J. Dairy Sci. 99:6494–6506
http://dx.doi.org/10.3168/jds.2015-10676

Prevalence of and risk factors for hock and knee injuries on dairy cows in tiestall housing in Canada

C. G. R. Nash,* D. F. Kelton,*† T. J. DeVries,†‡ E. Vasseur,‡ J. Coe,*† J. C. Zaffino Heyerhoff,* V. Bouffard,§ D. Pellerin,§ J. Rushen,# A. M. de Passillé,# and D. B. Haley*†[1]
*Department of Population Medicine,
†Campbell Centre for the Study of Animal Welfare, and
‡Department of Animal Biosciences, University of Guelph, Guelph, ON, N1G 2W1 Canada
§Département des Sciences Animales, Université Laval, Québec, QC, G1V 0A6 Canada
#Animal Welfare Program, Faculty of Land and Food Systems, University of British Columbia, Vancouver, BC, V6T 1Z4 Canada

ABSTRACT

Leg injuries on dairy cows are a common and highly visible welfare concern on commercial dairy farms. With greater attention being placed on food animal welfare and limited research being conducted on tiestall farms, this study aimed to identify prevalence and risk factors for hock and knee injuries on dairy cows housed in tiestall barns in Ontario (n = 40) and Quebec (n = 60). A sample of 40 cows was purposively selected per farm and several animal- and farm-based measures were taken. Both hocks and both knees on each cow were scored as injured (presence of lesions or swelling) or not injured (no alterations or hair loss), and the highest score of each of the 2 knees and the 2 hocks was considered the cow's hock or knee score. Possible animal- and farm-based risk factors were incorporated into 2 separate multivariable logistic models for hock injuries and knee injuries respectively at the cow level. Mean (±SD) percentage of cow with hock injuries per farm was found to be 56 ± 18% and mean percentage of knee injuries per farm was found to be 43 ± 23%. Animal-based factors found to be associated with a greater odds of hock injuries at the cow level were increased days in milk (DIM), lower body condition score (BCS), lameness, higher parity, higher cow width, median lying bout duration, and median number of lying bouts. Environmental factors found to be associated with hock injuries at the cow level were province, stall width, tie rail position, stall base, chain length, and age of stall base. Animal-based factors found to be associated with knee injuries at the cow level were DIM, BCS, and median lying time. Environmental factors found to be associated with knee injuries at the cow level were stall width, chain length, province, stall base, and bed length. Quadratic and interaction terms were also identified between these variables in both the hock and knee models. This study demonstrates that hock and knee injuries are still a common problem on tiestall dairy farms in Canada. Several animal- and housing-based factors contribute to their presence. Further research to confirm causal relationships between these factors would help identify the cause of knee and hock injuries and determine how to best reduce the incidence of injuries in cows on commercial tiestall dairy farms in Canada.
Key words: dairy cow, Canada, hock injury, knee injury, tiestall

INTRODUCTION

Leg injuries on dairy cows are a common problem in commercial dairy herds. Injuries are most commonly seen on the tarsus (hock) and carpus (knee) joints of the cow (Laven and Livesey, 2011). These types of injuries are widely accepted as a welfare concern for dairy cattle (Whay et al., 2003) and efforts to reduce them have been addressed in the Code of Practice for the Care and Handling of Dairy Cattle in Canada (National Farm Animal Care Council, 2009) and internationally with programs such as the Farmers Assuring Responsible Management (**FARM**) program in the United States (National Milk Producers Federation, 2015).

The average herd-level prevalence of hock and knee injuries for cows in freestall herds has been estimated to range from 23 to 73% in Canada and internationally (Veissier et al., 2004; Lombard et al., 2010; von Keyserlingk et al., 2012; Zaffino Heyerhoff et al., 2014). Some of this variation can be explained by differences in scoring systems and region. However, limited research has been conducted on tiestall systems, even though this housing system makes up 72.4% of the farms in the Canadian dairy industry, housing an estimated 36% of the dairy cows in Canada (Canadian Dairy Information Center, 2014).

Received November 23, 2015.
Accepted April 23, 2016.
[1]Corresponding author: dhaley@uoguelph.ca

Hock and knee injuries have been found to be associated with several housing-, management-, and animal-based factors within Canada and internationally. The most commonly identified animal-based factors associated with leg injuries include early lactation (Busato et al., 2000; Kielland et al., 2009), high or low BCS (Busato et al., 2000; Lim et al., 2015), lameness (Brenninkmeyer et al., 2013; Burow et al., 2013), older age (Kielland et al., 2009; Potterton et al., 2011), and lower lying time (Rushen et al., 2007). The most commonly identified farm-based risk factors for injuries include hard stall surfaces (Livesey et al., 2002; Barrientos et al., 2013; Burow et al., 2013; de Vries et al., 2015), lack of bedding (Barrientos et al., 2013), long and short stalls (Regula et al., 2004; Kielland et al., 2009; Potterton et al., 2011), and no outdoor access (Keil et al., 2006; Barrientos et al., 2013; de Vries et al., 2015).

The objectives of this study were to provide an estimate of the prevalence of hock and knee injuries and identify risk factors for them among Holstein dairy cows housed on tiestall farms in Ontario and Quebec, Canada.

MATERIALS AND METHODS

All methods were approved by the respective University of Guelph and Laval University Animal Care Committee and Research Ethics Board (Guelph REB # 10DC021, AUP # 10R110; Laval CPAUL # 2010127). All standard operating procedures for this study can be found online on the Canadian Dairy Research Portal (2015).

Study Design

Data for this study were collected as part of a national cross-sectional study undertaken in 2011 (Vasseur et al., 2015). Tiestall farms (n = 100) were visited from January to December 2011 in the provinces of Ontario (n = 40) and Quebec (n = 60). Together these 2 provinces account for 95.3% of Canada's tiestall dairy farms (Canadian Dairy Information Center, 2014). One hundred farms was the maximum number of farms that could be assessed within the budgetary and time limitations of the project.

Herd Selection

Eligible tiestall herds for this study were selected from those enrolled in a milk recording program through Canwest DHI in Ontario, and Valacta in Quebec (Vasseur et al., 2015). Participation in this study was voluntary, with no financial compensation provided to the herd owners. The number of eligible tiestall herds sent invitation letters was based on an expected response rate of 10% and totaled 1,319 letters. Producers who responded to their invitation letter with interest were interviewed by telephone to further determine whether they met all inclusion criteria, and if so, to schedule farm visits. The criteria were the milking herd did not have outdoor access within 2 mo of the time of the visit and mean milk production was ≥7,000 kg/cow per year. A minimum herd size of 40 milking Holstein cows was required, and the facilities housing the milking herd had to have been in use for at least 1 yr.

Cow Selection

Based on previous work determining sample sizes for accurately estimating lying time at the herd level (Ito et al., 2009; Vasseur et al., 2012), 40 focal cows per herd were purposively selected for observation. Cow selection was balanced for parity, whenever possible, to reflect the proportion of primiparous and multiparous cows within the milking herd. Cows were purposively selected based on DIM, selecting cows 10 to 120 DIM whenever possible. This selection was done owing to the evidence that early lactation cows are at increased odds of having leg injuries (Kielland et al., 2009). Cows under 10 DIM were not selected because of a lack of opportunity for habituation to their environments postcalving. If a herd had fewer than 40 cows between 10 and 120 DIM, the selection window was extended beyond 120 DIM until the target sample size of 40 was reached. Based on the average size of tiestall herds in Ontario and Quebec (Canadian Dairy Information Center, 2014), a sample size of 40 cows per herd allowed us to sample an average of 70.5% of the adult dairy cows in each herd.

