The association between foot lesions and culling risk in Ontario Holstein cows

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ABSTRACT

The objective was to determine the association between specific foot lesions and culling in dairy cows. Using 5 trained professional hoof trimmers, data from 6,513 cows in 157 herds were recorded for analysis. During the study period, 1,293 cows (19.9%) were culled. Infectious lesions were most frequent in nonculled cows, whereas hoof horn lesions were most common in the culled cows. Median time to culling was 188 d [95% confidence interval (CI): 175–198 d] for cows without a lesion and 157 d (CI: 149–168 d) for cows with a lesion. Time from hoof trimming to culling was used to model the association between foot lesions and culling hazard. The final multivariate Cox proportional hazards model included heifers, infectious lesions, white line lesions, hemorrhages, sole ulcers, other lesions, and free-stall housing as covariates. Results of the final model showed that infectious hoof lesions had no significant association with culling. Yet, the hazard ratios for white line lesions, ulcers, and hemorrhage were 1.72 (CI: 1.39–2.11), 1.26 (CI: 1.05–1.52), and 1.36 (CI: 1.16–1.59), respectively. The association with culling for the grouped variable “other lesions” was time dependent and decreased with time. These results illustrate that there were significant associations with cow productivity for hoof horn lesions found at routine hoof trimming and that emphasis should be placed on proper treatment and earlier detection of these foot lesions.

Key words: foot lesion, culling, survival analysis

INTRODUCTION

Currently, within the dairy industry, there is widespread concern about the longevity of today’s dairy cow. Longevity is influenced by numerous cow-level factors,

including milk production, reproductive performance, and disease status, as well as various herd-level risk factors (Fetrow et al., 2006). Of the diseases having an effect on longevity, lameness is one of the most important because of its high prevalence (Cook, 2003) and its effects on milk production (Green et al., 2002; Amory et al., 2007) and reproductive performance (Melendez et al., 2003; Hultgren et al., 2004).

Several studies have evaluated the relationship between lameness or foot lesions and culling risk and have shown that the risk of being culled was increased (Dohoo and Martin, 1984; Sprecher et al., 1997; Booth et al., 2004), decreased (Barkema et al., 1994), or not affected by lameness or the presence of foot lesions (Beaudeau et al., 1994, 1995; Hultgren et al., 2004). One possible reason for these conflicting results is that several of these studies used producer-recorded data of acute lameness (Dohoo and Martin, 1984; Barkema et al., 1994; Beaudeau et al., 1995). However, it was shown that producers underestimate the prevalence of lameness (Espejo et al., 2006), and this underestimation makes extrapolation to populations outside of the study population difficult.

Rather than relying on producers to identify lame cows, a more objective way to collect lameness and foot-lesion data is to use records from hoof trimmers (HT) at the time of hoof trimming, an approach that was used by Hultgren et al. (2004). Nevertheless, the logistic regression analysis approach used in this study and by others (Beaudeau et al., 1994; Sprecher et al., 1997) did not take into account the length of survival after hoof trimming. Survival analysis using proportional hazards regression as used by Booth et al. (2004) was considered an appropriate analytical technique to account for length of survival following disease (Grohn et al., 1998). Currently no studies have determined the association between foot lesions and culling in multiple herds using both survival analysis and data collected at the time of routine hoof trimming.

The objective of this study was to determine the association between specific foot lesions and culling in dairy cows.

Received July 7, 2008.

Accepted February 12, 2009.

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MATERIALS AND METHODS

Five professional HT were recruited to enroll herds for participation. From March 2004 to May 2005, HT recorded the presence of specific foot lesions on all cows trimmed in participating herds. Along with recording lesions, HT completed a 3-page questionnaire that was used to collect descriptive herd-management data from the farms. Details of lesion-recording methods and HT recruitment and training are described by Cramer et al. (2008). Table 1 shows the specific lesions HT recorded. The HT were trained in lesion identification at the onset of the project using quizzes and digital images of common lesions. At the completion of the study, HT completed another lesion-identification quiz. Recording forms were provided that contained lesion codes based on the recommendations of the American Association of Bovine Practitioner's lameness committee (Shearer et al., 2004).

