2010; Microsoft Corp., Redmond, WA) and then exported into Microsoft Excel 2010 (Microsoft Corp.) and into SAS 9.3 (SAS Institute Inc., Cary, NC) for analysis. If any categories had too few observations, categories were combined based on biological cut-points or to equalize the number of observations per category. Body condition scores were categorized as <3 and ≥ 3 . Parity of the cow was categorized as 1, 2, 3, or 4+ due to few cows in parity 5 and above. Days in milk were categorized based on quartiles. Stall bases and bedding types that were not commonly seen (i.e., could not make their own category in analysis) were combined into a category called other. Stall dimensions for a farm were averaged from all stalls measured on that farm and the standard deviation of each measure was calculated. Lunge space was analyzed as the percentage of stalls per farm having adequate lunge space, so that a higher percentage indicated more stalls having adequate lunge space. Bedding depth was analyzed as the percentage of stalls per farm having ≥ 2 cm of bedding and stall cleanliness was analyzed as the percentage of clean stalls per farm.

Statistical Analysis

All data were analyzed using SAS 9.3. Descriptive statistics (mean, SD) were used to describe herd and cow characteristics. Analyses were done with scores at the cow level by using the higher of the 2 limb scores for hocks and knees. Cows with incomplete injury observations (only one hock or one knee scored) were excluded from the analysis. Spearman correlation coefficients were calculated to examine the correlation between left and right limbs of cows.

Parity and DIM were identified as potential confounders of the association between injuries and lying time and between injuries and lameness (Figures 1 and 2). The unit of analysis was the cow and the data were all collected in a cross-sectional design. Three separate models were built, one each for hock, knee, and neck injuries using logistic regression (Proc GLIMMIX in SAS with a binomial distribution and logit link function with chi-squared for significance testing). A Satterthwaite adjustment of the denominator DF was used to account for herd-level observations. Two random effects were included in each model: herd, and a second random residual effect to estimate the variance components at both the herd and cow level. For all 3 models, the outcome was injured (score ≥ 2) or not injured (scores 0 and 1). Province was considered as an explanatory variable. First, each explanatory variable was tested

separately, including quadratic terms in the case of continuous variables. Any variables having an association with injury at $P < 0.15$ were offered to the multivariable model after testing for correlation among variables using Spearman correlation coefficients. If 2 variables had a correlation coefficient greater than 0.6, the least significant or least biologically plausible variable was removed. If a nonlinear relationship was observed between any continuous variable and the log odds of the outcome, then that variable was categorized based on quartiles. Any nonsignificant variables ($P > 0.05$) were removed from the full model using backward elimination, starting with the least significant and checking for confounding as they were removed. If the removal of any variable changed the coefficient of another variable by more than 30%, and if the variable being removed could reasonably be considered a confounder (i.e., if it could be associated with the outcome and exposure but not a consequence of the exposure), then it was retained in the model. Biologically plausible 2-way interactions between the variables retained in the model were added. Again, any nonsignificant terms ($P > 0.05$) were removed from the full model using backward elimination, starting with the least significant. Influential observations were examined graphically. When putative influential observations were found, their influence was assessed by running the models with and without that observation and examining the coefficients.

RESULTS

Three farms were excluded from the analysis because they had no cows with complete records for any injury location. Of the 87 farms analyzed, the mean herd size was 151 ± 85 (SD) milking cows at the time of visit, 32 farms (37%) had cows sampled from more than one pen, and farms had an average of 75 stalls per pen. Water beds, dirt, rubber over sponge, carpet, and deep-bedded sawdust occurred rarely and were therefore put together as other stall bases. Sand was only recorded as a bedding type when it was also the stall base; therefore, sand was removed from the bedding type variable and kept only in the stall base variable. The mean proportion of milking cows assessed per farm was $33 \pm 16\%$ (SD). A total of 3,600 cows were observed with 2,713 cows from 75 farms having complete hock records, 3,020 cows from 84 farms having complete knee records, and 3,214 cows from 84 farms having complete neck records. The distribution of all cow and herd characteristics is presented in Tables 2 and 3.