Animal-Based Measures

Injuries. Hock and knee injuries were the 2 outcome variables of interest. Cows were scored for hock and knee injuries according to the criteria in Table 1 (adapted from Gibbons et al., 2012) while in their stalls. Both hocks and both knees on each animal were scored. Due to poor lighting in some barns, a headlamp was used to facilitate cow assessment.

BCS. Body condition score was recorded on a 5-point scale in 0.25 increments (Ferguson et al., 1994), using the procedure described in Vasseur et al. (2013).

Lameness. Lameness was assessed using in-stall lameness scores developed by Leach et al. (2009) and validated by Gibbons et al. (2014). Cows were individually video recorded using a Sony DCRSR88 camera (Sony, Tokyo, Japan) in their stalls from behind for 2.5 min. The 4 following behaviors were scored: resting a foot, shifting weight, placing a foot on edge of stall, and uneven weight bearing when moving side to side. A cow was considered lame if 2 or more of these behaviors were observed in her video recording. This novel method has a sensitivity of 0.63 and a specificity of 0.77 compared with locomotion scoring (Gibbons et al., 2014).

Lying Time. Lying time was recorded using an electronic data logger (Hobo Pendant G Accelerator Data Logger, Onset Computer Corporation, Pocasset, MA) attached to the lateral side of the metatarsus of one hind leg of each focal cow. Co-Flex vet wrap (Andover Healthcare Inc., Salisbury, MA) was used to attach a logger to the leg while a cow was in her stall, and the logger remained on the cow for a minimum of 96 h. The loggers recorded data at 1-min intervals starting at midnight of the day they were attached. Data on lying time (min/d), lying bout number, and individual lying bout duration were collected and averaged for each cow over 4 consecutive 24-h periods as validated by Ito et al. (2009) and Vasseur et al. (2012).

Cow Height and Width. The height of each focal cow was measured from the ground to the spine parallel to the hook bone, and the width was measured between the 2 widest points of the hook bones.

Parity, DIM, and milk production data for the focal cows were extracted through CanWest DHI and Valacta databases from the most recent milk recording visits on each farm. Days in milk on day of the visit were extrapolated from the milk recording date. To more easily illustrate associations, DIM was categorized in 10-d increments. Parity was categorized in 4 categories (1, 2, 3, and 4+) based on the distribution of the data. Our sample included a large number of cows within parity 1, 2, and 3, but fewer in parities 4 or greater; therefore, parities 4 or greater were grouped.

Training. Research teams in Quebec (n = 3) and Ontario (n = 2), each consisting of 2 people, followed an intensive 2-wk training program on all animal and farm measures. Regular inter- and intra-observer repeatability checks were performed for injury, lameness, BCS, and cleanliness scoring throughout the data collection period using the methodology described in Gibbons et al. (2012) and Vasseur et al. (2013). Repeatability between observers and the trainers was tested using a weighted Kappa coefficient as described in Gibbons et al. (2012) and Vasseur et al. (2013). Only observers who achieved and maintained a weighted kappa coefficient of $\geq$0.6 during training were used to assess injuries and other animal-based measures on farm, to align with previous work (Gibbons et al., 2012). If an observer demonstrated weak repeatability for a certain measure, they were paired with an observer who demonstrated strong repeatability for that measure to help record that data.

Farm Measures

Individual Stall Measurements. The following measures were taken on every stall occupied by a focal cow. The type of tiestall, including tie rail and chain, stanchions, chain, 2-bar stalls, and 6-bar stalls, was recorded. These types are illustrated in Figure 1. The width from the inside of one stall divider to the inside of the next divider was measured. For those stall designs with a chain to tether the cow, the chain length was measured. Lunge space ahead of each focal cow was scored as "no obstruction" if no obstruction was present within 76 cm ahead of the center top of the manger curb and to a 45° angle to the left and right (National Farm Animal Care Council, 2009). Electric trainer position above each focal cow was scored as "low" if less than 10 cm or acceptable if higher than 10 cm from the highest point of the cow (National Farm Animal Care Council, 2009).

Averaged Stall Measurements. To maximize time efficiency on farm and gather necessary data, the following measures were interpolated from a sample of stalls. A diagram of how the measurements were taken on the stall is provided in Figure 2. The length of the stall beds (a), the manger curb height (c), the height of the tie rail (d), and the position of the tie rail relative to the manger curb (b) were based on the length, height, and tie rail position of the stalls on either end of each row containing focal cows. A linear interpolation between the values of the stalls on each end was then

Table 1. Description of injuries assessed on lactating dairy cattle (adapted from 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, broken skin or scab on bald area, or both	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 or scab, swelling <2.5 cm high, or both; may have bald area	Swelling ≥2.5 cm high; may have bald area or lesion

[1]For the purpose of analysis, scores 0 and 1 were combined as "not injured" and scores 2 and 3 were combined as "injured."

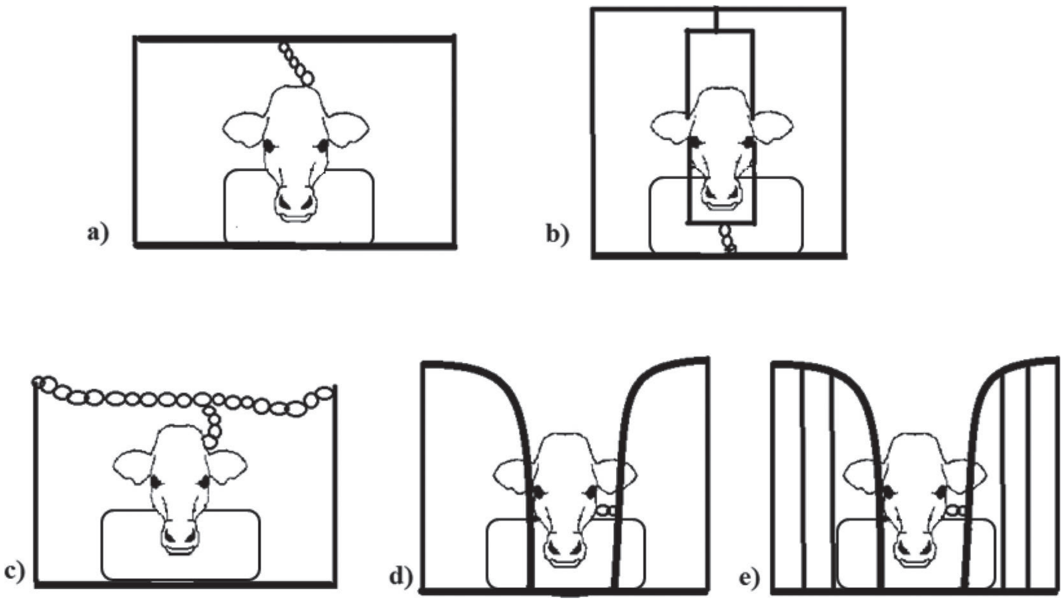

Figure 1. Diagram of observed stall configurations: (a) tie rail and chain, (b) stanchion, (c) chain, (d) 2-bar, and (e) 6-bar.

performed to calculate the respective dimensions for each stall that housed a focal animal.

