J. Dairy Sci. 88:3201–3210

Tie-Stall Design and its Relationship to Lameness, Injury, and Cleanliness on 317 Ontario Dairy Farms

K. Zurbrigg,[1,2] D. Kelton,[1] N. Anderson,[2] and S. Millman[1]
[1]Population Medicine Department, Ontario Veterinary College, University of Guelph, Ontario, Canada N1G 2W1
[2]Veterinary Science Division, Ontario Ministry of Agriculture and Food, Fergus, Canada N1M 2W3

ABSTRACT

The objective of this study was to identify relationships between tie-stall design and selected cow-based injury, lameness, and cleanliness measurements. All lactating dairy cows (n = 17,893) from 317 Ontario tie-stall dairy farms were evaluated once between March and September 2003. Stall dimensions were recorded and cows were scored for neck and hock lesions, broken tails, back arch, hind claw rotation, and udder and hind limb cleanliness. Neck lesions were significantly associated with tie-rail height. Hock lesions were positively associated with presence of an electric trainer and hind limb and udder cleanliness and negatively associated with tie-chain length. A negative association was found between broken tails and tie-rail height and a positive association between broken tails and udder and hind limb cleanliness. As mean stall length increased, fewer cows had hind-claw rotation. Having more dirty cows was associated negatively with stall length and chain length, and positively associated with the presence of an electric trainer. Proportion of cows with clean udders increased with the percentage of cows with clean hind limbs and with tie-rail height. As the prevalence of clean udders increased the prevalence of broken tails decreased. This study provides insight into how tie-stall dimensions may influence aspects of dairy cow welfare. Application of these principles could improve tie-stall design.
(**Key words:** tie-stall design, dairy cow injury, dairy cow cleanliness)

Abbreviation key: DFO = Dairy Farmers of Ontario.

INTRODUCTION

A number of studies indicate that relationships exist between stall design and dairy cattle injury, lameness, and cleanliness (Blom, 1983; Blowey, 1993; Busato et al., 2000). Only a few aspects of stall design, however, have been investigated regarding their relationship with animal cleanliness and injury, with much of the work involving only free-stall housing systems. Although scant information is available on the effects of stall dimensions such as tie-rail height or tie-chain length, numerous studies have focused on the impact of stall surface or bedding type on dairy cattle. One such study (Weary and Taszkun, 2000) quantified hock lesions and demonstrated an association with stall surface in free-stall housing. Cows were scored for severity of hock lesions on 20 farms that used sand, sawdust, or rubber-filled mattresses as the stall bedding surface. Hock lesions varied in severity and in relation to location on the hock depending on type of stall surface.

Similarly, Chaplin et al. (2000) found that hygiene scores of the udder and hind limbs were associated with stall surface and bedding materials. The author concluded that cows were cleaner on rubber mats than on rubber-filled mattresses, which was linked to behavioral observations that cows on mats spent more time standing than cows on mattresses. Cows on mattresses were deemed more comfortable and thus spent more time lying down.

Recommendations for tie-stall sizes and designs are plentiful and varied (Agriculture Canada, 1990; Walker, 1995; Anderson, 2003b). Few are based, however, on valid scientific studies that prove the benefits of, or reasons for, the recommended stall sizes. Anderson (2003b) used the size of a cow's body imprint on the ground at pasture to determine the amount of space a cow needs while lying. He also videotaped cows as they stood up and used grid analysis to determine amount of space needed to lunge forward upon rising. He used these observations to estimate stall sizes that would allow the cow to rise and lie down in a manner similar to that seen on pasture. Tie stalls are the most common style of housing used on Ontario dairy farms. Problems associated with tie-stalls include hock swellings and abrasions, neck lesions, broken tails, and lameness (Zurbrigg, 2005). Some of these problems may be a result of poor stall design.

Received November 18, 2004.
Accepted May 19, 2005.
Corresponding author: Kathy Zurbrigg; e-mail: kathy.zurbrigg@omaf.gov.on.ca.

The goal of the present study was to determine whether significant relationships exist between stall dimensions and dairy cattle lameness, injury, and cleanliness. In addition, the relationships between cattle injuries and cleanliness were explored. Significant relationships would support the need for changes in tie-stall dimensions to reduce lameness, injury, and improve cleanliness of dairy cattle.

MATERIALS AND METHODS

Selection of a Study Population

Farms participated in the study as part of the mandatory biannual Grade A inspection process by the milk marketing board, the Dairy Farmers of Ontario (**DFO**). Before the start of data collection, letters were sent to all 4400 DFO members having tie-stall housing. The letters described the project and the information the inspectors would be collecting at the time of inspection. In addition, a notice was placed in the DFO monthly magazine "Milk Producer," describing the project.

The DFO divides Ontario into 15 zones, each with a field staff inspector. The zone sizes and distribution are based on the number of producers within a geographical region. Farms for inspection are assigned randomly to a month in the 2-yr cycle. Within the group assigned to a particular month, farms with both free-stall and tie-stall housing were included. Starting in March 2003 and continuing until September 2003, data were collected from all tie-stall farms undergoing the biannual inspection. Three of 4 regions in Ontario (Eastern, Southern, and Central) were represented by project herds. The Northern region (Kenora, Rainy River, and Thunder Bay districts) was not represented. Few dairy farms are in this region and none was due for its biannual inspection during the study period.

