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Association between hoof trimming frequency in primiparous cows and hoof health and survival in second lactation

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ABSTRACT

Lameness, mostly resulting from claw lesions, causes major welfare problems in the dairy industry. One way to prevent claw lesions is hoof trimming, but the overall effect and the optimal hoof trimming frequency are unknown. In a retrospective cohort study, we investigated the association between hoof trimming frequency in primiparous cows and hoof health and culling in the second lactation. We based our analysis on breed, calving, and culling data in the period 2015 to 2018 for 30,613 primiparous cows in 202 Swedish dairy herds. Of the cows enrolled, 20% were not hoof-trimmed, 30% were trimmed once, 34% were trimmed twice, 13% were trimmed 3 times, and 2% were trimmed ≥4 times. We used multivariable mixed-effect logistic and multivariable multinomial logistic regression models to investigate the association between trimming frequency and 2 outcomes: hoof lesions at first trimming occasion within 90 d from second calving and culling in the second lactation within 300 d after the second calving. In general, cows trimmed 2 or 3 times during the first lactation were at lower odds of having claw lesions compared with cows that were not trimmed (odds ratio [OR] = 0.66, 95% CI = 0.62–0.71 and 0.60, 95% CI = 0.55–0.66, respectively) or cows trimmed once (OR = 0.80, 95% CI = 0.75–0.85 and OR = 0.72, 95% CI = 0.66–0.79, respectively), and this beneficial effect was observed for most types of claw lesions. Moreover, cows trimmed 2, 3, or ≥4 times were at lower odds of being culled compared with cows that were not trimmed (OR = 0.71, 95% CI = 0.65–0.77, 0.68, 95% CI = 0.61–0.76 and 0.70, 95% CI = 0.54–0.90, respectively) or trimmed once (OR = 0.77, 95% CI = 0.71–0.83, OR = 0.74, 95% CI = 0.66–0.82 and OR = 0.75, 95% CI = 0.59–0.97, respectively). In particular, 2 trimmings, compared with 1 or no trimming, lowered the relative risk ratio of dying or being euthanized on-farm, or being culled due to claw and leg disorders. More than 1 hoof trimming in the first lactation also reduced the relative risk ratio of being culled for other reasons. In conclusion, 2 or 3 hoof trimmings during the first lactation were generally beneficial for hoof health in early second lactation and survival in the second lactation. These findings can help improve animal welfare and production by reducing claw lesions, and thereby lameness, among dairy cows, which would increase the longevity of dairy cows and the sustainability of the dairy industry.

Key words: mortality, lameness, sole ulcer, digital dermatitis, routine hoof trimming

INTRODUCTION

Lameness in dairy cows is a major welfare problem in the dairy industry (Ventura et al., 2013), due to the underlying pain causing the lameness (Whay and Shearer, 2017). Lameness in dairy cows is common, with a global mean prevalence of 23%, shown by Thomsen et al. (2023) in a literature review of 53 international studies reporting the prevalence of lameness in dairy cows. From the 2 prevalence studies performed in Sweden, lameness seems less common, with a prevalence of 5% to 7% (Manske et al., 2002a; Sjöström et al., 2018). Lameness leads to impaired health and performance, with economic losses for the farmer (Cha et al., 2010), impaired fertility (Charfeddine and Pérez-Cabal, 2017; Melendez et al., 2018; Omontese et al., 2020), reduced milk production (Huxley, 2013; Maxwell et al., 2015; Charfeddine and Pérez-Cabal, 2017), and involuntary culling (McConnel et al., 2008; Machado et al., 2010; Charfeddine and Pérez-Cabal, 2017). Lameness can also negatively affect public opinion about the sustainability of dairy production (Jackson et al., 2022).

Lameness is most often a result of claw lesions of different types, such as sole ulcer, white line disease, digital dermatitis, and foot rot (Manske et al., 2002a; Flower

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and Weary, 2006; Archer et al., 2010). There are 2 major groups of claw lesions, infectious lesions and claw horn lesions. Infectious lesions occur in the skin of the lower legs and are most often caused by an infective agent and unhygienic environment around the foot, and claw horn lesions are situated in the claw horn capsule and are most often caused by trauma (from external factors that directly or indirectly increase the pressure on the claw capsule) or animal-based risk factors related to the internal structure and function of the claw (Randall et al., 2018; Alvergnas et al., 2019).

One important factor in preventing claw lesions, and thus lameness, is hoof trimming (Manske et al., 2002b; Hernandez et al., 2007; Baranovič et al., 2016), which prevents claw lesions in 2 ways. First, a correct shape of the claw creates more even weight distribution between claws and puts the load on the bearing surface, thereby preventing new claw horn lesions from developing (van der Tol et al., 2004; Zeiner et al., 2007; Telezhenko et al., 2019). Second, routine trimming allows detection of claw lesions at the subclinical stage and treatment before they become more severe and cause lameness. Therefore hoof trimming can be prophylactic in nonlame cows (Manske et al., 2002b; Hernandez et al., 2007; Mahendran et al., 2017), or therapeutic in lame cows (Gomez et al., 2015; Thomas et al., 2015). Frequent hoof trimming may be associated with a reduction in lameness and claw lesion prevalence, for example, Manske et al. (2002b) showed that trimming twice yearly can significantly reduce lameness prevalence and prevalence of claw horn lesions (sole ulcer, white line disease, double sole) compared with trimming only once per year. However, Dembele et al. (2006) found that overgrown claws were associated with higher prevalence of lameness, but not that continuous/more frequent trimming reduced overgrowth or lameness in Czech dairy herds. In a more recent Swedish study, a trimming interval >174 d (<2.1 trimmings per year) was associated with increased prevalence of sole ulcers compared with a trimming interval < 140 d (>2.6 trimmings per year; Bergsten et al., 2015). However, Hernandez et al. (2007) found that 1 routine trimming in midlactation significantly reduced lameness later in the same lactation. Hoof trimming has also been shown to prevent infectious claw lesions such as interdigital and digital dermatitis, and heel horn erosion (Somers et al., 2005a,b). Thus, previous studies have provided valuable information concerning the associations between hoof trimming and some claw lesions but did not specifically investigate hoof trimming frequency and its associations with all major claw lesions. Moreover, none of the studies cited above (Manske et al., 2002b; Somers et al., 2005a,b; Dembele et al., 2006; Hernandez et al., 2007; Bergsten et al., 2015) investigated hoof trimming frequency of >2 trimmings or compared more than 2 different trimming frequencies. Hence, there is a lack of knowledge about the optimal hoof trimming frequency and whether different hoof trimming frequencies are more preventive for specific claw lesions.