Prevalence of Hock, Knee, and Neck Injuries

A subset of the sampled cows ($n = 2,304$) had complete records for all 3 injury locations. Of these cows,

Table 2. Distribution of all cow-level explanatory variables hypothesized to be associated with hock, knee, and neck injury as measured on 3,480 cows from 87 freestall farms in Canada

Variable	Classification	Cows, ¹ n (%)	Mean	SD
Parity	1	1,327 (38)		
	2	916 (26)		
	3	533 (15)		
	4+	580 (17)		
DIM	<50	838 (24)		
	50–82	861 (25)		
	83–120	828 (24)		
	>120	838 (24)		
BCS	<3	1,856 (53)		
	≥3	1,544 (44)		
Lying time	Minutes per day	3,393	638	137
Lying bouts	Bouts per day	3,395	11	4
Lying bout duration	Minutes per bout	3,395	67	27
SD of lying bout duration	Minutes	3,395	41	17

¹Does not always equal 3,480 cows (or 100%) per variable because of missing observations.

46% had an injury at 1 of the 3 anatomical locations, 15% at 2 locations, and 2% at all 3 locations. Among the cows with an injury at 2 locations, most were injured on the hock and knee (72%), 17% were injured on the hock and neck, and 11% were injured on the knee and neck.

Of the 2,713 cows with complete hock records, 38, 15, 44, and 3% had a maximum hock score of 0, 1, 2, and 3, respectively. Twenty percent of cows had an injury on both hocks and 52% of hock injuries were on the left leg and 48% on the right. Of the 3,020 cows with complete knee records, 63, 13, 22, and 2% had a maximum knee score of 0, 1, 2, and 3, respectively. Ten percent of cows had an injury on both knees and 50% of knee injuries were observed on the left and right legs. Of the 3,214 cows with a neck observation, 84, 7, and 9% were assigned score 0, 1, and 2, respectively. The correlation coefficient between the left and right hocks was 0.46 ($P < 0.001$) and between the left and right knees was 0.57 ($P < 0.001$).

Factors Associated with Hock, Knee, and Neck Injuries

After univariable analysis, the following variables were considered for the multivariable models for hock injury: parity, BCS, lameness, DIM, lying time, lying bout duration, stall base, bedding type, stall length, bed length, neck rail distance from curb, milking time, bedding depth, and clean stalls. For knee injury, the following variables were considered for the multivariable models: province, parity, lameness, DIM, lying time, lying bouts, lying bout duration, SD of lying bout duration, stall base, slips and falls, flooring type, stall width, stall length, bed length, brisket height, divider height, curb height, stocking density, bedding

depth, and lunge space. For neck injury, the following variables were considered for the multivariable models: parity, lameness, DIM, lying bouts, lying bout duration, bed length, neck rail distance from curb, feed rail type, and feed rail height. Lying bout duration was highly correlated with lying bouts ($R = -0.78$) and with the SD of lying bout duration ($R = 0.75$), and so was not presented to the multivariable model for knee injury. The type and height of feed rail were highly correlated ($R = -0.73$), thus only the feed rail height was presented to the multivariable model for neck injury.

Table 4 shows factors associated with hock injuries based on the multivariate analysis. Lameness was associated with greater odds of hock injury. Factors associated with lower odds of hock injury were DIM <83 (compared with >120), sand and concrete stall bases (compared with mattresses), and an increase in the distance from the neck rail to rear curb. Table 5 shows the factors associated with knee injury. Having any slips or falls on the farm, concrete stall bases compared with mattresses, and an increase in the SD of lying bout duration was associated with greater odds of knee injury. Factors associated with lower odds of knee injury were parities 1 to 3 compared with parity 4+, and having rubber flooring in front of the feed bunk. Table 6 shows the factors associated with neck injury. Feed rail heights <140 cm were associated with greater odds of neck injury. Days in milk <83 (compared with >120) and parities 1 and 2 (compared with parity 4+) were associated with lower odds of neck injury.