Data Collection

Determining the data to collect was a multistage process. Initially, a literature search was conducted seeking all materials on cattle welfare or cow comfort scoring indicators. Information on the aspects of stall design that affects lameness, injury, or cleanliness of cattle was also gathered. A list encompassing all possible cow comfort indicators was created and presented to a group of experts from the dairy industry. The group included veterinarians, animal scientists, DFO administrative staff, and DFO inspectors.

Both the amount of data needed for the study and the time inspectors had at each farm visit were considered when deciding which traits to include in the study. A consensus meeting was held to determine the 10 most important factors to be recorded. The list of factors used in this study did not give a complete picture of all aspects of stall design that could affect lameness, injury, or cleanliness. The factors chosen were a compromise between the comprehensive list that would completely describe tie-stall housing and animal well-being in the sample population, and a list that was predicted to provide good compliance and reliability of data recording.

Cow-based measures were: presence of hock or neck lesions, presence of teat injuries, presence of broken or docked tails, presence of a back arch, presence of hind claws that rotated outward more than 20 degrees from the cow's midline, and cleanliness of udder and hind limbs. Trait definitions are given in Table 1.

Concise definitions of each possible score of the cow-based factors and their representative pictures were placed on a laminated reference card. For traits involving limbs, the most severely affected limb was scored. For stall-based measurements, the precise points of measurement were described. The DFO inspectors were presented with the laminated scoring cards (available online at http://jds.fass.org) and stall-based measurements and asked to review the wording and make suggestions to ensure the repeatability of scoring. Suggested wording and picture changes were made. Training sessions were held in which farms were visited and all inspectors were asked to identify and score the same cows using the scoring card for guidance. After scoring, scores were compared among inspectors. When discrepancies were found, the cows were studied by the group and a consensus reached. Inspectors were then asked to identify and re-score the cows in the opposite order from which they had initially scored the cattle. Scores were informally compared for agreement both between inspectors and with the inspector's previous score for that cow. If agreement was poor for a particular inspector, individual training was continued until the repeatability of their scoring was acceptable (for a specific group of cows, the inspector's scores agreed with their own previous scores and with those of another inspector 80% of the time).

Data were initially collected on paper recording forms. During their Grade A farm inspections, DFO inspectors use a handheld electronic data recorder to input answers to standard report questions. Once programmed, these handheld data loggers were used to record the stall measurements and animal scores.

The inspectors individually scored all of the lactating cattle on each of the study farms for hock, neck, teat, and tail appearance, presence of back arch, rotated hind claws, and cleanliness of the udder and hind limbs. Measurements (in inches) for stall bed length, width, tie-rail height, and chain length were made from one of the stalls. If the farm had more than one size of stall,

Table 1. Cow- and stall-based factor definitions.

Trait	Definition
Back arch 0	No arch is seen in the back while standing
Back arch 1	An arch is seen in the back while standing
Hind claw 0	No rotation of the hind claw
Hind claw 1	Hind claw rotated outward more than 20 degrees from the cow's midline
Hind limb 0	No manure on hind leg from claw to hock
Hind limb 1	Manure is seen only up the dewclaw
Hind limb 2	Manure is seen from dewclaw to shank
Hind limb 3	Manure is seen from dewclaw up to or over hock joint
Hock 0	No hair loss broken skin or scabs
Hock 1	Hock is swollen with no hair loss, broken skin or scabs
Hock 2	Hock has hair loss with or without swelling
Hock 3	Hock has broken skin or scabs with or without swelling
Neck 0	No hair loss, broken skin or scabs visible
Neck 1	The neck has hair loss, broken skin or scabs visible
Teat 0	No visible injury to the teat
Teat 1	Visible injury to the teat
Udder 0	No manure visible on udder
Udder 1	Slight amount of manure visible on udder
Udder 2	Significant amount of manure visible on udder
Tail 0	Tail is not docked or broken
Tail 1	Tail has a deviation in the vertebrae from a previous or recent break
Tail 2	Tail is docked
Stall length	From inside (stall bed side) of manager curb to inside of gutter curb
Stall width	Between the stall dividers on their center
Chain length	From snap at cow collar to tie rail
Tie-rail height	From stall bed to underside of tie rail

the most common size of stall was measured. Data were then downloaded from the data logger to a central database. Animal scores, stall measurements, date inspected, inspector, farm ID, and cattle breeds were then entered into a Microsoft Excel spreadsheet.

Teat injury was originally included as a measure to be recorded. After viewing the total data set and speaking with several of the DFO inspectors, it became obvious that compliance on recording teat injury was low. For this reason, the teat injury scores were dropped from the data set and not listed in the results. Compliance for correctly recording all other factors was excellent.