Studies in Europe investigating euthanized cows postmortem report high proportions of claw and leg disorders (Thomsen et al., 2004, 2012; Alvåsen et al., 2014b; Reimus et al., 2020). In the studies by Alvåsen et al. (2014b) and Thomsen et al. (2004), 23% and 40% to 45%, respectively, of farmers cited locomotor disorders as the primary reason for cows being euthanized. However, neither study investigated the association between hoof trimming frequency and mortality. The study by Reimus et al. (2020) found that routine trimming was associated with lower mortality, and those authors concluded that strategies to improve hoof health could also reduce herd mortality. However, the data were analyzed on herd level and only mortality was investigated.

There is thus a lack of knowledge on the associations between hoof trimming frequency, claw lesions, and mortality (including culling) at herd and individual-cow level. In addition, farmers have expressed a need for more information about the optimal trimming frequency in general (Pedersen et al., 2022). To fill these knowledge gaps, we investigated the optimal hoof trimming frequency per lactation that gives the best preventive effect for most common claw lesions and whether more frequent trimming can reduce the risk of being culled. Specific objectives were to identify associations at cow level between trimming frequency in primiparous cows and hoof health and survival in the second lactation, and to provide farmers with practical, evidence-based advice on improving hoof health in dairy cows.

MATERIALS AND METHODS

Study Herds

The largest dairy association for cattle farmers in Sweden, Växa, has approximately 200,000 dairy cows enrolled in the Swedish Official Milk Recording Scheme (SOMRS). The SOMRS database holds information on approximately 73% of Swedish dairy cows and 70% of Swedish dairy herds. Cow data from all freestall herds in SOMRS with herd size ≥200 cows and hoof trimming records from 2015 to 2018 were included in the present retrospective cohort study. The number of eligible herds during the study period varied between 193 and 196 per year (Växa, 2018; Växa, 2020). In this study, exposure comprised different hoof trimming frequencies and the outcomes considered were claw health and survival in the second lactation.

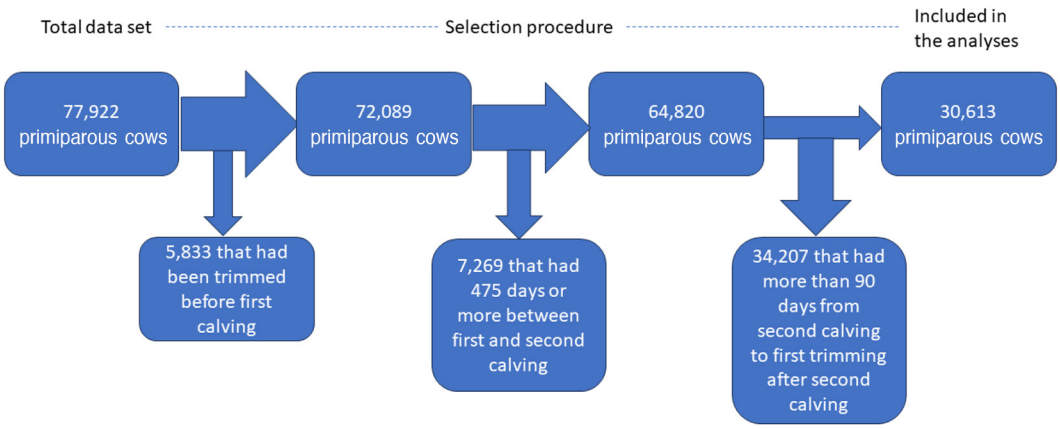

Figure 1. Flowchart showing the procedure used for selection of primiparous cows from 202 Swedish dairy herds to be included in statistical analysis of associations between claw trimming in the first lactation and hoof health and survival in the second lactation.

Study Animals

Primiparous cows in the selected herds that also had a second calving were considered eligible for inclusion (n = 77,922). Data on breed, including Swedish Red (**SR**), Swedish Holstein (**SH**), SR×SH, and all other breeds and crosses; calving date; and culling (sent to slaughter, death on-farm, euthanization on-farm) for these cows in the study period from 2015 to 2018 were retrieved from the SOMRS database. The inclusion criteria were: (1) no claw trimming before first calving, (2) interval between first and second calving of <475 d, and (3) claw trimming within 90 d of second calving. After applying inclusion criteria (1) and (2), 64,820 cows remained, and after applying criterion (3) 30,613 cows remained in the dataset (Figure 1).

We opted to include only primiparous cows in the analysis to reduce potential bias caused by previous claw lesions and to make the association between hoof trimming and claw lesions and survival more explicit. We applied inclusion criterion (1) in an effort to create a more similar group regarding claw lesions, thus reducing the probability of participating cows having a preventive or therapeutic trimming that could influence the results. Inclusion criterion (2) was intended to give a more similar study population, based on the assumption that primiparous cows with a very long first lactation could differ in several ways from those with a more normal first lactation length. Inclusion criterion (3) was applied to include cows in a similar stage of lactation and reduce the potential effect of other factors that could change over time.

For the outcome "survival in second lactation," only cullings performed up to 300 d after second calving were included because later decisions on culling would probably be less affected by hoof trimming during the first lactation.

Hoof Trimming Data

In hoof trimming data obtained from SOMRS for the study period, all hoof trimming records followed the Nordic Claw Atlas definitions (Nordic Cattle Genetic Evaluation, 2020) and were voluntarily reported by Swedish hoof trimmers to the Swedish National Database on Hoof Health (SNDHH), which is managed by Växa. Claw lesions recorded by hoof trimmers in the period from 2015 to 2018 and categories of lesions used in statistical analyses are presented in Table 1. Claw lesions were categorized into 3 major groups: infectious claw lesions (skin of lower legs, caused by an infective agent or poor hygiene), claw horn lesions (claw horn, related to trauma or animal-based risk factors related to the internal structure and function of the claw) and other claw lesions (deviant claw conformation, leg injury, lameness for unknown reasons), as described in the Nordic Claw Atlas (Nordic Cattle Genetic Evaluation, 2020). A further subdivision was made for infectious claw lesions and claw horn lesions into mild and severe, based on the likelihood of the lesions to induce lameness.

Professional hoof trimmers in Sweden are in general certified, meaning that their trimming technique is scrutinized in a practical examination. The recommended, and most commonly used, trimming method is the Dutch Five-Step Method, with the modification of greater modeling of the sole at typical sole ulcer sites. Swedish hoof trimmers use a grinder with a range of disks (125–150 mm diameter, 2–6 welded blades).