DISCUSSION

We found that 47% of cows in the study had at least one type of injury, which is concerning from a cow welfare perspective. The prevalence of hock injuries was

Table 3. Distribution of all herd-level explanatory variables hypothesized to be associated with hock, knee, and neck injury as measured on 3,480 cows from 87 freestall farms in Canada

Variable	Classification	Herd, ¹ n (%)	Mean	SD
Stall base ²	Mattress	49 (56)		
	Concrete	12 (14)		
	Sand	10 (12)		
	Other	9 (10)		
	Rubber	7 (8)		
Bedding type ²	Wood shavings	28 (32)		
	Sawdust	26 (30)		
	Straw	17 (20)		
	Other	6 (7)		
Bedding depth ≥ 2 cm ²	Percent of stalls	87	37	44
Clean stalls ²	Percent of stalls	87	88	17
Width ²	cm	87	115	5
SD width ²	cm	87	3	2
Stall length	cm	87	241	14
SD stall length	cm	87	11	9
Bed length	cm	86	178	13
SD bed length	cm		7	7
Brisket height ²	cm	57	12	5
SD Brisket height ²	cm		2	2
Divider height ^{2,3}	cm	87	33	11
SD divider height ²	cm		4	4
Neck rail height ⁴	cm	86	117	8
SD neck rail height ⁴	cm		4	3
Neck rail distance from curb	cm	86	169	10
SD neck rail distance from curb	cm		7	5
Curb height ²	cm	87	23	5
SD curb height ²	cm		2	1
Adequate lunge space	Percent of stalls	87	67	32
Stocking density ²	Cows per stall	87	0.96	0.14
Feed rail type ⁴	Post and rail	38 (44)		
	Headlock	48 (55)		
	≤ 127.5 cm	22 (25)		
	127.6–139.9 cm	19 (22)		
Feed rail height ⁴	140–148.9 cm	20 (23)		
	≥ 149 cm	24 (28)		
	Rubber	13 (15)		
	Concrete	74 (85)		
Flooring type ^{2,5}				
Feed bunk space ^{4,6}	spaces per cow	87	1.01	0.29
Feeding frequency ⁴	Once per day	51 (59)		
	2–3 times per day	34 (39)		
	≥ 2 times per day	77 (89)		
Feed push-up ⁴	Not needed, trough	8 (9)		
	Yes	14 (16)		
Slip and fall	No	65 (75)		
	Yes	14 (16)		
Milking time	Min per day	79	199	89

¹Does not always equal 87 herds (or 100%) per variable because of missing observations.²Variables tested only in the hock and knee injury model.³Height of bottom divide rail above bedding surface.⁴Variables tested only in the neck injury model.⁵Flooring type in the cow alley adjacent to the feed bunk.⁶Number of 60-cm spaces per cows.

similar to that found previously in Canada and the United States (42%; von Keyserlingk et al. 2012), the United Kingdom (46%; Rutherford et al., 2008), and in Germany and Austria (50%; Brenninkmeyer et al., 2013), but lower than that found previously by Weary and Taszkun (2000) in Canada (73%), likely because they scored more areas of the hock. The prevalence of knee injuries (24%) is greater than that reported in Norway (Kielland et al., 2009; 6% with swelling or

wounds), and the prevalence of neck injuries (9%) is similar (Kielland et al., 2010; 6% with swelling). We specifically excluded farms with >2 h/d of pasture access for their milking cows, and thus expected to see a higher prevalence of injuries on our sample cows compared with those in studies from Europe, where pasture access is more common.