Analyses

All data were sent electronically from DFO headquarters in an Excel spreadsheet monthly and imported into a Microsoft Access database. Stall data were organized and graphed to identify outliers. Data were considered to be outliers when values were less than the stall dimensions listed in the Canadian Codes of Practice (Agriculture Canada, 1990) for a 700-kg cow or greater than those listed in current extension publications for a 700-kg cow (Anderson, 2003b). Validation of the outlier data was done by contacting the DFO inspector responsible for collecting it and checking the measurements. The dairy producer was also called and measurements were validated. Thirty other study farms were selected randomly and their data were validated in a similar manner. All measurements were found to be accurate. The spreadsheet was used to calculate the proportion of cows in each herd having arched backs, rotated hind claws, neck lesions, broken tails, docked tails, and each score of hock appearance and hind limb and udder cleanliness. Each of the study farm's stall type and measurements (in inches), geographical region, inspector, and breed of cows were then added to the spreadsheet. The spreadsheet was imported into the statistical program STATA (Statacorp LP, College Station, TX) for analysis. Stall dimensions were analyzed in inches, but interpreted in centimeters, using a conversion of 1 inch = 2.54 cm.

To explore the relationships between outcome and explanatory variables, all combinations of these variables were graphed. For continuous explanatory variables, such as stall dimensions, data were broken down categorically by common stall recommendations and regraphed to further investigate the relationship.

The majority of data were count data; for example, the number of cows on a farm having a hock score of 3. When the variance and mean of each of the scores were evaluated, the data were found to be overdispersed. To compensate for this, a negative binomial multivariate regression analysis was used to establish

Table 2. Significant results from a zero-inflated negative binomial regression analysis with percentage broken tails as the outcome.

Outcome	Explanatory variable	Prevalence ratio[1]	P value	95% CI Lower	95% CI Upper
Tail 1 (broken tails)	Tie-rail height[2]	0.9893	<0.001	0.9840	0.9945
	Udder 1 (slightly dirty)	1.0238	<0.001	1.0160	1.0318
	Hind limb 0 (clean)	1.0085	0.001	1.0034	1.0135
Logistic portion of negative binomial regression[3]	Hind limb 3[3] (dirty)	0.9818	0.026	0.9661	0.9978
	Hind claw 1 (rotated)	1.0395	<0.001	1.0178	1.0616

[1]Prevalence ratios can be interpreted as odds ratios.

[2]Interpretation example: For each 2.54-cm increase in the height of the tie rail, there was a 1% decrease in the proportion of cows with broken tails.

[3]Zero-inflated negative binomial models deal with the excess of zeros by simultaneously fitting a logistic regression model and a negative binomial model. The outcome in the logistic portion is the probability of zero counts (Dohoo et al., 2003). For example, the probability of zero counts of broken tails decreased ($P < 0.05$) by 1.8% for every 1% increase in dirty hind limbs (Hind limb 3). More simply stated, the proportion of cows with broken tails increased by 1.8% for every 1% increase in cows with dirty hind limbs.

statistically significant relationships between stall design and cattle lameness, injury, and cleanliness.

Although some of the data were collected at the cow level, the final analysis was at the herd level. A separate manual stepwise regression analysis was completed for each of the scored traits, using the percentage of affected cows per herd as the outcome variable and stall measurements and all other scores as the explanatory variables. If the coefficients of the explanatory variables within the model changed by more than 20% after the addition of another explanatory variable, the variable being added was retained in the model regardless of its P value, as a potential confounder. The explanatory variables breed, inspector, and geographical region were forced into each model to control for the effects of these variables as confounders. Breed was used to represent and control for relative size of the cow in the model.

Several of the scores had a large number of zero counts. After running a negative binomial regression analysis, the Vuong test was used to determine if a zero inflated negative binomial analysis was required. If the Vuong statistic was greater than 1.96, a zero-inflated analysis was used. (Dohoo et al., 2003) If the statistic was <–1.96, a regular negative binomial regression was used. Vuong values lying between –1.96 and 1.96 can be interpreted as having neither model favored. In this situation, a regular negative binomial regression was used. Zero-inflated models deal with the large number of zero counts by fitting both a logistic regression and a negative binomial regression model (Dohoo et al., 2003). The models may or may not have the same set of explanatory variables. The outcome of the logistic portion was interpreted as the probability of a zero count of the outcome.

When using the negative binomial regression program in STATA, explanatory variable coefficients can be listed as incidence rate ratios. In the present study, it was prevalence, not incidence, that was calculated, and thus, the explanatory variables are presented as prevalence ratios in the results. These may be interpreted as odds ratios. Statistical significance was set at $P < 0.05$.

RESULTS

None of the variables breed, region, or inspector were found to be statistically significant in any of the models.

Broken Tails

Relationship with stall dimensions. The results for the regression analysis using broken tails as the outcome are summarized in Table 2. Tie-rail height was associated with an increase in the prevalence of broken tails. The prevalence increased ($P < 0.001$) 1% for each 2.5-cm decrease in tie-rail height.