Data Editing

All data from SOMRS and SNDHH (breed, calving dates, hoof trimming records) were obtained as.dct files. These files were imported into Stata (release 17.0; Stata-

Table 1. Categories of recorded claw lesions used in this study

Category	Claw lesion status
Healthy	Cows with reported hoof trimming without any claw lesions.
Severe infectious claw lesions	Digital dermatitis (includes M1, M2, and M4.1 scores; Döpfer et al., 1997; Berry et al., 2012), foot rot, interdigital hyperplasia, chronic dermatitis or wart growth (includes M4 score).
Mild infectious claw lesions	Mild dermatitis (interdigital dermatitis), heel horn erosion.
Severe claw horn lesions	Sole ulcer, toe ulcer, white line ulcer or abscess.
Mild claw horn lesions	White line lesion, double sole, chronic laminitis or laminitic ring, sole hemorrhage.
Other	Asymmetric claw, scissor claw, overgrown claws, corkscrew claw, hock lesion, lameness.

Corp LLC) and merged by the unique cow identity (herd ID, animal ID, and birth year).

A hoof trimming performed within 30 d of a previous trimming was not counted as a new trimming occasion, but considered part of the same trimming, because such close trimmings are usually follow-ups. After adjustment for this, a maximum of 9 trimmings per cow was obtained. The variable "trimming frequency" had several categories with few observations (for trimming >3 times), so trimming frequency was combined to none, 1, 2, 3, and ≥4.

Statistical Analyses

Descriptive statistics were used to describe the distribution of primiparous cows with a certain number of hoof trimmings in the first lactation, number and type of claw lesions at first trimming in the second lactation, and number of the cows culled in total and per culling reason (using the "tabulate" command in Stata).

As only 2 explanatory variables (trimming frequency and breed) were included in each model for the 2 outcomes (hoof health at first trimming within 90 d from second calving and culling in second lactation within 300 d after second calving), and because we were not interested in the univariable unadjusted associations, univariate analysis was not performed. We also chose not to include herd characteristics, because the aim was not to investigate associations between herd types and the outcomes, but we included herd as cluster or random factor to adjust for these in the model. Because all cows were primiparous, there was no need to adjust for parity. However, previous Swedish studies have shown an association between breed and claw lesions (Manske, 2002; Bergsten et al., 2015), so breed was included as an explanatory variable.

The outcome "hoof health at first trimming within 90 d from second calving" was first analyzed in a multivariable mixed-effect logistic regression model (hereafter referred to as the **L1 model**), with the outcome coded as healthy (i.e., no claw lesions) or not (i.e., having one or more claw lesions), and including trimming frequency and breed as explanatory variables. Herd was included as a random effect using an independent variance-covariance structure of the random effects equation ("melogit" command in Stata). To investigate specific associations between the different categories of claw lesions (outcome) in Table 1 (healthy, mild infectious claw lesion, mild claw horn lesions, mild infectious claw lesions and claw horn lesions, severe infectious claw lesions, severe claw horn lesions, severe infectious claw lesions and claw horn lesions, other) and trimming frequency and breed (as explanatory variables), a multivariable multinomial logistic regression model (**ML1 model**) was used. Standard errors in the ML1 model were adjusted for repeated measurements within herd ("mlogit" command in Stata with herd as cluster sandwich estimator). The interaction between trimming frequency and breed was investigated in both the L1 and ML1 models, with statistical significance set at $P < 0.05$. All explanatory variables were found to be significantly associated with the outcome in both models, so no elimination procedure was needed. To graphically describe the associations found in the ML1 model, mean predicted probabilities were obtained using the "margins" command in Stata after running the model. Interpretation of results from the L1 model was assumed not to require this step.

The outcome "culling in second lactation within 300 d after second calving" was also first analyzed using a multivariable mixed-effect logistic regression model (**L2 model**), including trimming frequency and breed as explanatory variables. Herd was included as a random effect using an independent variance-covariance structure of the random effects equation ("melogit" command in Stata). To investigate specific associations between different reasons given for culling (outcome), including not culled (cows surviving second lactation), death or euthanasia on-farm, slaughtered with primary reason "claw and leg disorder," slaughtered for "other reason," and trimming frequency and breed (explanatory variables), a multivariable multinomial logistic regression model (**ML2 model**) was used. Standard errors in the ML2 model were adjusted for repeated measurements within herd ("mlogit" command in Stata with herd as

cluster sandwich estimator). Hoof health status at the first trimming after second calving (having a claw lesion or not) was also included as an explanatory variable in both the L2- and ML2 models, to adjust for that effect (intervening factor) and prevent it disguising the effect of trimming frequency in the first lactation on culling in the second lactation. Moreover, all 2-way interactions between the explanatory variables were investigated in both the L2- and ML2 models and retained if $P < 0.05$. To graphically describe the associations found between trimming frequency and culling in the second lactation in the ML2 model, mean predicted probabilities were obtained using the "margins" command in Stata after the model was run. Interpretation of results from the L2 model was assumed not to require this step.

Model fit of the L1 and L2 models was tested by visual examination of diagnostic plots (of observed and predicted outcome) and, based on Dohoo et al. (2010), normal plots of the standardized residuals and the predicted mean. There is no standard method for assessing the fit of multinomial logistic regression models, and therefore the fit of the ML1 and ML2 models was not assessed. However, the results were similar to those obtained with the L1 and L2 models, indicating that they were robust.

Table 2. Number and percentage of claw lesions recorded at first hoof trimming in the second lactation for 12,463 of 30,613 dairy cows with claw lesions in 202 Swedish herds

Claw lesion	Number of lesions[1]	Percentage of lesions
Mild infectious claw lesion		
Mild dermatitis	2,716	13.2
Heel horn erosion	5,340	25.9
Mild claw horn lesion		
White line lesion	781	3.8
Double sole	603	2.9
Chronic laminitis/laminitic ring	70	0.3
Sole hemorrhage	4,166	20.2
Severe infectious claw lesion		
Digital dermatitis	1,431	6.9
Foot rot	110	0.5
Interdigital hyperplasia	2,077	10.1
Chronic dermatitis/wart growth	33	0.2
Severe claw horn lesion		
Sole ulcer	942	4.6
Toe ulcer	29	0.1
White line ulcer/abscess	140	0.7
Other		
Asymmetric claw	1,499	7.3
Hock lesion	58	0.3
Overgrown claw	14	0.1
Corkscrew claw	510	2.5
Lameness	174	0.8
Total	20,635	100.0

[1]A cow can have several claw lesions at one trimming of one or more claws.