Bedding depth and cleanliness were assessed for 2 stalls per row of cows. Stalls on either side of the center stall of each row housing focal cows were scored. Bedding depth was evaluated as "none" (insufficient quantity to allow bedding to be raked), <2 cm (once raked evenly), or ≥2 cm (once raked evenly). Two centimeters was selected as the cutoff for bedding depth because this depth would be the minimum bedding required to cover the stall base leaving no bare spots. Stall cleanliness was evaluated qualitatively on the back one-quarter of the stall bed length after the cleaning routine had been performed. Cleanliness was categorized as either clean, little manure or visible wet areas, the manure-free area was larger than the contaminated area, the contaminated area was larger than the manure-free area, or the entire area contaminated with manure or urine. Bedding wetness was tested using a paper towel technique (Canadian Dairy Research Portal, 2015). Bedding was considered dry, wet, or very wet. Farms were attributed a bedding wetness, cleanliness, and depth score based

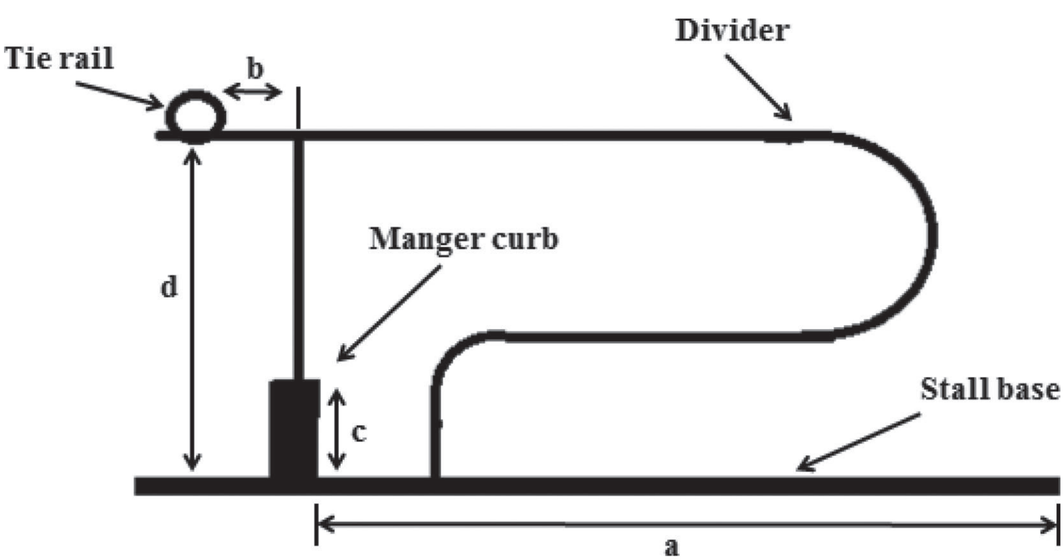

Figure 2. Diagram of stall measures taken on farm: (a) bed length, (b) tie rail position, (c) manger curb height, and (d) tie rail height.

on the worst stall score they received during the farm visit in each row, as well as attributed a mean bedding wetness, cleanliness, and depth score for all stalls.

Because some farms had more than one type of housing accommodations for cows, only the predominant (>50%) tie rail type, stall base, and bedding type were recorded on each farm.

Feed Management. Presence of feed in the manger was recorded on 4 separate occasions during the visit, with a minimum of 60 min between each observation. Presence of feed was scored as present if more than 90% of cows had some feed in front of them at the time of the assessment. Producers were asked how frequently they push up feed and this was recorded as 2 to 3 times per day, 1 time per day, or not applicable if cows were provided a sunken manger.

Data Handling

The data were entered into a relational database by observers (Microsoft Access 2010; Microsoft Corp., Redmond, WA). Data entry was evaluated 3 times by different individuals to minimize the risk of errors. These checks were done by comparing the data from the on-farm data sheets, to the data entered electronically. The data were exported into SAS 9.3 (SAS Institute Inc., Cary, NC) for analysis. Cows missing or who only had 1 score for hock or knee were excluded from analysis.

Statistical Analysis

Descriptive statistics (mean, standard deviation, minimum, and maximum) were generated using Proc Freq and Proc Means functions in SAS 9.3 to describe herd and cow characteristics.

Two generalized liner mixed models with logistic link function were built for hock and knee injury outcome variables using Proc GLIMMIX in SAS 9.3 with a binomial distribution. Farm nested within province was included in both models as a random effect to account for the fact that cows within a farm and farms within a province might not be independent. Predictor variables were tested for collinearity and if found to be highly correlated (correlation coefficient ≥ 0.8), the most significant variable when tested at the univariable level with the outcome of interest was retained for analysis in the model. All variables were included in the full multivariable model. All nonsignificant variables ($P > 0.05$) were removed from the model in a manual backward step-wise fashion. If the removal of any variable resulted in a greater than 20% change in the estimate of a remaining variable, the removed variable was considered a confounder and retained in the model. Continuous variables were tested for linearity by testing their quadratic form. Biologically plausible interactions between variables and quadratics were then tested and retained if $P \leq 0.05$ in addition to the significant main effects.

RESULTS

Of the 1,319 randomly selected tiestall farms that were sent invitations to participate in the study, 250 replied and agreed to participate, giving us a response rate of 19%. Mean milk yield per year in the herds in our sample was 9,570 kg and mean herd size was 66. In total, 303 cows were excluded from the hock analysis due to a missing hock score, and 92 cows were excluded from the knee analysis due to a missing knee score. Of the cows included in the analysis, 56.3% had a hock injury and 42.5% had a knee injury overall (scores 2 or 3); the distribution of hock and knee scores is described in Table 2. At the farm level, mean percentage (±SD) of cows with a hock injury was 56 ± 18% and knee injury was 43 ± 23%. In Ontario, mean percentage (±SD) of cows with a hock injury was 45 ± 18% and knee injury was 26 ± 15% at the farm level. In Quebec, mean percentage (±SD) of cows with a hock injury was 64 ± 18% and knee injury was 53 ± 21% at the farm level. The distribution of potential explanatory variables is presented in Tables 3 and 4. Age of stall base was assessed on 96 farms; mean age was 7.7 years with a SD of 5 yr and a range from 1 to 28 yr.

Factors Associated with Hock Injuries

The factors associated with hock injuries in the multivariable model are presented in Table 5. The proportion of random variation that occurred at the herd level was 25% in this model.

Animal-Based Measures. The odds of hock injury increased by 1.02 times with every 10-d increase in DIM

Table 2. Distribution of hock and knee injuries scores on 3,868 cows from 100 tiestall farms overall and by province

Variable	Overall, no.[1] (%)	Quebec, no. (%)	Ontario, no. (%)
Hock injury			
0	804 (21)	366 (17)	438 (30)
1	779 (20)	407 (19)	372 (25)
2	1,912 (49)	1,308 (60)	604 (42)
3	130 (3)	83 (4)	47 (3)
Knee injury			
0	1,374 (36)	599 (26)	775 (49)
1	831 (22)	440 (19)	391 (25)
2	1,575 (41)	1,182 (53)	393 (25)
3	69 (2)	53 (2)	16 (1)

[1]Does not always equal 3,868 (or 100%) because of missing data.

($P = 0.001$) and by 1.39 times with every 0.25-point decrease in body condition ($P = 0.002$). Median lying bout duration and median number of lying bouts had significant quadratic terms in the hock injury model ($P = 0.002$ and $P < 0.001$, respectively). The probability of hock injury increased when median lying bout duration was less than 110 min or more than 200 min. The probability of hock injury was lowest in cows with median number of lying bouts between 13 and 18. An interaction was also discovered between lameness and parity ($P = 0.02$). Cows in parity 4 or greater were more likely to have hock injuries if lame than if not lame ($P = 0.009$) as illustrated in Figure 3. All other parities showed no difference when lame or not lame. A second interaction was found between number of lying bouts and parity ($P = 0.04$) seen in Figure 4. Cows in parity 2 and 4 or greater were less likely to have hock injuries with fewer lying bouts than cows in parity 1 and 3. This relationship is reversed after 14 lying bouts per day, with cows in parity 2 and 4 or greater having higher probability of hock injuries than cows in parity 1 and 3. Finally, as illustrated in Figure 5, for narrower cows (<80 cm), increasing stall width lowered the probability of hock injury ($P = 0.01$). Whereas for wider cows (≥80 cm), increasing stall width increased the probability of hock injury. At a stall width of 127 cm, the probability of hock injury was the same for all cow widths. After this point, the probability of injury for narrower cows becomes lower than the probability of injury for wider cows.