We found 20% of cows had an injury on both hocks and 10% of cows had an injury on both knees, indicat-

Table 4. Factors associated with hock injury on 74 farms in the final model with a binomial distribution and logit link function, where not injured (no response) was a hock score of 0 or 1 ($n = 1,438$) and injured (response) was a hock score of 2 or 3 ($n = 1,275$)¹

Fixed effect	Class	Prevalence of hock injuries ²	Coefficient	SE	df	Odds ratio	95% CI	P-value
Lame	Yes	58	0.38	0.12	2,405	1.46	1.16–1.83	0.001
	No	44	Referent	—	—	—	—	—
DIM	<50	38	−0.75	0.14	2,399	0.47	0.36–0.62	<0.001
	50–82	47	−0.44	0.14	2,399	0.64	0.49–0.85	0.002
	83–120	50	−0.21	0.14	2,399	0.81	0.62–1.06	0.117
	>120	54	Referent	—	—	—	—	—
Stall base	Other	25	−1.62	0.38	66	0.20	0.09–0.43	<0.001
	Rubber	53	−0.44	0.47	66	0.64	0.25–1.64	0.351
	Sand	10	−2.66	0.45	66	0.07	0.03–0.17	<0.001
	Concrete	40	−0.81	0.37	66	0.44	0.21–0.93	0.033
	Mattress	60	Referent	—	—	—	—	—
Neck rail distance from curb	Per 10 cm increase		−0.30	0.13	65	0.74	0.57–0.96	0.026

¹The proportion of variation that occurred at the herd level was 47%.

²The percentage of cows within each categorical variable that had a hock injury.

ing it was more common for cows to be injured on just 1 leg rather than 2 (Potterton et al., 2011). This suggests that it may be more common for limbs to be injured one at a time rather than simultaneously. Whereas a moderately positive correlation was observed between injury scores on the left and right limbs, it was not high enough to be confident that scoring just one limb will provide information about overall injury prevalence. It is thus recommended from these data that all 3 types of injuries, as well as injuries on both hocks and both knees, be scored when assessing injuries.

The odds of hock injury were higher among lame cows compared with nonlame cows (Klaas et al., 2003; Rutherford et al., 2008; Brenninkmeyer et al., 2013; Burow et al., 2013). Lame cows may have difficulty

rising or lying down properly and bump or scrape their hocks during this process; alternatively, the hock injury is painful and may cause the animal to limp. Previous studies from Switzerland and Norway have found hock injuries to be more common in early lactation cows (Busato et al., 2000; Kielland et al., 2009). In contrast, we found the odds of hock injury were lower in cows with fewer DIM, perhaps related to the cows' exposure to the stall surface, as those with fewer DIM would not have been exposed to the milking cow environment for as long.

The odds of hock injury were lower with the use of sand stall bases in comparison to mattresses (Weary and Taszkun, 2000; Fulwider et al., 2007; Barrientos et al., 2013). The depth of the sand stalls likely make it a

Table 5. Factors associated with knee injury on 76 farms in the final model with a binomial distribution and logit link function, where not injured (no response) was a knee score of 0 or 1 ($n = 2,309$) and injured (response) was a knee score of 2 or 3 ($n = 711$)¹

Fixed effect	Class	Prevalence of knee injuries ²	Coefficient	SE	df	Odds ratio	95% CI	P-value
Parity	1	21	−0.79	0.14	2,588	0.45	0.35–0.60	<0.001
	2	21	−0.71	0.15	2,588	0.49	0.37–0.66	<0.001
	3	26	−0.53	0.16	2,588	0.59	0.43–0.81	0.001
	4+ ³	30	Referent	—	—	—	—	—
SD of lying bout duration	Per 30 min increase		0.27	0.08	2,626	1.31	1.11–1.54	0.001
Stall base	Other	39	1.01	0.45	52	2.75	1.11–6.79	0.03
	Rubber	20	0.02	0.48	52	1.02	0.38–2.68	0.974
	Sand	10	−0.50	0.46	52	0.60	0.24–1.53	0.283
	Concrete	49	1.16	0.38	52	3.19	1.49–6.82	0.003
	Mattress	17	Referent	—	—	—	—	—
Flooring type ⁴	Rubber	7	−1.68	0.39	72	0.19	0.09–0.41	<0.001
	Concrete	27	Referent	—	—	—	—	—
Slip and fall	Yes	41	0.99	0.37	53	2.69	1.28–5.64	0.010
	No	21	Referent	—	—	—	—	—

¹The proportion of variation that occurred at the herd level was 53%.