RESULTS

Descriptive Statistics

In total, 202 individual herds in the SOMRS database had ≥200 milking cows during the study period and were hence included in the analysis. Information about housing, milking and production system, major breed in the herd, and milk yield were available for 197 of these 202 herds. All herds except one had freestalls, and used a milking parlor (44%), automatic milking system (39%), or rotary milking system (15%). The majority of the herds were conventionally managed (82%), and 18% had organic production. In 41% of the herds the major breed (≥80%) was SH, 1% had SR as the major breed, 23% had SR×SH as the major breed, and 34% had no major breed. Average milk production of the herds included was 10,746 kg ECM (SD = 1,372 kg ECM). For the 202 herds, there were records of 369,468 hoof trimmings during the study period, including trimmings on dairy cows, young stock, and bulls. A total of 128 different hoof trimmers registered hoof lesions on at least one of the 202 herds during the study period.

More than half of the cows included (58% of 30,613) had no claw lesions at the first trimming within 90 d after second calving. The remaining 12,463 cows had a total of 20,635 recorded claw lesions (Table 2). The most common claw lesion types were heel horn erosion (25.9% of claw lesions) and sole hemorrhage (20.2% of claw lesions).

Trimming frequency during first lactation and recorded claw lesions at first trimming after second calving are shown in Table 3. Two hoof trimmings (34%) or 1 hoof trimming (30%) were most common, and 20% of the primiparous cows included in the analysis had no trimming during the first lactation, 13% were trimmed 3 times, and 1.5% were trimmed ≥4 times. The proportion of cows considered healthy (i.e., no claw lesions) at the first trimming after second calving was numerically higher for cows trimmed 1 to 3 times than for cows not trimmed or trimmed ≥4 times (Table 3).

Of the 30,613 primiparous cows with a trimming within 90 d after their second calving, 18% (5,494 cows) were culled within 300 d in their second lactation. The trimming frequency of these cows during first lactation in relation to culling during second lactation is presented in Table 4. The numerically highest proportion of cows culled was in the group that had not been trimmed during first lactation, and the lowest proportion was in the group that had been trimmed 2 or 3 times, but the differences were numerically small.

Of the 30,613 primiparous cows included in the analysis, 61% were SH, 30% were SR, 7% were SR×SH, and 2% were other breeds.

Table 3. Trimming frequency in the first lactation and number (%) of recorded claw lesions at cow level at first hoof trimming within 90 d after the second calving for cows with a calving interval of 474 d or less (n = 30,613 cows in 202 dairy herds)

	Trimming frequency, n (%)					
Claw lesion type	None	1	2	3	≥4	Total
Healthy (no claw lesions)	3,748 (56)	5,292 (58)	6,360 (61)	2,504 (62)	246 (52)	18,150 (59)
Mild infectious claw lesion[1]	924 (14)	1,021 (11)	1,068 (10)	413 (10)	52 (11)	3,478 (11)
Mild claw horn lesion[2]	450 (7)	755 (8)	783 (8)	289 (7)	39 (8)	2,316 (8)
Mild infectious claw lesion and mild claw horn lesion	426 (6)	573 (6)	561 (5)	173 (4)	30 (6)	1,763 (6)
Severe infectious claw lesion[3]	692 (10)	902 (10)	1,110 (11)	468 (11)	79 (17)	3,251 (11)
Severe claw horn lesion[4]	242 (4)	304 (3)	258 (2)	92 (2)	12 (3)	911 (3)
Severe infectious claw lesions and severe claw horn lesion	62 (1)	58 (1)	43 (0)	23 (1)	1 (0)	187 (1)
Other[5]	134 (2)	145 (2)	166 (2)	102 (3)	10 (2)	557 (2)
Total	6,678	9,050	10,349	4,067	469	30,613

[1]Mild dermatitis and heel horn erosion.
[2]Chronic laminitis/laminitic ring, double sole, sole hemorrhage, and white line lesion.
[3]Wart growth, digital dermatitis, foot rot, and interdigital hyperplasia.
[4]Sole ulcer, toe ulcer, white line ulcer/abscess.
[5]Asymmetry, scissor claw, hock lesion, overgrown claw, corkscrew claw, lameness.

Associations Between Trimming Frequency in First Lactation and Hoof Health In Second Lactation

The results of the L1 model of the association between number of hoof trimmings in the first lactation and hoof health at first trimming in the second lactation (outcome: claw lesions or not) are presented in Table 5. Cows trimmed 1, 2, or 3 times were at lower odds of having a claw lesion compared with cows not trimmed (Table 5). Moreover, cows trimmed 2 or 3 times were at lower odds of having claw lesions compared with cows trimmed once (odds ratio [**OR**] = 0.80, 95% CI = 0.75–0.85, $P < 0.001$ and OR = 0.72, 95% CI = 0.66–0.79, $P < 0.001$, respectively) or ≥4 times (OR = 0.72, 95% CI = 0.58–0.89, $P = 0.002$ and OR = 0.65, 95% CI = 0.52–0.81, $P < 0.001$, respectively). There was no significant difference in odds between cows trimmed ≥4 times and cows trimmed once. Cows trimmed 3 times were at lower odds of having claw lesions compared with cows trimmed twice (OR = 0.91, 95% CI = 0.83–0.99, $P = 0.04$).

The odds of having claw lesions at first trimming in the second lactation were significantly lower for cows of the SR, SR×SH, and other breeds than for SH cows (Table 5). The random effect of herd was significant, and visual examination of the model fit showed good fit of the data.

The ML1 model of the association between number of hoof trimmings in the first lactation and different outcome categories (no claw lesions, that is, healthy;

Table 4. Trimming frequency in the first lactation and culling numbers (%) during the second lactation for cows with a first hoof trimming in their second lactation within 90 d and a calving interval of 474 d or less (n = 30,613 cows in 202 dairy herds)

	Trimming frequency, n (%)					
Outcome	None	1	2	3	≥4	Total
Not culled	5,312 (79)	7,312 (81)	8,716 (84)	3,955 (84)	389 (83)	25,119 (82)
Mortality (dead or euthanized on farm)	228 (3)	271 (3)	263 (2)	141 (3)	15 (3)	918 (3)
Slaughter with primary reason claw and leg disorders	133 (2)	166 (2)	145 (1)	75 (2)	12 (3)	531 (2)
Slaughter for other reasons	1,005 (15)	1,301 (14)	1,225 (12)	461 (11)	53 (11)	4,045 (13)
Total	6,678	9,050	10,349	4,067	469	30,613