Relationship with cleanliness and lameness. Slightly dirty udders (Udder 1) were associated positively ($P < 0.001$) with broken tails (Tail 1). Clean hind limbs (Hind limb 0) and broken tails (Tail 1) had a negative ($P = 0.001$) association. The logistic portion of the negative binomial regression indicated that as the percentage of cows with hind claw rotation (Hind claw 1) increased ($P < 0.05$), the probability of zero counts of broken tails also increased. Furthermore, as the prev-

Table 3. Significant results from a negative binomial regression with percentage of herds with percentages clean and moderately dirty udders as the outcome.

Outcome	Explanatory variable	Prevalence ratio[1]	P value	95% CI Lower	95% CI Upper
Udder 0[2] (clean)	Tie-rail height[2]	1.0024	0.033	1.0002	1.0046
	Hind limb 0 (clean)	1.0290	0.040	1.0013	1.0583
	Tail 1 (broken)	0.9934	0.004	0.9890	0.9979
Udder 1[3] (slightly dirty)	Electric trainer[3]	1.1814	0.019	1.0281	1.3575
	Hind limb 0 (clean)	0.9807	<0.001	0.9777	0.9837
	Hind limb 1 (slightly dirty)	0.9944	0.019	0.9898	0.9991
	Tail 1 (broken)	1.0127	0.010	1.0031	1.0224

[1]Prevalence ratios can be interpreted as odds ratios.

[2]Interpretation example: For each 2.54-cm increase in tie-rail height there was a 0.2% increase in the proportion of cows with clean udders (Udder 0).

[3]Cows housed in stalls with electric trainers were 18% more likely to have slightly dirty udders (Udder 1) than those housed in stalls without electric trainers.

alence of dirty hind limbs (Hind limb 3) increased ($P <$ 0.001), the probability of zero counts of broken tails decreased. This is the direct interpretation of the zero-inflated negative binomial model. More simply stated, as the prevalence of dirty hind limbs increased, so did the prevalence of broken tails.

Neck Lesions

Relationship with stall dimensions. Neck lesions were significantly associated with only 1 variable, tie-rail height. Rail heights were subdivided into low (71 to 96 cm), midrange (99 to 114 cm), and high (116 to 132 cm) categories. The midrange category was used as the reference. The prevalence ratio for the low and high categories was 0.3012 and 0.3003, respectively. This was interpreted as both the low ($P < 0.001$) and high ($P < 0.05$) tie-rail categories having 70% fewer neck lesions than the midrange category.

Hind Claw Rotation

Relationship with lameness. The percentage of cows having no hind claw rotation (Hind claw 0) increased ($P < 0.05$) by 0.5% (prevalence ratio= 1.0051) for each 1% increase in the percentage of cows without a back arch (Back arch 0). Prevalence of normal hind claws increased ($P = 0.05$) 0.4% (prevalence ratio= 1.0042) for each 2.5-cm increase in stall length.

Clean and Slightly Dirty Udders

Relationship with stall dimensions. Significant results from the regression analysis with udder cleanliness score as the outcome are presented in Table 3. Udder score 2 (dirty udders) as the outcome was presented separately due to the use of a zero-inflated negative binomial regression for analysis. Clean hind limbs (Hind limb 0; $P < 0.05$) and tie-rail height ($P < 0.05$) were associated positively with the prevalence of clean udders (Udder 0). For each 2.5-cm increase in the tie-rail height, the prevalence of clean udders increased by 0.2%. Slightly dirty udders (Udder 1) were 18% more ($P < 0.05$) prevalent in herds that had stalls with electric trainers than in those without trainers.

Relationship with cleanliness and injuries. As the prevalence of clean udders (Udder 0) increased ($P < 0.01$) the prevalence of broken tails (Tail 1) decreased. Slightly dirty udders (Udder 1) were associated negatively ($P < 0.001$) with clean hind limbs (Hind limb 0). Slightly dirty udders (Udder 1) were positively ($P <$ 0.01) associated with a 1% increase in broken tails.

Dirty Udders

Relationship with cleanliness and lameness. A zero-inflated negative binomial model was used for the outcome variable of udder score 2 and these significant results are in Table 4. Prevalence of clean hind limbs (Hind limb 0; $P < 0.001$) and cows without a back arch

Table 4. Significant results from a zero-inflated negative binomial regression analysis with percent dirty udders as the outcome.

Outcome	Explanatory variable	Prevalence ratio[1]	P value	95% CI Lower Upper
Udder 2[2] (dirty)	Back arch 0[2] (no arch)	0.9636	0.010	0.9369 0.9911
	Hind claw 0 (not rotated)	1.0098	0.015	1.0019 1.0177
	Hind limb 0 (clean)	0.9716	<0.001	0.9663 0.9767
	Hind limb 1 (slightly dirty)	0.9892	0.026	0.9798 0.9987

[1]Prevalence ratios can be interpreted as odds ratios.

[2]Interpretation example: For each 1% increase in cows without a back arch (normal backs), there was a 0.4% decrease in the proportion of cows with dirty udders (Udder 2).

($P < 0.01$) were associated negatively with dirty udders. Prevalence of cows without hind claw rotation (Hind claw 0) was associated positively ($P < 0.05$) with dirty udders (Udder 2).