²The percentage of cows within each categorical variable that had a knee injury.

³Parity 4 to 9 are combined into one category.

⁴Flooring type in the cow alley adjacent to the feed bunk.

Table 6. Factors associated with neck injury on 81 farms in the final model with a binomial distribution and logit link function, where not injured (no response) was a neck score of 0 or 1 ($n = 2,922$) and injured (response) was a neck score of 2 ($n = 292$)¹

Fixed effect	Class	Prevalence of neck injuries ²	Coefficient	SE	df	Odds ratio	95% CI	P-value
Parity	1	6	-1.31	0.16	2,940	0.27	0.20–0.37	<0.001
	2	8	-0.92	0.17	2,940	0.40	0.29–0.55	<0.001
	3	14	-0.14	0.17	2,940	0.87	0.63–1.21	0.417
	4+ ³	14	Referent	—	—	—	—	—
DIM	<50	6	-0.94	0.19	2,956	0.39	0.27–0.57	<0.001
	50–82	8	-0.42	0.18	2,956	0.66	0.46–0.93	0.016
	83–120	11	0.03	0.16	2,956	1.03	0.75–1.40	0.872
	>120	11	Referent	—	—	—	—	—
Height of feed rail	≤127.5 cm	13	3.78	0.74	76	43.82	10.15–187.97	<0.001
	127.6–139.9 cm	21	4.34	0.74	76	76.71	17.40–334.96	<0.001
	140–148.9 cm	11	1.39	0.82	76	4.01	0.80–20.21	0.091
	≥149 cm	1	Referent	—	—	—	—	—

¹The proportion of variation that occurred at the herd level was 82%.

²The percentage of cows within each categorical variable that had a neck injury.

³Parity 4 to 9 are combined into one category.

more comfortable lying surface, as it is more malleable to the shape of the cow compared with stall bases such as mattresses, rubber, or concrete. Others have found mattresses to be associated with reduced prevalence (Kielland et al., 2009), incidence (Livesey et al., 2002), and severity (Tierney and Thomson, 2001) of hock injury compared with rubber mats. We did not have similar findings in the current study, perhaps because our study did not have enough farms using rubber mats ($n = 7$) or because the specific types of rubber mats used differed from previous work. In agreement with previous work from Canada, Switzerland, and the United Kingdom (Weary and Taszkun, 2000; Keil et al., 2006; Fulwider et al., 2007), we found a longer lying space to be associated with reduced odds of hock injury. In particular, the longer distance from the neck rail to rear curb may allow the cow greater freedom of movement while rising, allowing for a more fluid movement and reducing the chance of injury.

Our findings support previous work (Haskell et al., 2006; Kielland et al., 2009), in that the odds of knee injury were lower in younger compared with older cows, perhaps because they have had less exposure to the physical conditions that cause injuries. Others found knee injuries to be associated with reduced frequency of lying bouts (Rushen et al., 2007), whereas we found cows with greater variation in the duration of their lying bouts had a greater odds of knee injury. Perhaps cows with knee injuries are uncomfortable and have to stand to reposition in the stall, resulting in some very short and some much longer lying bouts. This result demonstrates that the relationship between injuries and lying time is very complex.