Table 5. Results of the L1 model of the association between hoof trimming frequency in the first lactation and having claw lesions or not at the first trimming in the second lactation (n = 30,613 cows in 202 dairy herds)

Item	Coefficient	SE	OR	95% CI	*P*-value
Trimming frequency					
None	Referent	—	—	—	—
1	−0.18	0.04	0.83	0.77; 0.90	<0.001
2	−0.41	0.04	0.66	0.62; 0.71	<0.001
3	−0.51	0.05	0.60	0.55; 0.66	<0.001
≥4	−0.07	0.11	0.93	0.75; 1.15	0.50
Breed[1]					
SH	Referent	—	—	—	—
SR	−0.17	0.03	0.84	0.78; 0.90	<0.001
SR×SH	−0.17	0.05	0.84	0.76; 0.94	0.003
Other	−0.36	0.10	0.66	0.54; 0.81	<0.001
Intercept	−0.24	0.09			0.005

[1]SH = Swedish Holstein; SR = Swedish Red.

mild infectious claw lesion; mild claw horn lesion; mild infectious claw lesion and claw horn lesion; severe infectious claw lesion; severe claw horn lesion; severe infectious claw lesion and claw horn lesion; and other lesions) revealed significant associations (Table 6). Only statistically significant comparisons are discussed below. Model-predicted probabilities of a cow having no lesions or different claw lesion types are presented in Figure 2 to facilitate interpretation of the results. The results from the ML1 model showed that the predicted probability of not having claw lesions was highest for cows that had been trimmed 2 or 3 times in their first lactation (Figure 2A). The relative risk ratio (**RRR**) for a cow having mild infectious claw lesions, compared with no claw lesions, at first trimming after second calving was significantly lower for cows that had been trimmed 1, 2, or 3 times (Table 6) than for cows not trimmed during their first lactation (Figure 2B). The RRR for a cow having mild claw horn lesions, compared with no claw lesions, at first trimming after their second calving was significantly higher for cows that had been trimmed once during the first lactation than for cows not trimmed (Table 6; Figure 2C). The probability of having mild infectious claw lesions was in general higher than the probability of having mild claw horn lesions (Figure 2B, 2C). The RRR for a cow having mild infectious claw lesions and mild claw horn lesions, compared with no claw lesions, was significantly lower for cows trimmed 3 times than for cows not trimmed (Table 6) or cows trimmed ≥4 times (RRR = 0.56, 95% CI = 0.35–0.90, P = 0.02). The RRR was also lower for cows trimmed twice (RRR = 0.82, 95% CI = 0.69–0.97, P = 0.02) or 3 times (RRR = 0.64, 95% CI = 0.42–0.99, P = 0.04) compared with cows trimmed once. The RRR for a cow having severe infectious claw lesions, compared with no claw lesions, was lower for cows that were not trimmed (RRR = 0.58, 95% CI = 0.37–0.91, P = 0.02), trimmed once (RRR = 0.54, 95% CI = 0.35–0.82, P = 0.004), trimmed twice (RRR = 0.55, 95% CI = 0.36–0.83, P = 0.005), or trimmed 3 times (RRR = 0.58, 95% CI = 0.43–0.79, P < 0.001) than for cows trimmed 4 or more times (Figure 2D). The RRR for a cow having severe claw horn lesions, compared with no claw lesions, was significantly lower for cows trimmed 2 or 3 times than for cows not trimmed (Table 6) or trimmed once during their first lactation (RRR = 0.70, 95% CI = 0.57–0.86, P = 0.001 and RRR = 0.65, 95% CI = 0.49–0.87, P = 0.003, respectively; Figure 2E). The RRR for a cow having severe infectious claw lesions and claw horn lesions, compared with no claw lesions, was significantly lower for cows trimmed twice than for cows not trimmed (Table 6) or trimmed once (RRR = 0.62, 95% CI = 0.42–0.91, P = 0.02). The RRR for a cow having other claw lesions, compared with no claw lesions, was lower for cows trimmed once (RRR = 0.65, 95% CI = 0.42–0.98, P = 0.04) or twice (RRR = 0.63, 95% CI = 0.45–0.88, P = 0.007) than for cows trimmed 3 times.

Associations Between Trimming Frequency in First Lactation and Culling in Second Lactation

The results of the L2 model of the association between trimming frequency in the first lactation, in interaction with the trimming results at first trimming in the second lactation and culling in the second lactation are presented in Table 7. Cows trimmed during their first lactation were at significantly lower odds of being culled in their second lactation compared with cows not trimmed (Table 7), and cows trimmed 2, 3, or ≥4 times were at lower odds of being culled compared with cows trimmed once (OR = 0.77, 95% CI = 0.71–0.83, P < 0.001; OR = 0.74, 95% CI = 0.66–0.82, P < 0.001; and OR = 0.75, 95% CI = 0.59–0.97, P = 0.03, respectively). The odds did not differ significantly for cows trimmed 2, 3, or ≥4 times.

There was a significant interaction between breed and having claw lesions at first trimming in the second lac-

Table 6. Results of the ML1 model of associations between hoof trimming frequency in the first lactation and claw health at first trimming in the second lactation (n = 30,613 cows in 202 dairy herds)[1]