Lesion data for cows were merged with DHI test-day production data with the owner's permission. Production data collected for each cow from the test date before hoof trimming included calving date, DIM, lactation, linear score, and projected 305-d milk production (**305M**). Removal data were collected during June 2006 from the DHI database. Data collected included culling date or the next calving date, if the cow was not culled during the lactation in which hoof trimming occurred.

Both questionnaire and lesion data were entered into a database (MySQL 4.1, MySQL AB, Uppsala, Sweden). Data management and descriptive analysis were done using Excel (Microsoft, Redmond, WA) and a commercially available statistical program (Stata 9.2, Stata Corp., College Station, TX). Individual cows with duplicate, unreadable, or missing cow identification were removed from the data set. Several cows were trimmed on multiple occasions, but only the first occurrence in the data set was included for further analysis. Hoof trimmers collected data on all 4 feet, but for the analysis, the data were collapsed to the cow level. A cow was considered affected if one hoof had a lesion present. Cows with multiple lesions or limbs affected were considered affected by all lesions present. For example, a cow with an ulcer on her right hind foot and a hemorrhage on her left hind foot would be considered affected with both an ulcer and hemorrhage. Only cows with a DHI test <100 d before hoof trimming were included in the final data set. Cows were assumed dry at the time of hoof trimming if their lactation start date occurred after the hoof trimming date. These dry cows were not included in any further analyses.

Because of a low number of observations of deep sepsis, thin soles, vertical wall cracks, and korns (interdigital

Table 1. Definition of codes and lesions provided to hoof trimmers on standardized recording sheet

Code	Lesion name (alternative common names)	Definition
A	White line disease—abscess (pus pocket, abscess)	Abscess in white line region; if severe, can be accompanied by swelling of affected hoof
C	Deep sepsis in hoof	Swollen hoof with no visible exterior lesion; drains pus when pressure is relieved
D	Digital dermatitis (Mortellaro disease, strawberry foot rot, hairy heel warts)	Sore, raw, sometimes hairy area on the skin around the heels and between the hooves; can have a white rim around the lesion
E	Heel horn erosion (slurry heel, stable foot rot, heel cracks)	Pits, cracks, or fissures in the heel area of hoof; more extensive lesions will have V-shaped cracks on the heel
F	Foot rot (interdigital phlegmon, foul in the foot)	Symmetrical swelling above the hooves with spreading of the toes; usually accompanied with cracked, dead, smelly skin between the digits
H	Hemorrhage (bruising, laminitis)	Red or yellow discoloration of the sole or white line
K	Korn or interdigital hyperplasia (corns, fibroma)	Abnormal fibrous skin growth between the digits
S	White line disease—separations (fissures, white line disease)	Breaks or separations or fissures of the white line that can reach the corium but do not affect the corium or have pus associated with it
T	Thin soles	Cow has toe length <7.5 cm (3 inches) when measured from the coronary band
U	Ulcer	Defect in the sole horn that exposes corium and can be accompanied by granulation tissue; typically occurs on inner side of the sole but can occur in the toe or heel
V	Vertical wall crack	Vertical split in wall usually starting at junction of the wall and skin
N	Nonfoot	Cow is lame but no lesions were found in or on the foot and it has another cause of lameness (swollen hock)
X	Lame	Cow is noticeably lame when walking or standing
W	Wrap	Lesion of the foot had a bandage applied
B	Block	Lesion on hoof had a block applied to the opposite hoof

Table 2. Prevalence of foot lesions for nonculled cows and culled cows in 157 herds diagnosed by 5 professional hoof trimmers at routine hoof trimming of 6,513 Holstein cows

Item	Nonculled (n = 5,220)		Culled (n = 1,293)	
	%	n	%	n
Infectious lesion	23.5	1,225	23.7	306
Heel horn erosion	10.1	525	10.4	135
Digital dermatitis	15.4	805	15.2	196
Foot rot	0.1	5	0.4	5
Hoof horn lesion	17.2	896	27.7	358
White line abscess	1.0	51	1.5	20
White line separations	2.4	127	5.8	75
Ulcers	6.8	355	11.2	145
Hemorrhage	9.3	484	14.4	186
Other lesions	2.9	151	3.6	46
Deep sepsis	0.0	2	0.2	3
Thin soles	0.3	15	0.1	1
Vertical wall crack	0.1	7	0.2	3
Korn	2.4	127	3.0	39
Any lesion	36.5	1,906	46.0	595
Blocked	1.2	63	2.5	32

fibromas), these lesions were combined in a single category called “other lesions.” For similar reasons, a new lesion category was created that combined white line abscesses and white line separations into one category. Because of low numbers of non-Holstein breeds in the data set, analysis was restricted to Holstein cows.