Hind Limb Cleanliness

Relationship with stall design. Table 5 presents a summary of the results of the negative binomial regression analysis with the levels of hind limb cleanliness as the outcomes. For each 2.5-cm increase ($P < 0.05$) in the tie-chain length, there was a 1.4% decrease in the proportion of cows with moderately dirty hind limbs (Hind limb 2).

Dirty hind limbs (Hind limb 3) were associated negatively ($P < 0.05$) with stall length. Dirty hind limbs also were associated with electric trainers. Proportion of cows having dirty hind limbs was 17% greater ($P < 0.05$) in herds with trainers over those in stalls without.

Relationship with cleanliness and lameness. Hind limb cleanliness was associated with udder cleanliness. As the proportion of clean hind limbs (Hind limb 0) increased, clean udders (Udder 0) also were more ($P < 0.001$) likely to be present. Conversely, an increase ($P < 0.001$) in dirty hind limbs (Hind limb 3) was associated with a decrease in clean udders (Udder 0). Moderately dirty hind limbs (Hind limb 2) were associated negatively ($P < 0.001$) with the prevalence of cows without a back arch (Back arch 0).

Table 5. Significant results from a negative binomial regression analysis with hind limb cleanliness as the outcome.

Outcome	Explanatory variable	Prevalence ratio[1]	P value	95% CI Lower Upper
Hind Limb 0 (clean)	Udder 0 (clean)	1.0175	<0.001	1.0140 1.0210
	Udder 2 (dirty)	0.9755	<0.001	0.9655 0.9858
Hind Limb 2[2] (moderately dirty)	Chain length[2]	0.9860	0.050	0.9719 1.0003
	Back arch 0 (no arch)	0.9487	<0.001	0.9223 0.9758
	Udder 0 (clean)	0.9861	0.001	0.9779 0.9943
Hind Limb 3 (dirty)	Electric trainers	1.1775	0.050	0.9947 1.3940
	Stall length	0.9793	0.036	0.9605 0.9986
	Udder 0 (clean)	0.9694	<0.001	0.9647 0.9741

[1]Prevalence ratios can be interpreted as odds ratios.

[2]Interpretation example: For each 2.54-cm increase in tie-chain length, there was a 1.4% decrease in the proportion of cows with moderately dirty hind limbs (Hind limb 2).

Table 6. Significant results from a negative binomial regression analysis with hock lesion score as the outcome.

Outcome	Explanatory variable	Prevalence ratio[1]	P value	95% CI Lower Upper
Hock 0 (no lesion)	Electric trainer	0.8817	0.039	0.7825 0.9935
	Udder 0 (clean)	1.0128	0.019	1.0021 1.0237
	Udder 1 (slightly dirty)	1.0162	0.007	1.0045 1.0280
Hock 1 (swollen)	Chain length	0.9864	0.009	0.9763 0.9966
Hock 2 (hair loss)	Hind limb 2 (moderately dirty)	1.0061	0.034	1.0000 1.0117
Hock 3[2] (open wound)	Electric trainer[2]	1.3636	0.029	1.0322 1.8012

[1]Prevalence ratios can be interpreted as odds ratios.

[2]Interpretation example: Cows housed in stalls with electric trainers are 36% more likely to have open hock wounds (Hock 3) than those cows housed in stalls without electric trainers.

Hock Appearance

Relationship with electric trainers. Table 6 presents a summary of the significant results from a negative binomial regression analysis with hock score as the outcome. The prevalence of open hock wounds increased ($P < 0.05$) by 36% for cows housed in stalls having electric trainers over cows housed in stalls without them. Prevalence of normal appearing hocks decreased ($P < 0.05$) 11.8% when cows had electric trainers over their stalls compared with those without trainers. Prevalence of swollen hocks increased ($P < 0.01$) as tie-chain length decreased.

Relationship with cleanliness. Normal hock appearance was positively associated with the prevalence of clean ($P < 0.05$) and moderately dirty udders ($P < 0.01$). Prevalence of hocks with hair loss increased ($P < 0.05$) with moderately dirty hind limbs.

DISCUSSION

Although the definitions for the animal-based measurements were designed to maximize objective scoring, the given score for any of the traits, and thus, the overall prevalence could have been influenced by several factors. To control for this potential confounding, 3 factors were forced into the model: breed, region, and inspector. Size of each cow could affect whether stall dimensions would influence cattle lameness, injury, or cleanliness (Anderson, 2003b). Measuring height, width, and length of each of the 17,893 study animals was not possible due to time restrictions on the DFO inspectors. Instead, breed of cow was forced into the model to control for confounding due to cow size. Breed would account for the variation in size among breeds, but not within breeds. None of the breeds (Holstein, Jersey, or other purebreds) was statistically significant in any of the models. Lack of breed significance indicates that certain breeds are not more prone to injuries and dirtiness than other breeds.

In the present study, a number of different inspectors scored the cattle in the sample population. To control for personal bias and scorer discrepancies, the inspector variable was forced into each model. None of the 15 inspectors was statistically significant in any of the models. Lack of inspector significance indicates that good agreement existed among inspectors for scoring lameness, injury, and cleanliness of cows.