Item	Coefficient	SE	RRR	95% CI	*P*-value
No claw lesions	Base outcome	—	—	—	—
Mild infectious lesion					
Trimming frequency					
None	Referent	—	—	—	—
1	−0.24	0.08	0.79	0.67; 0.92	0.002
2	−0.37	0.10	0.69	0.57; 0.83	<0.001
3	−0.39	0.14	0.68	0.51; 0.90	0.007
≥4	−0.15	0.28	0.86	0.49; 1.51	0.61
Breed[2]					
SH	Referent	—	—	—	—
SR	0.33	0.15	1.38	1.04; 1.85	0.03
SR×SH	0.15	0.17	1.17	0.83; 1.62	0.36
Other	−0.09	0.24	0.91	0.57; 1.46	0.70
Intercept	−1.52	0.13			<0.001
Mild claw horn lesion					
Trimming frequency					
None	Referent	—	—	—	—
1	0.19	0.08	1.18	1.00; 1.40	0.047
2	0.02	0.10	1.02	0.84; 1.25	0.82
3	−0.04	0.15	0.96	0.71; 1.29	0.78
≥4	0.28	0.27	1.33	0.79; 2.24	0.29
Breed					
SH	Referent	—	—	—	—
SR	−0.23	0.11	0.79	0.64; 0.99	0.04
SR×SH	−0.30	0.12	0.74	0.58; 0.95	0.02
Other	−0.30	0.28	0.74	0.43; 1.29	0.29
Intercept	−2.02	0.10			<0.001
Mild infectious claw lesion and mild claw horn lesion					
Trimming frequency					
None	Referent	—	—	—	—
1	−0.05	0.13	0.95	0.73; 1.24	0.72
2	−0.25	0.13	0.78	0.60; 1.00	0.054
3	−0.49	0.23	0.61	0.39; 0.96	0.03
≥4	0.08	0.28	1.09	0.63; 1.88	0.76
Breed					
SH	Referent	—	—	—	—
SR	0.05	0.20	1.05	0.71; 1.54	0.81
SR×SH	−0.18	0.24	0.84	0.52; 1.35	0.46
Other	−1.15	0.40	0.31	0.14; 0.70	0.004
Intercept	−2.16	0.18			<0.001
Severe infectious lesion					
Trimming frequency					
None	Referent	—	—	—	—
1	−0.08	0.09	0.92	0.77; 1.11	0.39
2	−0.06	0.09	0.94	0.78; 1.14	0.53
3	0.006	0.16	1.01	0.73; 1.38	0.97
≥4	0.54	0.23	1.73	1.10; 2.69	0.02
Breed					
SH	Referent	—	—	—	—
SR	−0.02	0.16	0.98	0.71; 1.33	0.88
SR×SH	0.12	0.15	1.13	0.85; 1.51	0.41
Other	−0.11	0.23	0.89	0.57; 1.41	0.63
Intercept	−1.69	0.13			<0.001
Severe claw horn lesion					
Trimming frequency					
None	Referent	—	—	—	—
1	−0.12	0.10	0.89	0.72; 1.08	0.25
2	−0.47	0.12	0.62	0.49; 0.79	<0.001
3	−0.54	0.15	0.58	0.43; 0.78	<0.001
≥4	−0.29	0.27	0.75	0.44; 1.27	0.29
Breed					
SH	Referent	—	—	—	—
SR	−0.26	0.13	0.77	0.60; 0.99	0.04
SR×SH	−0.07	0.15	0.93	0.69; 1.26	0.64
Other	−0.48	0.27	0.61	0.36; 1.04	0.07
Intercept	−2.65	0.10			<0.001

Continued

Table 6 (Continued). Results of the ML1 model of associations between hoof trimming frequency in the first lactation and claw health at first trimming in the second lactation (n = 30,613 cows in 202 dairy herds)[1]

Item	Coefficient	SE	RRR	95% CI	*P*-value
Severe infectious claw lesion and severe claw horn lesion					
Trimming frequency					
None	Referent	—	—	—	—
1	−0.41	0.27	0.66	0.39; 1.11	0.12
2	−0.90	0.26	0.41	0.24; 0.68	0.001
3	−0.59	0.33	0.55	0.29; 1.06	0.08
≥4	−1.40	1.03	0.25	0.03; 1.87	0.18
Breed					
SH	Referent	—	—	—	—
SR	−0.23	0.21	0.80	0.53; 1.21	0.29
SR×SH	−0.23	0.28	0.79	0.46; 1.36	0.40
Other	−0.78	0.73	0.46	0.11; 1.92	0.29
Intercept	−4.01	0.25			<0.001
Other type of lesion					
Trimming frequency					
None	Referent	—	—	—	—
1	−0.25	0.13	0.78	0.60; 1.01	0.06
2	−0.28	0.19	0.75	0.52; 1.09	0.13
3	0.18	0.21	1.20	0.80; 1.81	0.38
≥4	0.17	0.40	1.19	0.54; 2.59	0.67
Breed					
SH	Referent	—	—	—	—
SR	0.83	0.17	2.29	1.63; 3.22	<0.001
SR×SH	0.07	0.24	1.07	0.66; 1.72	0.79
Other	0.16	0.44	1.17	0.49; 2.75	0.72
Intercept	−3.68	0.22			<0.001

[1]Standard error (SE) was adjusted for repeated measurements within herd.
[2]SH = Swedish Holstein; SR = Swedish Red.

tation and culling (Table 7). Among cows without claw lesions, SR cows were at higher odds of being culled compared with SH cows (Table 7), SR×SH cows (OR = 1.42, 95% CI = 0.19–1.70, $P < 0.001$), or cows of other breeds (OR = 1.40, 95% CI = 1.03–1.91, $P = 0.03$). No other significant differences were seen between cows of different breeds without claw lesions. Among cows with claw lesions, SR cows were at higher odds of being culled compared with SH cows (OR = 1.12, 95% CI = 1.11–1.37, $P < 0.001$) or SR×SH cows (OR = 1.43, 95% CI = 1.17–1.75, $P < 0.001$) with claw lesions. No other significant differences were seen between cows with claw lesions. Cows of the SH breed (Table 7), SR cows (OR = 1.58, 95% CI = 1.66–2.06, $P < 0.001$) and SR×SH cows (OR = 1.29, 95% CI = 1.07–1.57, $P = 0.009$) with claw lesions were at higher odds of being culled compared with SH cows without claw lesions. Cows of the SR breed with claw lesions had higher odds of being culled (OR = 1.27, 95% CI = 1.14–1.42, $P < 0.001$) than SR cows without claw lesions. The odds of being culled did not differ between SR×SH cows without claw lesions and SR×SH cows with claw lesions ($P = 0.057$) but were higher for SH cows (OR = 1.46, 95% CI = 1.23–1.74, $P < 0.001$) and SR cows (OR = 1.81, 95% CI = 1.51–2.17, $P < 0.001$) with claw lesions. Moreover, the odds of being culled were higher for SH cows (OR = 1.44, 95% CI = 1.06–1.96, $P = 0.01$) and SR cows (OR = 1.78, 95% CI = 1.30–2.44, $P < 0.001$) with claw lesions than for cows of other breeds without claw lesions. No other significant differences were seen. The random effect of herd was significant, and visual examination of model fit showed good fit of the data.