A 2-stage model-building procedure was used to determine the association between individual lesions and culling hazard. For all models, the dependent variable was time from hoof trimming to culling or censoring. Cows that were not culled during the lactation of hoof trimming were censored at the start of their next lactation or on June 21, 2006, whichever came first. June 21, 2006, was used as an ending date for data collection because it was approximately 13 mo (1 lactation) after the conclusion of data collection. Herds that ceased using DHI services were censored at the time of last test date.

In the first stage of model building, single-variable associations between explanatory variables and time from hoof trimming to culling or censoring were tested using the log-rank test for equality of survival functions (Dohoo et al., 2003). In the second stage, variables with a $P < 0.20$ were then offered to a multivariable analysis using Cox proportional hazards regression. Nonsignificant variables, based on the Wald statistic, were eliminated using stepwise backward elimination. Nonsignificant lesion categories were combined according to etiology (Guard, 2001) when possible and retained in the model to make the referent cow one with no lesion.

Herd effects were accounted for using robust standard errors (Lin and Wei, 1989). The effect of HT on lesion identification and cow survival was adjusted for in the Cox proportional hazards model using stratification.

For all variables eligible for inclusion in the Cox proportional hazards model, the proportional hazards assumption was evaluated graphically before model building by evaluating the log-cumulative hazard plot for parallel lines. The log-cumulative hazard plot graphs the $\ln(\text{cumulative hazard})$ versus the $\ln(\text{days at risk})$ (Dohoo et al., 2003). After the final model was selected, the proportional hazards assumption was assessed for each variable using a combination of the Grambsch and Therneau test and by evaluating the effect of adding a time-varying covariate to the model (Hosmer and Lemeshow, 1999). Variables identified as having nonproportional hazards were included in the model through the use of a time-varying covariate.

Final model fit was assessed using Arjas plots, which graph cumulative expected counts versus cumulative observed counts in different risk groups (Hosmer and Lemeshow, 1999). Individual observations were checked for outliers and influential observations using deviance and scaled score residuals (Dohoo et al., 2003).

To assess the effect of milk production on the final model, a separate model was run with 305M added to the final model. In addition, a separate model that included HT as a fixed effect was run to assess the effect of HT on the final model.

RESULTS

Throughout the study period, HT recorded lesions on 13,530 cows. For the current study, the inclusion criteria were met by 6,513 cows, of which 1,293 cows (19.9%) were culled. Table 2 shows the prevalence of foot lesions for nonculled and culled cows in the data set. Infectious lesions (digital dermatitis, heel horn erosion, and foot

Table 3. Frequency distribution of descriptive cow-level variables for nonculled and culled cows

Item	Nonculled (n = 5,220)		Culled (n = 1,293)	
	n	%	n	%
Lactation				
1	2,208	42.3	339	26.2
2	1,351	25.9	319	24.7
3+	1,661	31.8	635	49.2
Projected 305 d milk production				
<8,092	1,178	22.6	313	24.2
8,092–9,344	1,403	26.9	311	24.1
9,344–10,610	1,371	26.3	313	24.2
>10,610	1,268	24.3	356	27.5
Hoof trimmer				
1	2,086	40.0	485	37.5
2	920	17.6	204	15.8
3	799	15.3	244	18.9
4	1,100	21.1	268	20.7
5	315	6.0	92	7.1
Housing				
Tie stall and bedded pack	3,578	68.5	843	65.2
Free stall	1,642	31.5	450	34.8
Linear score				
<4	4,323	82.8	972	75.2
>4	897	17.2	321	24.8
Trimming season				
Winter	1,057	20.2	261	20.3
Spring	2,332	44.7	531	41.0
Summer	1,407	27.0	397	30.7
Fall	424	8.1	104	8.0
DIM at hoof trimming				
<90	1,089	20.9	412	31.8
90–120	1,915	36.7	519	40.2
120–305	1,507	28.9	226	17.5
>305	709	13.6	136	10.5