Table 3. Distribution of all cow-level explanatory variables hypothesized to be associated with hock and knee injuries measured on 3,868 cows from 100 tiestall farms in Canada

Variable	Cows, no.[1] (%)	Mean	SD	Minimum	Maximum	Univariable *P*-value hock	Univariable *P*-value knee
Cow variables							
Cow	3,868 (100)						
Leg hygiene						0.97	0.58
Dirty	160 (4)	—	—	—	—		
Not dirty	3,703 (96)	—	—	—	—		
Udder hygiene						0.68	0.61
Dirty	153 (4)	—	—	—	—		
Not dirty	3,710 (96)	—	—	—	—		
Flank hygiene						0.074	0.042
Dirty	411 (11)	—	—	—	—		
Not dirty	3,457 (89)	—	—	—	—		
Lameness						0.0001	0.028
Lame	914 (24)	—	—	—	—		
Not lame	2,837 (73)	—	—	—	—		
Parity						0.78	0.56
1	1,394 (36)	—	—	—	—		
2	994 (26)	—	—	—	—		
3	628 (16)	—	—	—	—		
≥4	850 (22)	—	—	—	—		
DIM (d)	3,868 (100)	156	94.5	12	500	0.084	0.16
Cow height (cm)	3,868 (100)	150.4	4.3	137	159	0.77	0.23
Cow width (cm)	3,785 (98)	66.4	4.3	52	76	0.84	0.59
BCS	3,940 (100)	2.75	0.5	1	4.5	0.06	0.12
Average lying time (min)	3,788 (98)	747	142	373	1,092	<0.0001	0.22
Average lying bout duration (min)	3,788 (98)	73	25	27	170.8	0.62	0.93
Average number of lying bouts	3,788 (98)	11.3	3.7	2.3	21.5	0.35	0.52
Median lying time (min)	3,788 (98)	748	143	400	1,087	<0.0001	0.18
Median lying bout duration (min)	3,788 (98)	72.5	25	27.2	166	0.51	0.79
Median number of lying bouts	3,788 (98)	11.3	3.6	2	23	0.37	0.45
Housing and management variables							
Stall width (cm)	3,788 (98)	126.6	11.1	99	154	0.15	0.75
Bed length (cm)	3,787 (98)	178.1	8.5	157	200	0.90	0.044
Manger height (cm)	3,787 (98)	20.4	8.5	0	39	0.16	0.35
Chain length (cm)	3,709 (96)	69.4	21.6	25	130	0.11	0.0003
Tie rail height (cm)	3,476 (90)	109.9	12.2	78	134	0.51	0.16
Tie rail position (cm)	3,122 (81)	15.6	16.3	−36	67	0.04	<0.0001
Trainer position						0.72	0.21
Adjusted	3,167 (82)	—	—	—	—		
Not adjusted	134 (3)	—	—	—	—		
Lunge space						0.18	0.44
Yes	3,699 (96)	—	—	—	—		
No	88 (2)	—	—	—	—		

[1]Does not always equal 3,868 (or 100%) because of missing data.

Farm-Based Measures. The odds of hock injury decreased by 1.03 times for every 1-yr increase in the age of the stall base ($P = 0.02$) and by 1.01 for every 1-cm reduction in chain length ($P = 0.03$). Additionally, the odds of hock injury were 1.44 times greater on rubber mats ($P = 0.01$) and 2.64 times greater on concrete ($P = 0.15$) compared with mattresses.

Last, an interaction was found between tie rail position and province ($P = 0.03$) illustrated in Figure 6. The further forward the tie rail was positioned, the greater the probability of hock injury. Tie rail position only went from −36 to 35 cm in Quebec and 0 to 67 cm in Ontario. The probability of hock injuries was consistently higher in Quebec; however, the slope of the probability was greater in Ontario.

Table 4. Distribution of all herd-level explanatory variables hypothesized to be associated with hock and knee injury as measured on 3,868 cows from 100 tiestall farms in Canada

Variable	Herds, no.[1] (%)	Univariable *P*-value	
		Hock	Knee
Herd	100 (100)		
Province		<0.0001	<0.0001
Ontario	40 (40)		
Quebec	60 (60)		
Stall base		0.0097	<0.0001
Mattress	44 (44)		
Rubber mat	51 (51)		
Concrete	3 (3)		
Bedding type		0.57	0.53
None	3 (3)		
Other	4 (4)		
Shavings	1 (1)		
Sawdust	1 (1)		
Straw	92 (92)		
Stall type		0.0010	0.18
Tie rail and chain	89 (89)		
Stanchion	1 (1)		
2-bar stall	5 (5)		
6-bar stall	3 (3)		
Minimum bedding depth		0.15	0.40
None	1 (1)		
<2 cm	57 (57)		
≥2 cm	40 (40)		
Mean bedding depth		0.01	0.13
0.5 cm	1 (1)		
1 cm	39 (39)		
1.5 cm	18 (18)		
2 cm	40 (40)		
Maximum bedding wetness		0.47	0.28
Dry	68 (68)		
Wet	25 (25)		
Very wet	5 (5)		
Mean bedding wetness		0.10	0.21
0	68 (68)		
0.5	22 (22)		
1	8 (8)		
Maximum manure contamination		0.32	0.28
Clean	31 (31)		
Little	52 (52)		
Clean >50%	11 (11)		
Dirty >50%	4 (3)		
Completely dirty	0 (0)		
Mean manure contamination		0.37	0.14
0	31 (31)		
0.5	37 (37)		
1	19 (19)		
1.5	6 (6)		
2	4 (4)		
2.5	1 (1)		
Feed access		0.15	0.74
Yes	51 (51)		
No	2 (2)		
Feed pushup		0.14	0.24
2–3 times per day	46 (46)		
1 time per day	4 (4)		
Not applicable	3 (3)		

[1]Does not always equal 100 (or 100%) because of missing data.

Factors Associated with Knee Injuries

Factors associated with knee injuries at the multivariable level are presented in Table 6. The proportion of random variation that occurred at the herd level was 31% in this model.

Animal-Based Measures. The probability of knee injury was found to decrease with increasing DIM within the distribution of our data ($P = 0.005$). In addition, an interaction was identified between BCS and DIM ($P = 0.009$). As illustrated in Figure 7, for cows with a BCS of 2, the probability of knee injury decreased with increased DIM. For cows with a BCS of 3, the probability of knee injury dropped until 200 DIM, and then began to rise. For cows with a BCS of 4, the probability of knee injury increased with increasing DIM. Lastly, lying time was found to have a quadratic association with injuries: the probability of knee injury decreased with increasing lying time until cows were lying 12 h a day, at which point the probability of knee injuries began to rise with increasing lying time ($P < 0.001$).

Farm-Based Measures. The odds of knee injuries were found to increase by 1.10 times with every 10-cm decrease in chain length ($P = 0.001$), increased by 1.10 times with every 5-cm decrease in bed length ($P = 0.01$), and decreased with increasing stall width ($P = 0.001$). Additionally, the odds of knee injury were 2.90 times greater in Quebec than in Ontario ($P < 0.001$). The odds of knee injury were also 2.01 times greater on rubber mats ($P < 0.001$) and 3.01 times greater on concrete ($P = 0.01$) compared with mattresses.