The ML2 model showed significant associations between trimming frequency in the first lactation and the outcome categories not culled, dead or euthanized on-farm (mortality), slaughtered with primary reason "claw and leg disorder," and slaughtered for "other reason" (Table 8). Predicted probabilities from the model are presented in Figure 3 to facilitate interpretation of the results. The results from the ML2 model showed that cows with >1 trimming had a higher probability of not being culled (Figure 3A). The RRR for a cow dying or being euthanized on-farm, compared with not being culled, was significantly lower for cows that had been trimmed twice compared with cows not trimmed (Table 8), trimmed once (RRR = 0.82, 95% CI = 0.69–0.97, $P = 0.02$), or trimmed 3 times (RRR = 0.73, 95% CI = 0.60–0.88, $P = 0.001$) during first lactation (Figure 3B). Moreover, the RRR for a cow dying or being euthanized on-farm, compared with not being culled, was significantly higher for cows with claw lesions than for cows without claw lesions at first trimming in their

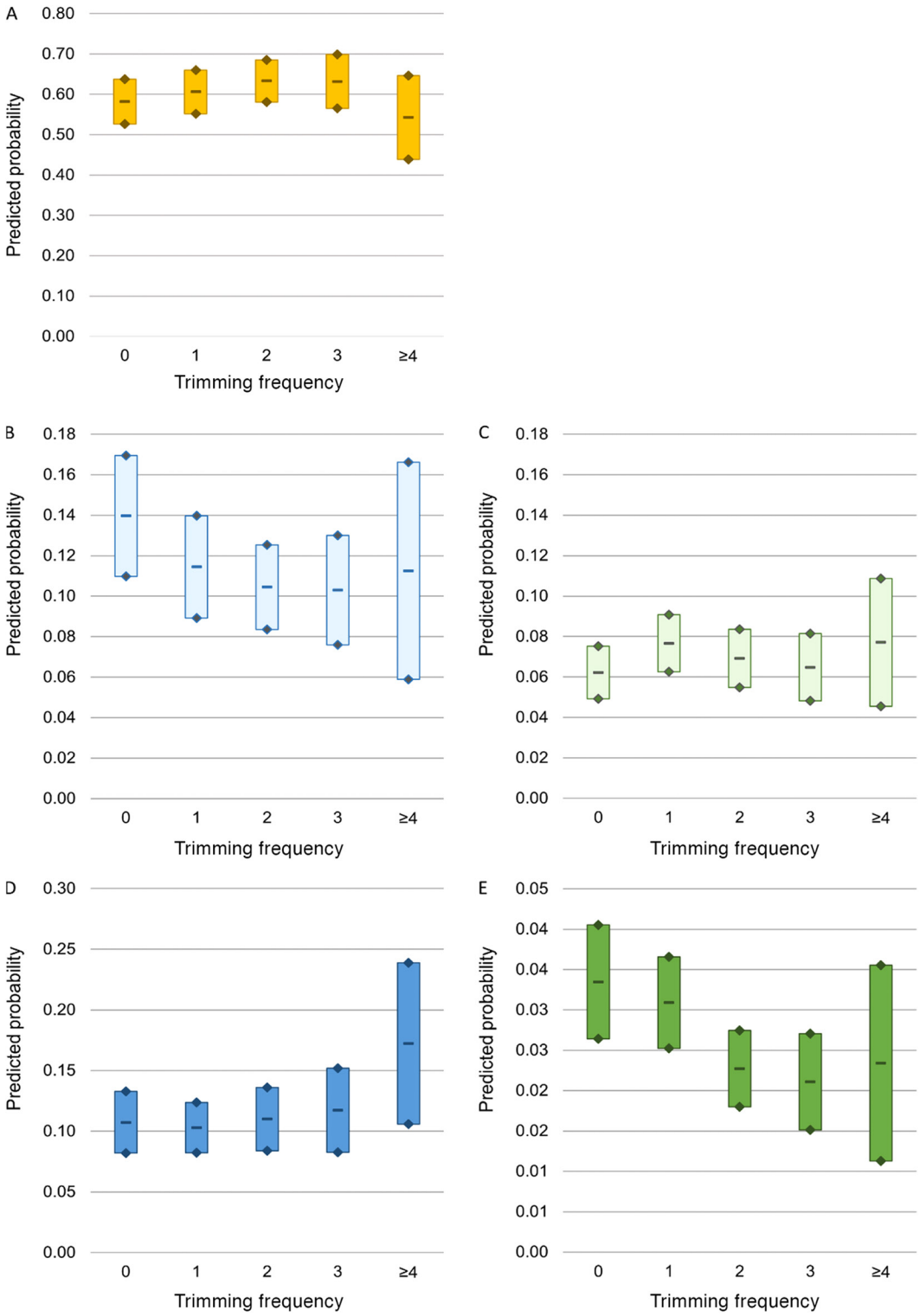

Figure 2. Mean predicted probability (line), adjusted for breed and herd effects, and 95% CI (diamonds) in the ML1 model of being a cow with (A) no claw lesions, (B) mild infectious claw lesions, (C) mild claw horn lesions, (D) severe infectious claw lesions, or (E) severe claw horn lesions at first hoof trimming in the second lactation depending on trimming frequency (0, 1, 2, 3, or ≥4 times) in the first lactation (n = 30,613 cows in 202 dairy herds). Note the differing scale on the y-axis depending on the outcome.

Table 7. Results of the L2 model of the association between hoof trimming frequency in the first lactation, in interaction with having claw lesions or not at first trimming in the second lactation, and culling in the second lactation (n = 30,613 cows in 202 dairy herds)

Item[1]	Coefficient	SE	OR	95% CI	*P*-value
Trimming frequency					
None	Referent	—	—	—	—
1	−0.08	0.04	0.92	0.85; 1.00	0.049
2	−0.35	0.04	0.71	0.65; 0.77	<0.001
3	−0.38	0.06	0.68	0.61; 0.76	<0.001
≥4	−0.36	0.13	0.70	0.54; 0.90	0.006
Interaction between breed and having claw lesions or not at first trimming in the second lactation:					
SH and no claw lesions	Referent	—	—	—	—
SR and no claw lesions	0.38	0.05	1.45	1.32; 1.61	<0.001
SR×SH and no claw lesions	0.02	0.09	1.02	0.86; 1.21	0.78
Other breeds and no claw lesions	0.04	0.16	1.04	0.77; 1.41	0.80
SH and claw lesions	0.41	0.04	1.50	1.38; 1.63	<0.001
SR and claw lesions	0.62	0.05	1.85	1.66; 1.06	<0.001
SR×SH and claw lesions	0.26	0.10	1.29	1.07; 1.57	0.009
Other and claw lesions	0.31	0.19	1.36	0.94; 1.97	0.10
Intercept	−1.69	0.05			<0.001

[1]SH = Swedish Holstein; SR = Swedish Red.