rot) were most frequent for nonculled cows, whereas hoof horn lesions (white line lesions, ulcers, and hemorrhage) were most prevalent in the culled cows. The frequency distribution of the descriptive variables and fixed effects that were considered for inclusion in the Cox proportional hazards model is shown in Table 3. Figure 1 shows an adjusted Kaplan-Meier graph for cows with and without a lesion. Median time to culling was 188 d (95% confidence interval: 175–198 d) for cows without a lesion and 157 d (95% confidence interval: 149–168 d) for cows with a lesion.

Initial single-variable analysis identified heifers, white line lesions, hemorrhages, sole ulcers, other lesions, free-stall housing, and trimming season as variables eligible for inclusion in the multivariate Cox proportional hazards model. Table 4 shows the results from the final Cox proportional hazards model. Only trimming season was removed during model development. Results of the final model show that infectious hoof lesions had no significant association with culling. However, all individual hoof-horn lesion categories and the “other-lesion” category had associations ($P < 0.05$) with culling. The association for “other lesions” was time dependent. The effect of this time dependency indicates that the as-

sociation with culling for the “other-lesion” category decreases sharply with time (Table 5).

Assessment of model fit indicated that model fit was good. Residual analysis identified one outlying observation. However, rerunning the model without this observation did not change the model outcome considerably, so the presented hazard ratios include this observation.

The addition of 305M did not result in major changes in the lesion coefficients or to the model’s Akaike’s information criteria (Dohoo et al., 2003). Nonetheless, it did cause a violation of the proportional hazards assumption. Running the final model with HT as a fixed effect indicated that a single HT had a higher hazard ratio, but the hazard ratios for the different foot lesions were not affected.

DISCUSSION

Model Development

A critical step in model development was the identification of intervening and confounding variables (Dohoo et al., 2003). In the current study, 305M and linear score

Table 4. Final Cox proportional hazard model for the time from hoof trimming to culling for 6,513 Holstein dairy cows trimmed by 5 professional hoof trimmers on 157 Ontario dairy farms

Item	Hazard ratio ¹	P-value	95% Confidence interval	
			Lower	Upper
No lesion	Referent ²	Referent	Referent	Referent
White line lesions ³	1.72	<0.001	1.39	2.11
Ulcers	1.26	0.011	1.05	1.52
Hemorrhage	1.36	<0.001	1.16	1.59
Infectious lesions ⁴	0.97	0.679	0.85	1.11
Other lesion ⁵	6.91	0.001	2.16	22.13
Parity 1	0.55	<0.001	0.48	0.62
Free-stall housing	1.19	0.048	1.00	1.41
Time-varying covariate Other lesion ⁶	0.69	0.003	0.53	0.88

¹Hazard ratios are from a Cox proportional hazards model, stratified on hoof trimmer, with robust standard errors used to account for correlation within herd.

²Referent cow is a cow in second or greater lactation with no lesions in a non-free-stall barn.

³Combined category of white line abscesses and white line separations.

⁴Combined category of heel horn erosion, digital dermatitis, and foot rot.

⁵Combined category of deep sepsis, thin soles, vertical wall crack, and korns.

⁶Time-varying covariate: Effect of variable varies with natural logarithm of time; for interpretation see Table 5.

were considered intervening variables. Milk production may have had a circular relationship with lameness and was potentially a confounder and intervening variable (Grohn et al., 1997; Green et al., 2006). Other studies that considered the effect of disease on culling have considered milk production to be a confounder (Booth et al., 2004) or an intervening variable (Grohn et al., 2005). If milk production was considered an intervening variable and yet was included in the model, the association identified in the model between foot lesions and culling would have been an indirect relationship (Grohn et al., 1998; Grohn et al., 2005) because the

effects of foot lesions on milk production would have been accounted for in the model. In the current study, the objective was to determine the direct relationship between foot lesions and culling; thus, milk production was not included in the final model. Even so, when a milk-production variable was added to the model, it did not result in major changes in the hazard ratios for the foot lesions.