DISCUSSION

To our knowledge, this project was the most comprehensive on-farm cow comfort study of its kind in Canada, assessing 3,868 cows on 100 tiestall farms across Ontario and Quebec. Through this study, we identified that hock and knee injuries are a common problem on Canadian tiestall farms. The mean milk yield per year in the herds in our sample was 9,570 kg and mean herd

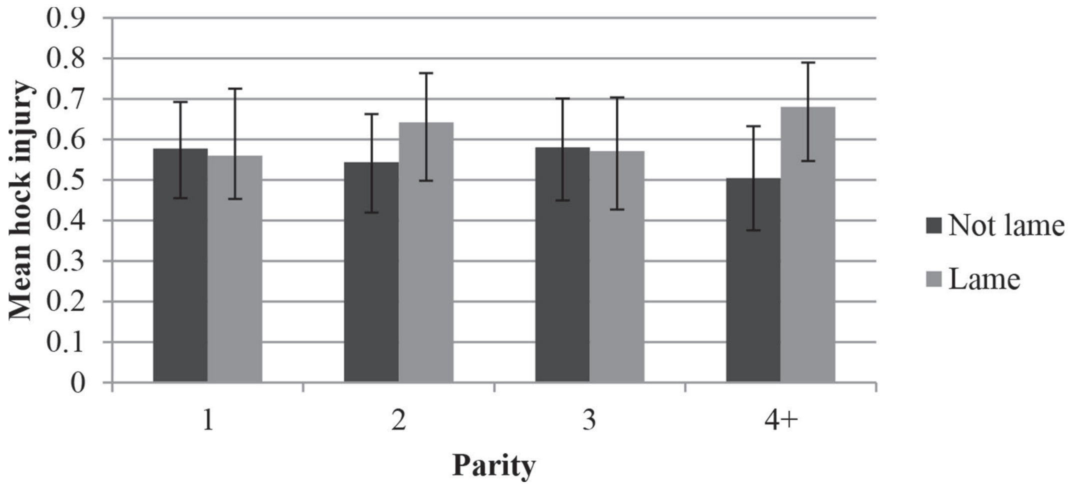

Figure 3. Mean level of hock injury by parity and lameness. Error bars indicate 95% CI.

size was 66. These values are slightly higher than the provincial means of 8,673 kg and 57 cows in Ontario and 8,696 kg and 55 cows in Quebec (Canadian Dairy Information Center, 2014). The differences were likely because of our selection criteria for production and herd size. On average, 56% of our sample of each herd had hock injuries and 43% had knee injuries. This level of hock injury was higher than the 47% reported on cows in freestall systems in Canada (Zaffino Heyerhoff et al., 2014). The level of knee injuries identified was also higher than the 27% reported in freestall systems (Zaffino Heyerhoff et al., 2014). This finding is possibly because of the greater prevalence of cement- and rubber mat-based systems in tiestall systems compared

Table 5. Factors associated with hock injuries on 87 farms in the final logistic regression model with a binomial distribution, not injured (no response) (n = 1,438) and injured (response) (n = 1,275)

Fixed effect	Coefficient	SE	df	Odds ratio	95% CI	*P*-value
DIM per 10 d	0.016	0.0049	2,780	1.02	1.01–1.03	0.001
BCS	−0.33	0.10	2,780	1.39	1.14–1.70	0.002
Age of stall base per 1 yr	−0.033	0.014	2,780	1.03	1.01–1.06	0.02
Chain length per cm	−0.0063	0.0029	2,780	1.01	1.00–1.01	0.03
Lameness	—	—	—	—	—	0.004
Not lame	−0.73	0.18	2,780	—	—	—
Lame	Referent	—	—	—	—	—
Parity	—	—	—	—	—	0.06
1	0.67	0.43	2,780	—	—	—
2	0.21	0.44	2,780	—	—	—
3	0.40	0.46	2,780	—	—	—
≥4	Referent	—	—	—	—	—
Lameness × parity	—	—	2,780	—	—	0.02
Province	—	—	—	—	—	<0.001
Ontario	−1.34	0.34	82	—	—	—
Quebec	Referent	—	—	—	—	—
Tie forward position per cm	0.0036	0.0066	2,780	—	—	0.003
Tie forward × province	—	—	2,780	—	—	0.03
Stall base	—	—	—	—	—	0.03
Concrete	0.97	0.67	2,780	—	—	—
Rubber mat	0.37	0.15	2,780	—	—	—
Mattress	Referent	—	—	—	—	—
Cow width per cm	−0.27	0.11	2,780	—	—	0.01
Stall width per 5 cm	−0.78	0.28	2,780	—	—	0.006
Stall width × cow width	0.011	0.0042	2,780	—	—	0.01
Median bout duration per min	−0.36	0.082	2,780	—	—	<0.001
Bout duration squared	0.012	0.0038	2,780			0.001
Median number bouts	−0.26	0.068	2,780	—	—	<0.001
Bout number squared	0.0092	0.0024	2,780			<0.001
Bouts × parity	—	—	2,780	—	—	0.04

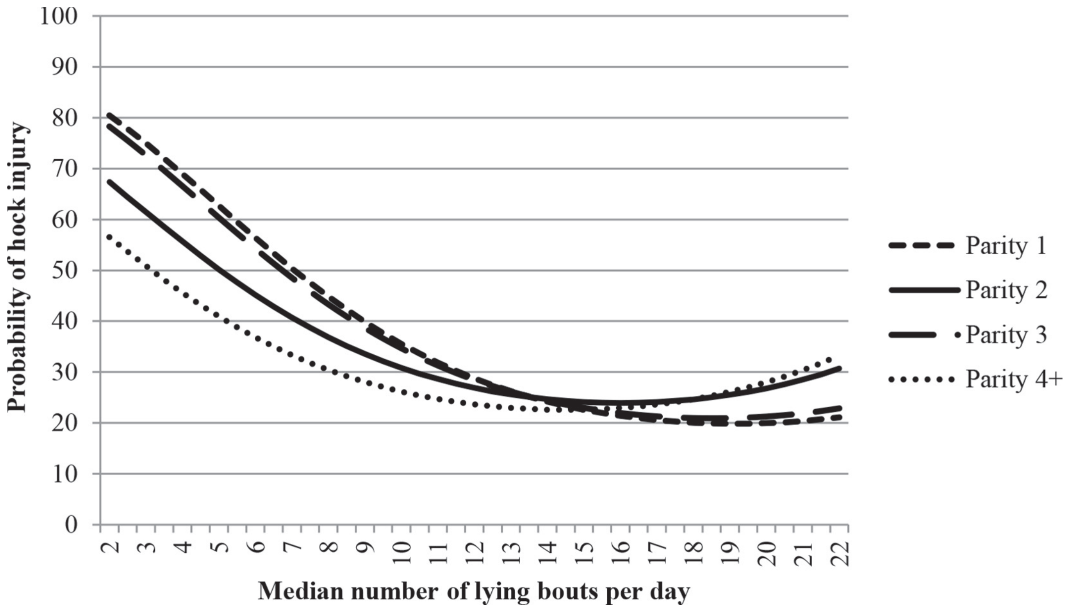

Figure 4. Probability of hock injury by median number of lying bouts per cow per day and parity.

with freestall housing, thus leading to higher impacts on cows' joints. We also identified tiestall herds with levels of hock injuries as low as 5.7% and knee injuries as low as 0%, indicating that it is possible to minimize the odds of injuries on dairy cows in tiestall housing systems.

The levels of hock and knee injuries were both higher on farms in Quebec. This finding can be explained in part by the interaction we identified between stall design and province described earlier. The design and material make-up of the manger wall may have also contributed to the difference in knee injuries. Though this factor was not measured, manger walls may be more likely to have been made of cement or other abrasive surfaces in Quebec than in Ontario. Furthermore, it is possible that the suppliers of stall bases in Quebec and Ontario differ: mattresses or rubber mats offered in Quebec may be more abrasive than those offered in Ontario, thereby causing a greater number hock and knee injuries in Quebec.