Barn builders have different ideas about dairy cattle management. These differences could lead to regions in which many farms have similar stall designs and sizes or management techniques. These regional differences in tie-stall dimensions or husbandry techniques could have influenced lameness, injury, and cleanliness scores; thus, the region variable was used to control for this confounding effect.

Broken Tails

No published studies investigating the cause of broken tails in tie-stall-housed dairy cattle exist. Tail fractures in cattle housed in tie stalls may result from the tail being stepped on or through forceful manipulation of the tail by dairy producers. Tie-rail height significantly affected the prevalence of broken tails in a herd. One reason for this relationship could be that low tie rails force cows to stand toward the back of the stall or make a cow reluctant to rise quickly. Either situation could cause impatient producers to twist the tail to force the cow to rise or change its position in the stall.

A positive association was detected between broken tails and cows with dirty hind limbs and/or udders. Depending on the location and severity of the break, broken tails may have a decreased range of motion (McDuffee et al., 1993). If the tail cannot be lifted normally at the time of elimination, manure clings to the tail. The tail could then transfer manure to the udder and hind limbs (Abe, 1999). A second explanation could be that poor stall hygiene and rough handling are both associated with a particular management style. Barkema and Schukken (2003) reported that producers whose management was classified as "quick and dirty" were more likely to have udder health problems such as an elevated SCC.

A positive association was found between normal tail appearance (Tail 0) and rotated hind claws (Hind claw 1). The lack of literature available on the associations between tail appearance and lameness indicators made this relationship difficult to interpret. Further research is needed to elucidate this relationship.

Neck Lesions

Height of the tie rail is important in allowing normal rising behavior and preventing soft-tissue lesions on the dorsal aspect of the neck. (Blom, 1983; Leonard et al., 1994) In the present study, cows housed in stalls with both low [71 to 96 cm (28 to 38 in)] and high [117 to 132cm (46 to 52 in)] tie rails had fewer neck lesions than those cows housed in stalls with a tie rail from 99 to 114 cm (39 to 45 in). Incidence of neck lesions is similar to a finding by Blom (1983) on free-stall housed cattle in which he reported more neck lesions when the neck rail was >80 cm above the stall bed. A possible explanation for more neck lesions may be that at very low tie-rail heights, cows cannot extend their neck under the tie rail, and thus, do not develop lesions on the dorsal aspect of their neck. As tie-rail height approaches 96 cm, the rail becomes high enough for the cow to extend its neck underneath, but not high enough to prevent contact between the dorsal aspect of the neck and the underside of the tie rail; thus, lesions are created. At heights above 117 cm, fewer lesions are seen, as the tie rail no longer comes in contact with the cow's neck as it extends its head under the rail.

Rotated Hind Claws

Outward rotation of the hind hoof of greater than 20 degrees from the midline and the presence of an arch in the cow's back while standing are both associated with poor foot health and lameness (Kloosterman, 1997; Sprecher et al., 1997). A relationship is expected between cows that possess these 2 lameness indicators, and a positive association was found between study cows with normal claws (i.e., no outward rotation) and normal back conformation (no arch).

To provide relief from sole pain and the pressure of overgrown claws, cows will rotate the claws of the affected hind feet outwards to transfer their weight from the lateral to the medial claw (Kloosterman, 1997; Van Lenteren and Korsten, 2002). Stall length has been associated with lameness (Wells et al., 1995), because short stalls may cause cows to stand for longer periods of time or with their hind feet in the gutter (Leonard et al., 1994). The hind feet therefore have greater exposure to urine, manure, and wet bedding that may decrease foot health and lead to lameness (Blowey, 1993). The significant positive association found in this study between cows with no hind claw rotation (Hind claw 0) and greater stall length agrees with this explanation and supports the argument for increasing stall length.

Udder and Hind Limb Cleanliness

Similar to the work of Schreiner and Ruegg (2003), the present study found that cleanliness of udders and hind limbs were associated positively. Several explanatory variables from the udder and hind limb cleanliness analyses (outcome variables) were similar and will be discussed together. Udder and hind limb cleanliness are associated with stall base and bedding materials, husbandry techniques, influence of an electric trainer, and stall dimensions (Bergsten and Pettersson, 1992; Chaplin et al., 2000; Cook, 2002). In our study, data on stall base, bedding material, and frequency of cleaning the stalls were not collected. Therefore, these relationships could not be further explored as to their influence on udder and hind limb cleanliness.

Presence of electric trainers was found to be significantly associated with both udder and hind limb cleanliness. Both the prevalence of moderately dirty udders (Udder 1) and dirty hind limbs (Hind limb 3) were found to be greater in cows that were housed in tie stalls with electric trainers than those that were housed in stalls without trainers. In contrast, Bergsten and Pettersson (1992) found that cows housed in tie stalls with electric trainers were cleaner. In our study, the location of the trainer relative to the stall bed and height of the trainer above the cow's back were not recorded. This information is important in providing an explanation for our study's findings because improper placement of the electric trainer could result in its incorrect function and cows being dirtier than those without trainers. Several studies of the use of electric cow trainers and cow cleanliness indicated that proper placement of the trainer in relation to both the cow and stall is imperative for the trainers to work effectively (Hultgren, 1989; Bergsten and Pettersson, 1992; Busato et al., 2000).