During model development, HT was considered a confounding variable because of the potential for differential misclassification bias of foot lesions by the 5 individuals (Cramer et al., 2008). Hoof trimmers were considered a crucial fixed effect that needed to be accounted for because of study design, but an estimate of their association with survival was not important. In this context, stratification was an appropriate way to account for their effects (Hosmer and Lemeshow, 1999).

Figure 1. Kaplan-Meier graph of survival times after routine hoof trimming for 6,513 Holstein cows from 157 herds with and without lesions.

Table 5. Hazard ratios for cows diagnosed with other lesions at different time points after hoof trimming

Time after hoof trimming (d)	Adjusted hazard ratio ¹	95% Confidence interval	
		Lower	Upper
1	6.91	2.16	22.13
10	2.90	0.51	16.47
30	1.92	0.26	14.31
50	1.58	0.19	13.40
100	1.22	0.12	12.27
200	0.94	0.08	11.22
300	0.80	0.06	10.65

¹Adjusted hazard ratio = hazard ratio × time-varying covariate hazard ratio^{ln(time)} = 6.91 × 0.69^{ln(time)}.

The use of strata for HT assumes a separate baseline hazard for each HT. This assumption was possible because differences in therapy, technique, or follow-up care might result in different survival functions among HT.

In contrast to Booth et al. (2004), the stage of lactation at lesion diagnosis was not included because the current study was cross-sectional in nature and the stage of lactation in which the cows were trimmed was decided by the producer. The majority of cows trimmed were trimmed as part of a routine whole-herd trim. As such, the stage of lactation would have been arbitrarily decided by the producer. The study by Booth et al. (2004) was prospective in nature with the dependent variable being time from calving to culling and used mainly lame cows. For those 2 reasons, the use of stage of lactation as a time-dependent variable could be considered more appropriate for their study. There are inherent problems with the use of a time-dependent variable with respect to lameness or foot lesions because of the lag from time of initial injury at the level of the corium or skin to the time of hoof trimming or lameness diagnosis. This lag has been estimated to be 1 to 2 mo for hoof lesions (Ossent et al., 1997). In addition to the lag of 1 to 2 mo, there would be the lag from the time of lesion appearance at the sole to time of hoof trimming or lameness detection.

Lesions

The results showed that the association between foot lesions and survival was dependent on the lesion identified at the time of hoof trimming. Comparing the results to other studies is difficult. The current study used data from multiple herds collected at the time of routine hoof trimming and analyzed using Cox proportional hazards regression. To our knowledge, no published study has used this combination. A study from Sweden used hoof-trimming records and logistic regression and found no effect on culling risk for sole ulcers (Hultgren et al., 2004). A study from New York, using data collected mainly from lame cows and some routine trimmings, reported an increased culling hazard for a combined category of all lameness diagnoses, sole ulcers, and foot rot. Nevertheless, the increased hazard depended on when lameness was diagnosed in lactation and when culling occurred (Booth et al., 2004). As previously discussed, the majority of cows in the current study were trimmed as part of a routine hoof trimming. Therefore, the use of an analytic technique that uses time-dependent covariates, such as stage of lactation or time of culling, was considered unsuitable.

Hoof Horn Lesions

All hoof horn lesions considered had an association ($P < 0.05$) with culling. The majority of cows involved were trimmed as part of a routine annual or biannual trimming event, and a lesion would have been considered incidental by the producer for most cows. An incidental hoof horn lesion such as hemorrhage is unlikely to result in lameness (Toussaint Raven et al., 1985). However, an incidental lesion such as hemorrhage had an association ($P < 0.001$) with culling, which indicates that the damage done to the corium that resulted in the blood-stained sole was likely more permanent than previously thought and potentially similar to the advanced stages of hoof horn disease such as sole ulcers (van Amstel and Shearer, 2006) or white line lesions (Leach et al., 1997). Only at these advanced stages is lameness likely to become visible to the producers.