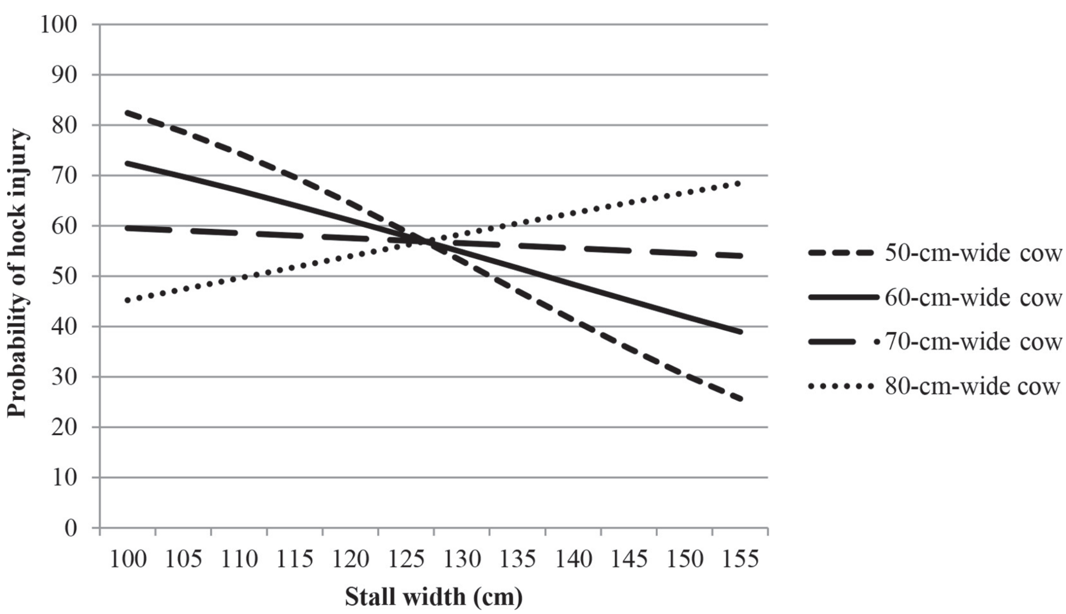

Figure 5. Probability of hock injury of cows of different widths by increasing stall width.

Table 6. Factors associated with knee injuries on 97 farms in the final logistic regression model with a binomial distribution, not injured (no response; n = 2,309) and injured (response; n = 711)

Fixed effect	Coefficient	SE	df	Odds ratio	95% CI	*P*-value
Chain length per cm	−0.072	0.028	3,477	1.07	1.02–1.14	0.01
Bed length	−0.097	0.037	3,477	1.10	1.02–1.19	0.009
DIM per 10 d	−0.11	0.027	3,477	—	—	<0.001
DIM squared	0.00093	0.00033	3,477	—	—	0.005
BCS	−0.60	0.19	3,477	—	—	0.001
DIM × BCS	0.024	−0.0094	3,477	—	—	0.01
Median lying time per min	−0.0058	0.0017	3,477	—	—	<0.001
Lying time squared	0.0000040	0.0000012	3,477	—	—	<0.001
Stall width per 5 cm	−0.44	0.17	3,477	—	—	0.01
Stall width squared	0.0081	0.0032	3,477	—	—	0.01
Province	—	—	3,477	—	—	<0.001
Ontario	−1.21	0.17	93	—	—	—
Quebec	Referent	—	—	—	—	—
Stall base	—	—	—	—	—	<0.001
Concrete	1.092	0.46	3,477	—	—	—
Rubber mat	0.66	0.16	3,477	—	—	—
Mattress	Referent	—	—	—	—	—

Factors Associated with Hock Injury

The proportion of random variation that occurred at the herd level was 25% in this model. As expected, the outcome was clustered within herd likely due to herd-level variables. However, 75% of variation occurred at the cow level, making cow-level analysis appropriate.

Animal-Based Measures. The odds of hock injuries increased with increasing DIM, which agrees with previous research (Potterton et al., 2011; Burow et al., 2013; Zaffino Heyerhoff et al., 2014). This association could be explained by cows with higher DIM being exposed to the stall surface for a longer period and this prolonged exposure causing the injury.

Additionally, a higher probability of hock injuries was found for thin cows. This association was also reported by Lim et al. (2015). It is hypothesized that thinner cows have less of a fat pad on their hocks to protect the joint, therefore putting them at greater odds of injuring the hock. Lameness was also identified as having an association with hock injuries, depending on parity. Older cows that were also lame had the greatest odds of having hock injuries, and lameness increased these odds compared with older nonlame cows. This finding

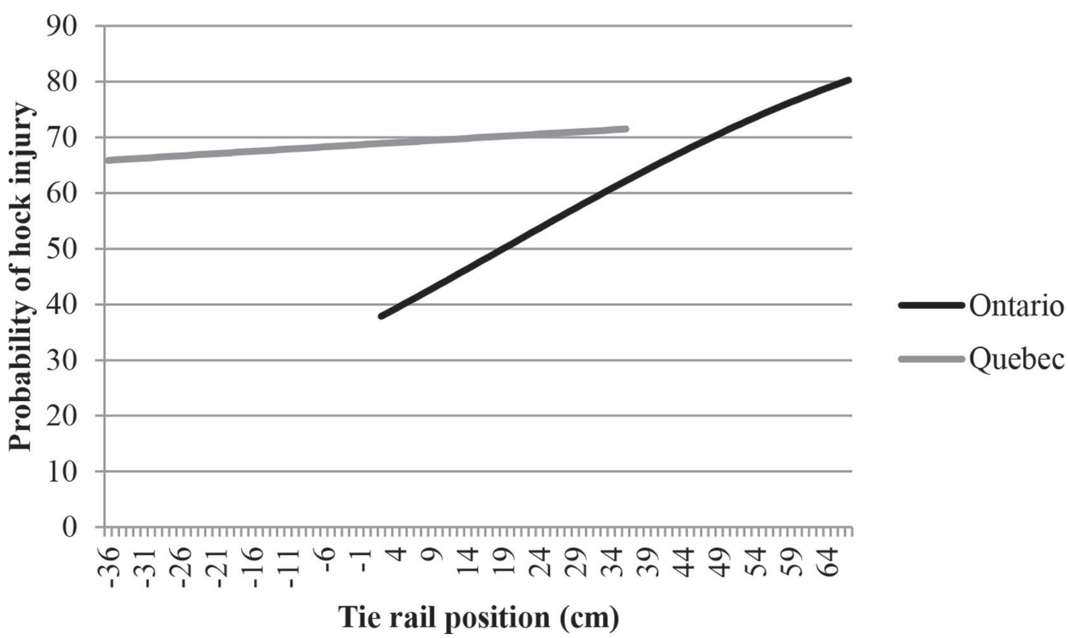

Figure 6. Probability of hock injury by tie rail position in relation to the front edge of the manger curb for Ontario and Quebec.

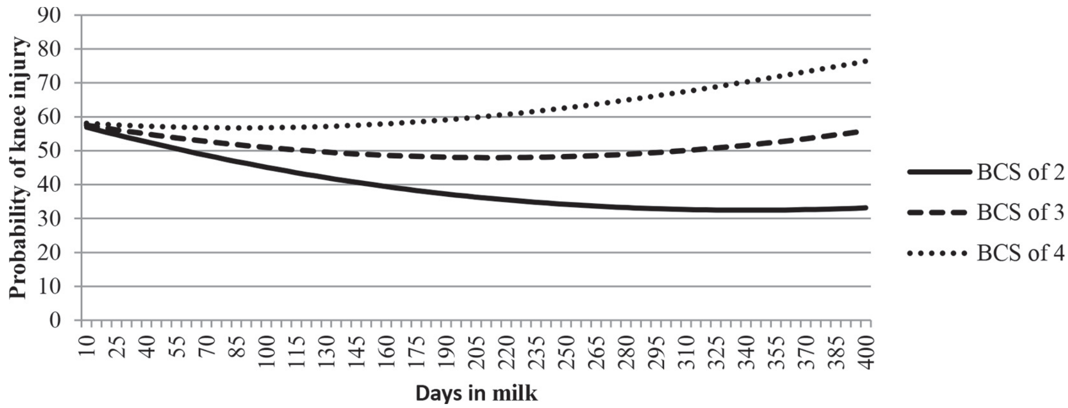

Figure 7. Probability of knee injury in different cow BCS by increasing DIM.

supports previous research that identified older cows as being at higher risk of injury, as well as lameness being an additional risk factor (Rutherford et al., 2008; Potterton et al., 2011; Lim et al., 2015). Lying time was found to be associated with increased odds of hock injuries. Cows with low (<8) or high (>20) number of lying bouts and low (<60 min) or high (>240 min) lying bout durations had increased odds of having hock injuries. This association between lying behavior and hock injuries is still unclear in the literature; however, a study by Ito et al. (2010) demonstrated that severe lameness was associated with cows with longer lying bout durations. It is possible that cows with mild hock injuries are uncomfortable and therefore have shorter lying bouts, whereas cows with more severe injuries are high-risk cows that may be so uncomfortable that they get up and down less and stay down once lying, which would explain the fewer, longer lying bouts.