Type of stall base was associated with knee injuries, with concrete bases having greater odds of injury compared with mattresses, supporting other studies that

have found concrete to be a risk factor for knee injury (Sogstad et al., 2005; Rushen et al., 2007; Kielland et al., 2009). A great amount of pressure is applied to the knees when a cow rises or lies down, and concrete provides little cushioning during such movements, especially when bedding is not deep, as was the case with most of the farms in the current study. Rubber flooring in front of the feed bunk, in comparison to concrete, was associated with reduced odds of knee injury. The Canadian Code of Practice for dairy cattle recommends the best practice for flooring is to “provide soft, high traction flooring in areas where cattle stand for long periods” (National Farm Animal Care Council, 2009), which our findings support. The odds of knee injury were greater on farms where cows were observed to slip or fall while being moved into the holding pen for milking; this highlights the importance of proper handling in relation to injuries and cow welfare.

The odds of neck injury were lower in parity 1 and 2 cows compared with older cows, which is in contrast to observations of cows in Norway (Kielland et al., 2010) where no association was seen. Cows in Norway likely have a greater level of outdoor access compared with our study cows, mitigating the effect of increased exposure to the feed rail as parity increases. In this study, the odds of neck injury increased with increasing DIM and this is perhaps also related to the cows’ exposure to the feed rail, as those with fewer DIM would not have been exposed to the milking cow environment for as long. Additionally, heifers are still growing in their first lactation and perhaps come into contact with the feed rail further along their lactation as they get bigger. The odds of neck injury were much greater on farms with lower feed rail heights compared with feed rail heights ≥ 149 cm. In tiestall cows, Zurbrigg et al. (2005) found that neck rails below 99 cm or above 114 cm were as-

sociated with less neck injury, whereas Kielland et al. (2010) found that tall cows had more neck injury on farms with feed rail heights between 98 and 109 cm, compared with feed rails <98 or >109 cm.

We acknowledge the possibility for intervening variables within our injury models; for example, lying behavior and lameness could be intervening variables between the environment and injuries. We explored this possibility by looking at our full models with and without these intervening variables and found that their inclusion did not change the other coefficients or *P*-values.

Environmental measurements were taken on multiple pens when focal cows were not all from the same group. Thus, in just over one-third of farms in which more than one pen was assessed, potential environmental risk factors were averaged over the entire farm and not specific to the pen where a given study cow was being housed. In the current study, the within-herd variability tended to be small. For example, the standard deviation of stall dimensions within a farm was small and few farms used different stall bases, bedding types, or feed barriers within the farm (Table 3). Thus, the use of one herd-level measure for each cow on a given farm is justified because this is the nature of the variables such as stall dimensions: each cow would be exposed to that same environment or herd-level condition. This was controlled with Satterthwaite's adjustment of the degrees of freedom for these herd-level predictor variables, as well as by including herd as a random effect.

We found no factors associated with injuries at all 3 locations. Younger cows had lower odds of both knee and neck injury and early lactation (<83 DIM) was associated with reduced odds of hock and neck injury. The associations of stall bases were opposite for hock and knee injury; in comparison to mattresses, concrete stall bases were associated with lower odds of hock injury but increased odds of knee injury. This suggests that hock, knee, and neck injuries develop by different processes. We suggest that hock injury is related to abrasion with the stall surface, knee injuries are related to impact with stall surface or flooring, and neck injuries are related to contact with the feed rail. The differences in these 3 injury models highlights that the underlying etiology and development of these injury types is likely to be different. Longitudinal and experimental studies are needed to examine the causes and progression of these injuries over time.

CONCLUSIONS

This is the largest study to date to investigate factors associated with hock, knee, and neck injuries on freestall-housed dairy cows in Canada. The results

herein will help in setting targets for injury reduction, provide preliminary guidance about barn design, and identify areas for further investigation. Hock, knee, and neck injuries are prevalent on freestall dairy farms in Ontario and Alberta. Having sand stall bases, feed rail heights above 149 cm, and managing cows to reduce slips and falls were associated with reduced injury prevalence.

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