Regarding stall dimensions, tie-rail height was found to be significantly associated with udder cleanliness and stall length with hind limb cleanliness. Increasing the height of tie rails is often associated anecdotally with dirtier cows because cows may stand forward in the stall, and defecate and urinate in the stall bed. The presence of dirty stall beds is the main argument used in justifying lower placement of tie rails. In the present study, however, the percentage of cows with clean udders increased with tie-rail height. No scientific literature could be found to support an established association in either direction between tie-rail height and udder cleanliness. The explanation for this finding could be related to husbandry techniques and how often the stalls are scraped and refilled with fresh bedding. This information, however, was not collected and further investigation is warranted.

Shorter stalls force cows to stand on the diagonal if they want to have all 4 feet in the stall or to stand with their hind feet in the gutter (Anderson, 2003a). Cows standing diagonally in the stall have a greater chance of urinating and defecating in the rear of the stall. If cows then lie down before the stall has been cleaned, their hind limbs become dirty. This could explain why there was an increase in the percentage of study cows with dirty hind limbs (Hind limb 3) as the stall length decreased. Cows that stand with their hind feet in the manure gutter may have large amounts of manure and soiled bedding stuck to their feet. Once these cows lie down, this manure and soiled bedding may be dragged into the stall and the cows are seen to have dirty hind limbs.

As the percentage of cows with clean udders (Udder 0) increased the percentage of cows with broken tails decreased. As the percentage of cows with moderately dirty udders (Udder 1) increased, so did broken tails. Both of these regression analyses support the previously stated findings for the regression analysis using broken tails as the outcome variable.

Both dirty udders (Udder 2) and dirty hind limbs (Hind limb 2) were associated with an increasing number of cows with a back arch. As back arch is associated with lameness, several possible explanations exist for this association (Sprecher et al., 1997). To relieve the pain, lame cows may spend more time lying down and thus have a greater chance of lying in manure (Kloosterman, 1997). Severely lame cows may find it difficult to rise once they have lain down, and may urinate or defecate while lying (Herlin, 1997). Alternatively, standing lame cows may not be able to properly arch their back to urinate and defecate. Both situations would make the back of the stall wet and dirty, and increase the chances of those cows having dirty udders and hind limbs. A third possible explanation may be related to management. Stall cleaning, regular hoof trimming, and foot care may be considered a low priority for some producers.

Hock Appearance

Stall dimensions (or the cow's usable space) are associated with hock lesions (Blom, 1983). Stalls that restrict normal rising and lying behavior can contribute to increased hock injuries as cows try to adapt to restricted space. A short tie chain severely restricts a cow's natural movements. Cows with short tie chains could be more restless in their stalls while lying and have more frequent movements of their down leg, which could increase hock injuries. In our study, fewer swollen hocks were found on farms with longer tie chains.

Electric trainers restrict the stall space available to cows (and thus their natural movement) and have been shown to affect cattle health (Hultgren, 1989; Oltenacu et al., 1998; Busato et al., 2000). In our study, only the presence or absence of electric trainers in the stalls was recorded. Whether the electrical current was turned on to the trainers was not known. It has been demonstrated, however, that once cows have received an electrical shock from the trainer they quickly learn to change their posture and movement to avoid contact with the trainer and this avoidance behavior remains after the current to the trainers is turned off (Hultgren, 1989). The regression analysis using Hock 0 (normal hock appearance) and Hock 3 (open wound with or without swelling) as the outcome variables indicated that farms having electric trainers had significantly less Hock 0 cows and more Hock 3 cows than those in which stalls had no electric trainers. This is in agreement with the findings of Alban et al. (1996).

Hock appearance was found to be associated with udder and hind limb cleanliness. As the percentage of clean udders increased so did the percentage of cows without hock lesions. A positive relationship also was found between Hind limb 2 (moderately dirty hind limbs) and hair loss from the hock (Hock 2). Management choices and husbandry practices could explain these relationships. Both stall surface and husbandry affect udder and hind limb cleanliness (Chaplin et al., 2000; Barkema and Schukken, 2003). These data were not collected in this study and further investigation into this explanation is not possible.

CONCLUSIONS

The present study identified several significant relationships between tie-stall design and cow-based measurements. Shorter stalls were associated with an increase in the number of cows with dirty hind limbs and rotated hind claws. Low tie rails were associated with an increase in cows with both broken tails and neck lesions. Increasing the tie-rail height was associated with an increased number of cows with clean udders. Short tie chains were associated with an increase in cows with swollen hocks and moderately dirty hind limbs.

Presence of electric trainers was associated with more cows with open hock wounds and dirty hind limbs. Although no single tie-stall factor measured in the present study explained the majority of the variation in any of the cow-based measurements for lameness, injury, or cleanliness, the significant associations found support the link between stall design and animal welfare. Further investigation is warranted to evaluate effectively cow size and the specific stall dimensions and stall management necessary to prevent lameness, injury, and dirtiness of cattle housed in tie stalls.