Farm Measurements. Older stall bases were negatively correlated with hock injuries. Potterton et al. (2011) found a similar association: stall surfaces may become less abrasive through rubbing and being worn over time. Is it also hypothesized that farms with older stall bases compensate for aging stall bases through other housing and management factors such as bedding. Our measures were likely not sensitive enough to account for this compensation effect.

Stall width was found to be associated with hock injuries, though it was dependent on the width of the cow. Wider stall was hypothesized to lower the probability of hock injury, and this relationship was the case for narrower and average cows in our study. However, wider cows had increased odds of hock injury when in wider stalls. This outcome could be due to confounding factors related to management. Perhaps producers purposely provided their larger cows wider stalls and may have especially done so for those wide cows that had already sustained an injury. Additionally, wider cows may also be heavier, therefore placing more weight and pressure on their knees when lying and rising.

Finally, tie rail position played a role in the probability of hock injury, with forward tie rails increasing the probability of injuries. This finding could be explained by the further forward the tie rail, the further forward the cow is placed in the stall, and so the cow may not have as much flexibility to move her hocks when lying down and getting up. This effect varied between the 2 provinces, with the probability of injury rising much more quickly as the tie rail moves forward in Ontario than in Quebec. However, the overall probability of hock injury was consistently greater in Quebec. This interaction could be explained by tie rail positions in Ontario being further forward, whereas herds in Quebec had tie rails further back from the manger curb.

Factors Associated with Knee Injury

Knee injuries had different risk factors than hock injuries. This finding agrees with research demonstrating that hock and knee injuries do not necessarily correlate with each other (Brenninkmeyer et al., 2016). The proportion of random variation that occurred at the herd level was 31% in this model. Again as expected, the outcome was clustered within herd likely because of herd-level variables. However, 69% of the variation occurred at the cow level, making cow-level analysis appropriate.

Cow Measurements. In this study, body condition interacted with DIM: cows with higher BCS had a higher probability of knee injuries with increasing DIM than cows with low or average BCS. This finding may be because cows with higher BCS tend to be heavier and are thereby putting more pressure on their knees. Additionally, cows within a median lying time range of between 10 and 14 h were found to have the lowest probability of knee injuries. This finding supports previous research demonstrating this range as being optimal for cow comfort (Ito et al., 2010).

Farm Measurements. The odds of knee injuries were increased with shorter chain length. This outcome is perhaps due to cows having less free space to rise and lie down with shorter chains and causing them to struggle on their knees. Knee injuries were also more common in Quebec than Ontario, which could be explained by the difference in stall designs observed between the 2 provinces. This difference in tie rail position is demonstrated in Figure 6, where tie rail positions range much further back in the stall on farms in Quebec than they do on farms in Ontario. Stall base was also found to be associated with knee injuries, as reported by others (Rushen et al., 2007; Zaffino Heyerhoff et al., 2014). Harder stall surfaces such as concrete and simple rubber mats provide higher odds of knee injuries possibly because of lower compressibility of concrete and rubber mats compared with mattresses (Fulwider and Palmer, 2004). Lastly, the odds of knee injuries increased in narrower and shorter stalls. This increase may have been due to lack of adequate space to rise and lie down, forcing the cow to fall more harshly to her knees when lying down than if she had more room and causing friction when rising to stand. She would also be more likely to rub against the manger wall in this scenario.

Limitations

Several limitations exist in this study that should be addressed with future research. This study was voluntary; therefore, nonresponse bias may be present. Even though our sample size reflects national mean milk yield and herd size for tiestall herds, the individuals who responded may be different from our target population regarding interest, knowledge, and application of on-farm cow welfare issues. Farms with serious injury problems may have chosen not to participate out of concern that they might be judged. Therefore, our sample may have lower levels of injuries than our target population. Unfortunately, this bias is an unavoidable limitation in voluntary studies. Given that this study had a cross-sectional design, cause and effect could not be established, especially between animal-based measures. Additionally, because of our large sample size and large number of variables, spurious results may have been identified that may not truly reflect the nature of these relationships. Further longitudinal study is required to understand the causal relationship among these factors. With regard to the study design, it would be wise in future studies to record housing and management of heifers and dry cows on farms. Some of the factors measured on fresh cows may have been a consequence of the heifer or dry housing and management they were exposed to and not the milking cow housing and management.

Furthermore, our measures of cow cleanliness, bedding depth, and stall cleanliness may not have been sensitive enough to pick up associations with hock injuries. A more detailed scoring system may have been more successful. Lastly, little variation was seen among the lunge space, bedding types, stall types, and trainer position, and so few analyses were performed and no significant results were found. This outcome does not preclude that other variations of these measures could have significant impacts on hock and knee injuries if they are present.

CONCLUSIONS

Reducing or eliminating hock and knee injuries on dairy cows is generally accepted to improve animal well-being. This study found that hock and knee injuries were common on tiestall dairy farms in Canada. An effort should be made to reduce such injuries. Several stall-based factors were found to contribute to injuries. This study provides a starting benchmark to track changes in the level of hock and knee injuries on tiestall farms over time with the improvement of these contributing factors, including age and type of stall base, chain length, and tie rail position for hock injuries, and bed length, bed width, and chain length for knee injuries. Producers should aim to provide adequate space for cows to stand up and lie down and a comfortable base to lie on to reduce the odds of hock and knee injuries. Animal-based factors such a lying time, age, BCS, and DIM were also found to be associated with injures; however, the direction of these associations are impossible to identify in a cross-sectional study. Additional longitudinal studies should be performed to better understand the causal relationships between these factors.

ACKNOWLEDGMENTS

This study was funded by Dairy Farmers of Canada (Ottawa, ON, Canada), the Canadian Dairy Commission (Ottawa, ON, Canada), and Agriculture and Agri-Food Canada (Ottawa, ON, Canada) as part of the national Dairy Science Research Cluster Initiative and by Fonds Québecois de la Recherche sur la Nature et les Technologies (FQRNT; Québec city, QC, Canada) – Novalait (Québec city, QC, Canada) – Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ; Québec city, QC, Canada). We thank all the collaborators, technicians, and students from Agriculture and Agri-Food Canada, University of British Columbia (Vancouver, BC, Canada), University of Guelph (Guelph, ON, Canada), CanWest

DHI (Guelph, ON, Canada), University of Calgary (Calgary, AB, Canada), University Laval (Quebec City, QC, Canada), and Valacta (Sainte-Anne-de-Bellevue, QC, Canada). We also thank all the producers who volunteered their time to be part of this study.

REFERENCES

Barrientos, A. K., N. Chapinal, D. M. Weary, E. Galo, and M. A. von Keyserlingk. 2013. Herd-level risk factors for hock injuries in freestall-housed dairy cows in the northeastern United States and California. J. Dairy Sci. 96:3758–3765.