This study was not able to show how hoof horn lesions affect culling, but it is likely that hoof horn lesions have an indirect effect on culling through factors such as impaired milk yield and reproductive performance (Grohn et al., 1998). Recent attempts to elucidate the relationship between foot lesions and milk yield have provided conflicting results (Green et al., 2002; Hultgren et al., 2004; Amory et al., 2007). In the current study, milk production was considered an intervening variable a priori, but adding milk production to the final model did not change the hazard ratios for hoof horn lesions. This lack of effect of the milk yield variable on hoof horn lesion estimates indicated that milk yield was not the major contributor through which hoof horn lesions were associated with increased culling hazards.

The other possible way foot lesions could have an indirect effect on culling is through reduced reproductive performance (Barkema et al., 1994; Melendez et al., 2003; Hultgren et al., 2004). Both Melendez et al. (2003) and Hultgren et al. (2004) independently proposed 3 different hypotheses as possible explanations for the association between lameness and reproduction. In the current study, the reproductive status of the cows was unknown; therefore, it cannot prove a direct relationship between hoof horn lesions and reproductive performance. However, it is likely that the factors identified by both Melendez et al. (2003) and Hultgren et al. (2004) had a combined and possibly cyclical effect on the hoof and ovary, leading to the associations identified in the current study.

A complicating factor in attempting to determine possible explanations for the association between hoof horn lesions and culling is the treatment applied by the HT. Hoof trimming on its own reduces the number of

lesions, if trimming frequency is increased (Manske et al., 2002). It remains unclear if hazard ratios for hoof horn lesions would have been greater if the cows in the current study were just assessed, with no maintenance trimming or treatments such as the application of a hoof block to the unaffected digit. Relatively few cows were treated with hoof blocks, and there is no peer-reviewed evidence that the use of a hoof block would improve survival, although it is likely.

Other Lesions

The association ($P = 0.001$) between the grouped category “other lesions” and culling was time dependent, indicating that the association decreased with time after hoof trimming. Care should be taken when interpreting this finding because hoof trimming was an arbitrary event and the time-dependency factor was only added to address a violation of the proportional hazards assumption. It is plausible that the reason these other lesions were time dependent is that producers aggressively cull the cows most severely affected by a lesion because of poor prognosis and attempt to retain the remaining cows.

The main lesion in this “other” category was korns (interdigital hyperplasia). This is a chronic lesion typically not associated with severe lameness, unless the lesion is large (Berry, 2001). The remaining lesions in this category are usually severe. One of these lesions, deep sepsis, had a severe effect on productivity, even if treated by trained personnel (Bicalho et al., 2006). To more fully determine the association between culling and other lesions, a prospective study with more cows or a higher prevalence of other lesions would be necessary.

Infectious Lesions

The lack of association between culling and infectious lesions including foot rot, digital dermatitis, and heel horn erosion was not surprising. With proper treatment, the majority of these lesions are short term in nature or are superficial lesions. However, digital dermatitis had a high recurrence rate (Berry, 2001). The lack of a significant association between infectious lesions and culling supports the findings by Booth et al. (2004), who did not discover a significant association in lame cows diagnosed with digital dermatitis. In the current study, infectious lesions included a small number of foot-rot cases. Because of the low number of these cases, there was not sufficient power to include them as an individual category. The lack of significant associations between infectious lesions and culling indicated that although there was likely a short-term effect of

these lesions on the cow, there were no long-term effects on cow productivity.

CONCLUSIONS

The current study used hoof-trimming records, the majority of them from routine foot trimmings, to determine the association with culling. Infectious foot lesions did not have a significant association with culling, whereas hoof horn lesions were associated with an increased culling risk. These findings illustrate that there is a need for earlier detection of hoof horn lesions to potentially reduce the effect of these lesions on cow longevity. In addition, long-term prospective studies are needed to determine cause-and-effect relationships, efficacy of treatment strategies, and the relationship between time of diagnosis and time of culling.

ACKNOWLEDGMENTS

Funding for this project was provided by the Dairy Farmers of Ontario (Mississauga, Ontario, Canada), American Association of Bovine Practitioners (Auburn, AL), Ontario Ministry of Agriculture and Food (Guelph, Ontario, Canada), Natural Science and Engineering Research Council (Ottawa, Ontario, Canada), and the Hoof Trimmers Association (Missoula, MT). We are grateful for the statistical advice offered by Olaf Berke (Guelph, Ontario, Canada), the assistance provided by the participating hoof trimmers, and our summer student Janyk Laferrière.

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