Tie-stall design and husbandry practices should be considered together when evaluating environments in dairy barns. In addition to changes to stall dimensions, changes in husbandry practices also may be needed to improve animal health and comfort.

REFERENCES

Abe, N. 1999. The deeper the mud. Hoard's Dairyman 144:439.

Agriculture Canada. 1990. Recommended code of practice for the care and handling of dairy cattle. Agriculture Canada Publications, Ottawa, Ontario, Canada.

Alban, L., J. Agger, and L. Lawson. 1996. Lameness in tied Danish dairy cattle: The possible influence of housing systems, management, milk yield and prior incidents of lameness. Prev. Vet. Med. 29:135–149.

Anderson, N. 2003a.Observations on dairy cow comfort: Diagonal lunging, resting, standing and perching in free stalls. Pages 26–34 in Proc. ASAE Dairy Housing Conf. Fort Worth, TX. ASAE, St. Joseph, MI.

Anderson, N. 2003b. Tie stall dimensions. Ontario Ministry of Agriculture and Food (OMAF) Livestock Technology fact sheet. OMAF, Ontario, Canada.

Barkema, H. W., and Y. H. Schukken. 2003. The effect of management style on udder health. Pages 68–74 in Proc. Natl. Mastitis Counc. Mtg., Ft. Worth, Texas. Natl. Mastitis Counc., Madison, WI.

Bergsten, C., and B. Pettersson. 1992. The cleanliness of cows ties in stalls and the health of their hooves as influenced by the use of electric trainers. Prev. Vet. Med. 13:229–238.

Blom, J. 1983.Traumatic injuries and foot diseases as related to housing systems. Pages 216–223 in Farm animal housing and welfare. S. Baxter, M. Baxter, and J. MacCormick, ed. Martinus Publishers, Lancaster, UK.

Blowey, R. 1993.Cattle lameness and hoofcare: An illustrated guide, 1st ed. Farming Press, Ipswich, UK.

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

Chaplin, S. J., G. Tierney, C. Stockwell, D. N. Logue, and M. Kelly. 2000. An evaluation of mattresses and mats in two dairy units. Appl. Anim. Behav. Sci. 66:263–272.

Cook, N. 2002. The influence of barn design on dairy cow hygiene, lameness and udder health. Pages 97–103 in Proc. Amer. Assoc. Bovine Pract., Madison, WI.

Dohoo, I., W. Martin, and H. Stryhn. 2003. Veterinary Epidemiologic Research. AVC Inc., Charlottetown, Prince Edward Island, Canada.

Herlin, A. 1997. Comparison of the lying area surfaces for dairy cows by preference, hygiene and lying down behaviour. Swed. J. Agric. Res. 27:189–196.

Hultgren, J. 1989. Biological interaction and effects on cow behaviour, health and production of stray voltage, electric cow-trainers and high voltage transmission lines. Ph.D. Thesis. Swedish University of Agricultural Sciences, Skara, Sweden.

Kloosterman, P. 1997. Claw Care. Pages 123–126 in Lameness in Cattle. 3rd ed. P. Greenough, ed. W. B. Saunders, Toronto, Ontario, Canada.

Leonard, F., J. O'Connell, and K. O'Farrell. 1994. Effect of different housing conditions on behaviour and foot lesions in Friesian heifers. Vet. Rec. 134:490–494.

McDuffee, L., N. Ducharme, and J. Ward. 1993. Repair of sacral fracture in two dairy cattle. JAVMA 202:1126–1128.

Oltenacu, P., J. Hultgren, and B. Algers. 1998. Associations between the use of electric cow-trainers and clinical diseases, reproductive performance and culling in Swedish dairy cattle. Prev. Vet. Med. 37:77–90.

Schreiner, D., and P. Ruegg. 2003. Relationship between udder and leg hygiene scores and subclinical mastitis. J. Dairy Sci. 86:3460–3465.

Sprecher, D., D. Hostetler, and J. Kaneene. 1997. A lameness scoring system that uses posture and gait to predict dairy cattle reproductive performance. Theriogenology 47:1179–1187.

Van Lenteren, A., and G. Korsten. 2002. Sub-optimal cow and barn condition and its effects on the visiting frequency at the milking robot. Pages 64–68 (Vol. III) in Proc. N. Am. Conf. Robotic Milking. Wageningen Pers, Wageningen, The Netherlands.

Walker, C. 1995. Pages 26–64 in Dairy Reference Manual. 3rd ed. Northeast Regional Agricultural Engineering Service Cooperative Extension, Ithaca, NY.

Weary, D., and I. Taszkun. 2000. Hock lesions and free-stall design. J. Dairy Sci. 83:697–702.

Wells, S., A. Trent, W. Marsh, N. Williamson, and R. Robinson. 1995. Some risk factors associated with clinical lameness in dairy herds in Minnesota and Wisconsin. Vet. Rec. 136:537–540.

Zurbrigg, K. 2005. The relationships between aspects of dairy cow welfare and tie stall design, milk production and milk quality. M.S. Thesis, University of Guelph, Ontario, Canada.