Brenninkmeyer, C., S. Dippel, J. Brinkmann, S. March, C. Winckler, and U. Knierim. 2013. Hock lesion epidemiology in cubicle housed dairy cows across two breeds, farming systems and countries. Prev. Vet. Med. 109:236–245.

Brenninkmeyer, C., S. Dippel, J. Brinkmann, S. March, C. Winckler, and U. Knierim. 2016. Investigating integument alterations in cubicle housed dairy cows: Which types and locations can be combined? Animal 10:342–348.

Burow, E., P. T. Thomsen, T. Rousing, and J. T. Sorensen. 2013. Daily grazing time as a risk factor for alterations at the hock joint integument in dairy cows. Animal 7:160–166.

Busato, A., P. Trachsel, and J. W. Blum. 2000. Frequency of traumatic cow injuries in relation to housing systems in Swiss organic dairy herds. J. Vet. Med. A Physiol. Pathol. Clin. Med. 47:221–229.

Canadian Dairy Information Center. 2014. Dairy facts and figures. Accessed Oct. 1, 2015. http://www.dairyinfo.gc.ca/index_e.php?s1=dff-fcil.

Canadian Dairy Research Portal. 2015. Research documents. Accessed Nov. 11, 2015. https://www.dairyresearch.ca/research-documents.php.

de Vries, M., E. A. Bokkers, C. G. van Reenen, B. Engel, G. van Schaik, T. Dijkstra, and I. J. de Boer. 2015. Housing and management factors associated with indicators of dairy cattle welfare. Prev. Vet. Med. 118:80–92.

Ferguson, J. D., D. T. Galligan, and T. Thomsen. 1994. Principal descriptors of body condition score in Holstein cows. J. Dairy Sci. 77:2695–2703.

Fulwider, W. K., and R. W. Palmer. 2004. Use of Impact testing to predict softness, cow preference, and hardening over time of stall bases. J. Dairy Sci. 87:3080–3088.

Gibbons, J., D. B. Haley, J. H. Cutler, C. G. Nash, J. C. Zaffino Heyerhoff, D. Pellerin, S. Adam, A. Fournier, A. M. de Passillé, J. Rushen, and E. Vasseur. 2014. Technical note: A comparison of 2 methods of assessing lameness prevalence in tiestall herds. J. Dairy Sci. 97:350–353.

Gibbons, J., E. Vasseur, J. Rushen, and A. M. de Passillé. 2012. A training programme to ensure high repeatability of injury scoring of dairy cows. Anim. Welf. 21:379–388.

Ito, K., M. A. von Keyserlingk, S. J. LeBlanc, and D. M. Weary. 2010. Lying behavior as an indicator of lameness in dairy cows. J. Dairy Sci. 93:3553–3560.

Ito, K., D. M. Weary, and M. A. von Keyserlingk. 2009. Lying behavior: Assessing within- and between-herd variation in free-stall-housed dairy cows. J. Dairy Sci. 92:4412–4420.

Keil, N. M., T. U. Wiederkehr, K. Friedli, and B. Wechsler. 2006. Effects of frequency and duration of outdoor exercise on the prevalence of hock lesions in tied Swiss dairy cows. Prev. Vet. Med. 74:142–153.

Kielland, C., L. E. Ruud, A. J. Zanella, and O. Osteras. 2009. Prevalence and risk factors for skin lesions on legs of dairy cattle housed in freestalls in Norway. J. Dairy Sci. 92:5487–5496.

Laven, R., and C. Livesey. 2011. Getting to grips with hock lesions in cattle. Vet. Rec. 169:632–633.

Leach, K. A., S. Dippel, J. Huber, S. March, C. Winckler, and H. R. Whay. 2009. Assessing lameness in cows kept in tie-stalls. J. Dairy Sci. 92:1567–1574.

Lim, P. Y., J. N. Huxley, M. J. Green, A. R. Othman, S. L. Potterton, C. J. Brignell, and J. Kaler. 2015. Area of hock hair loss in dairy cows: Risk factors and correlation with a categorical scale. Vet. J. 203:205–210.

Livesey, C. T., C. Marsh, J. A. Metcalf, and R. A. Laven. 2002. Hock injuries in cattle kept in straw yards or cubicles with rubber mats or mattresses. Vet. Rec. 150:677–679.

Lombard, J. E., C. B. Tucker, M. A. von Keyserlingk, C. A. Kopral, and D. M. Weary. 2010. Associations between cow hygiene, hock injuries, and free stall usage on US dairy farms. J. Dairy Sci. 93:4668–4676.

National Milk Producers Federation. 2015. National Dairy FARM Program. Accessed Nov. 11, 2015. http://www.nationaldairyfarm.com/.

National Farm Animal Care Council. 2009. Code of practice for the care and handling of dairy cattle. Accessed Nov. 11, 2015. https://www.nfacc.ca/codes-of-practice/dairy-cattle.

Potterton, S. L., M. J. Green, J. Harris, K. M. Millar, H. R. Whay, and J. N. Huxley. 2011. Risk factors associated with hair loss, ulceration, and swelling at the hock in freestall-housed UK dairy herds. J. Dairy Sci. 94:2952–2963.

Regula, G., J. Danuser, B. Spycher, and B. Wechsler. 2004. Health and welfare of dairy cows in different husbandry systems in Switzerland. Prev. Vet. Med. 66:247–264.

Rushen, J., D. Haley, and A. M. de Passillé. 2007. Effect of softer flooring in tie stalls on resting behavior and leg injuries of lactating cows. J. Dairy Sci. 90:3647–3651.

Rutherford, K. M., F. M. Langford, M. C. Jack, L. Sherwood, A. B. Lawrence, and M. J. Haskell. 2008. Hock injury prevalence and associated risk factors on organic and nonorganic dairy farms in the United Kingdom. J. Dairy Sci. 91:2265–2274.

Vasseur, E., J. Gibbons, J. Rushen, and A. M. de Passillé. 2013. Development and implementation of a training program to ensure high repeatability of body condition scoring of dairy cows. J. Dairy Sci. 96:4725–4737.

Vasseur, E., J. Gibbons, J. Rushen, D. Pellerin, E. Pajor, D. Lefebvre, and A. M. de Passillé. 2015. An assessment tool to help producers improve cow comfort on their farms. J. Dairy Sci. 98:698–708.

Vasseur, E., J. Rushen, D. B. Haley, and A. M. de Passillé. 2012. Sampling cows to assess lying time for on-farm animal welfare assessment. J. Dairy Sci. 95:4968–4977.

Veissier, I., J. Capdeville, and E. Delval. 2004. Cubicle housing systems for cattle: Comfort for dairy cows depends on cubicle adjustment. J. Anim. Sci. 82:3321–3337.

von Keyserlingk, M. A., A. Barrientos, K. Ito, E. Galo, and D. M. Weary. 2012. Benchmarking cow comfort on North American freestall dairies: Lameness, leg injuries, lying time, facility design, and management for high-producing Holstein dairy cows. J. Dairy Sci. 95:7399–7408.

Whay, H. R., D. C. J. Main, L. E. Green, and A. J. F. Webster. 2003. Animal-based measures for the assessment of welfare state of dairy cattle, pigs and laying hens: Consensus of expert opinion. Anim. Welf. 12:205–217.

Zaffino Heyerhoff, J. C., S. J. LeBlanc, T. J. DeVries, C. G. Nash, J. Gibbons, K. Orsel, H. W. Barkema, L. Solano, J. Rushen, A. M. de Passillé, and D. B. Haley. 2014. Prevalence of and factors associated with hock, knee, and neck injuries on dairy cows in freestall housing in Canada. J. Dairy Sci. 97:173–184.