second lactation (Table 8). Cows of the SR breed had a significantly lower RRR of death or euthanasia on-farm than SH cows, when compared with cows not culled (Table 8). The RRR for a cow being sent to slaughter with primary reason "claw and leg disorder," compared with not being culled, was as significantly lower for cows trimmed twice than for cows not culled (Table 8) or trimmed once (RRR = 0.76, 95% CI = 060–0.95, P = 0.02) during their first lactation (Figure 3C). Moreover, the RRR for a cow being sent to slaughter in their second lactation with the primary reason "claw and leg disorder," compared with not being culled in their second lactation, was significantly higher for cows with claw lesions at first trimming in the second lactation than for cows without claw lesions on this occasion (Table 8). The RRR for a cow being sent to slaughter with the primary reason "claw and leg disorder," compared with not being culled, was significantly higher for SR cows than for SH cows (Table 8). The RRR for being sent to slaughter for "other reason," compared with not being culled, was significantly lower for cows trimmed 2, 3, or ≥4 times compared with cows not trimmed (Table 8; Figure 3D) or trimmed once (RRR = 0.80, 95% CI = 0.71–0.89, $P < 0.001$; RRR = 0.78, 95% CI = 0.67–0.90, P = 0.001; and RRR = 0.77, 95% CI = 0.60–0.98, $P = 0.03$, respectively). The RRR for cows being sent to slaughter for "other reason," compared with not being culled, was also significantly higher for cows with claw lesions than for cows without claw lesions, at first trimming in their second lactation (Table 8). The RRR for cows being sent to slaughter for "other reason," compared with not being culled, was significantly higher for SR cows than for SH cows (Table 8) or SR×SH cows (RRR = 1.36, 95% CI = 1.15–1.60, $P < 0.001$).

DISCUSSION

This study investigated associations between hoof trimming frequency in the first lactation and hoof health and survival in the second lactation and found that 2 or 3 trimmings were most beneficial for hoof health and cow survival in the second lactation. A novel aspect of the study was that we investigated the association between a wide range of hoof trimming frequencies in individual cows and subsequent claw lesions and different reasons for culling. Hoof trimming in this case referred to inspection of cows' feet in a trimming chute, with the hoof trimmer assessing the need to trim the weight-bearing part of the sole and the need for other actions, including treatment of different claw lesions and modeling the sole at the typical sole ulcer site, which is a part of the sole that should not bear weight. Applying 2 or 3 trimmings may, however, not be optimal in all cases and hoof trimming frequency should be determined on each specific farm, taking other farm-specific factors into consideration. Many factors affect hoof health in a herd and hoof trimming frequency is just one of these (Cramer et al., 2009; Kulualp et al., 2021). Apart from trimming frequency, other important aspects are when in lactation the trimming occurs and the technique used, but these were outside the scope of the present study. To not include these aspects is a limitation of the present study. However, most claw trimmers in Sweden are certified according to a standard and mainly use a modification of the Dutch Five-Step Method for trimming (with greater modeling of the sole at the typical sole ulcer site), so we believe including the fixed effect of claw trimmer in the model would probably not have altered the results substantially. Moreover, the potential effect of hoof trim-

Table 8. Results of the ML2 model of associations between hoof trimmings in the first lactation, in interaction with trimming results at first trimming in second lactation and culling at second lactation (n = 30,613 cows in 202 dairy herds)[1]

Item	Coefficient	SE	RRR	95% CI	*P*-value
Not culled	Base outcome	—	—	—	—
Mortality (dead or euthanized on-farm)					
Trimming frequency					
None	Referent	—	—	—	—
1	−0.14	0.10	0.87	0.71; 1.05	0.15
2	−0.34	0.10	0.71	0.59; 0.86	<0.001
3	−0.02	0.11	0.98	0.78; 1.23	0.87
≥4	−0.12	0.25	0.88	0.54; 1.44	0.63
Claw lesion at first trimming in second lactation					
No	Referent	—	—	—	—
Yes	0.42	0.07	1.52	1.32; 1.74	<0.001
Breed[2]					
SH	Referent	—	—	—	—
SR	−0.32	0.09	0.73	0.60; 0.87	0.001
SR×SH	−0.24	0.17	0.78	0.61; 1.09	0.15
Other	−0.57	0.30	0.57	0.31; 1.02	0.06
Intercept	−3.23	0.09			<0.001
Slaughter with primary reason claw and leg disorders					
Trimming frequency					
None	Referent	—	—	—	—
1	−0.06	0.12	0.94	0.74; 1.19	0.60
2	−0.34	0.17	0.71	0.51; 1.00	0.050
3	−0.04	0.19	0.96	0.66; 1.40	0.83
≥4	0.18	0.29	1.20	0.67; 2.13	0.54
Claw lesion at first trimming in second lactation					
No	Referent	—	—	—	—
Yes	1.12	0.13	3.05	2.38; 3.92	<0.001
Breed					
SH	Referent	—	—	—	—
SR	0.35	0.14	1.42	1.07; 1.89	0.01
SR×SH	0.12	0.19	1.12	0.77; 1.64	0.52
Other	0.17	0.35	1.19	0.60; 2.25	0.62
Intercept	−4.45	0.14			<0.001
Slaughtered for other reasons					
Trimming frequency					
None	Referent	—	—	—	—
1	−0.05	0.06	0.95	0.84; 1.06	0.37
2	−0.28	0.06	0.76	0.67; 0.86	<0.001
3	−0.30	0.08	0.74	0.63; 0.86	<0.001
≥4	−0.32	0.13	0.73	0.57; 0.94	0.01
Claw lesion at first trimming in second lactation					
No	Referent	—	—	—	—
Yes	0.15	0.06	1.16	1.03; 1.30	0.01
Breed					
SH	Referent	—	—	—	—
SR	0.28	0.06	1.32	1.17; 1.51	<0.001
SR×SH	−0.03	0.09	0.97	0.82; 1.15	0.76
Other	0.03	0.17	1.03	0.75; 1.43	0.83
Intercept	−1.83	0.06			<0.001

[1]Standard error (SE) was adjusted for repeated measurements within herd.
[2]SH = Swedish Holstein; SR = Swedish Red.

mer was partly accounted for by the random effect and by adjusting for clustering within herd. Nevertheless, further research on the association between hoof trimming method, timing of hoof trimmings in lactation, and prevalence of claw lesions is needed. Our results are important because few studies have been performed in this field (Sadiq et al., 2020) and hoof health is a key factor in the sustainability of the dairy industry because of its close connection to productive lifespan (Machado et al., 2010), milk yield (Charfeddine and Pérez-Cabal, 2017), reproduction (Charfeddine and Pérez-Cabal, 2017), and animal welfare (Weigele et al., 2018).

Trimming Frequency and Hoof Health

Our results support the current recommendation in Sweden to hoof-trim dairy cows at least twice yearly to reduce the probability of most claw lesions. More

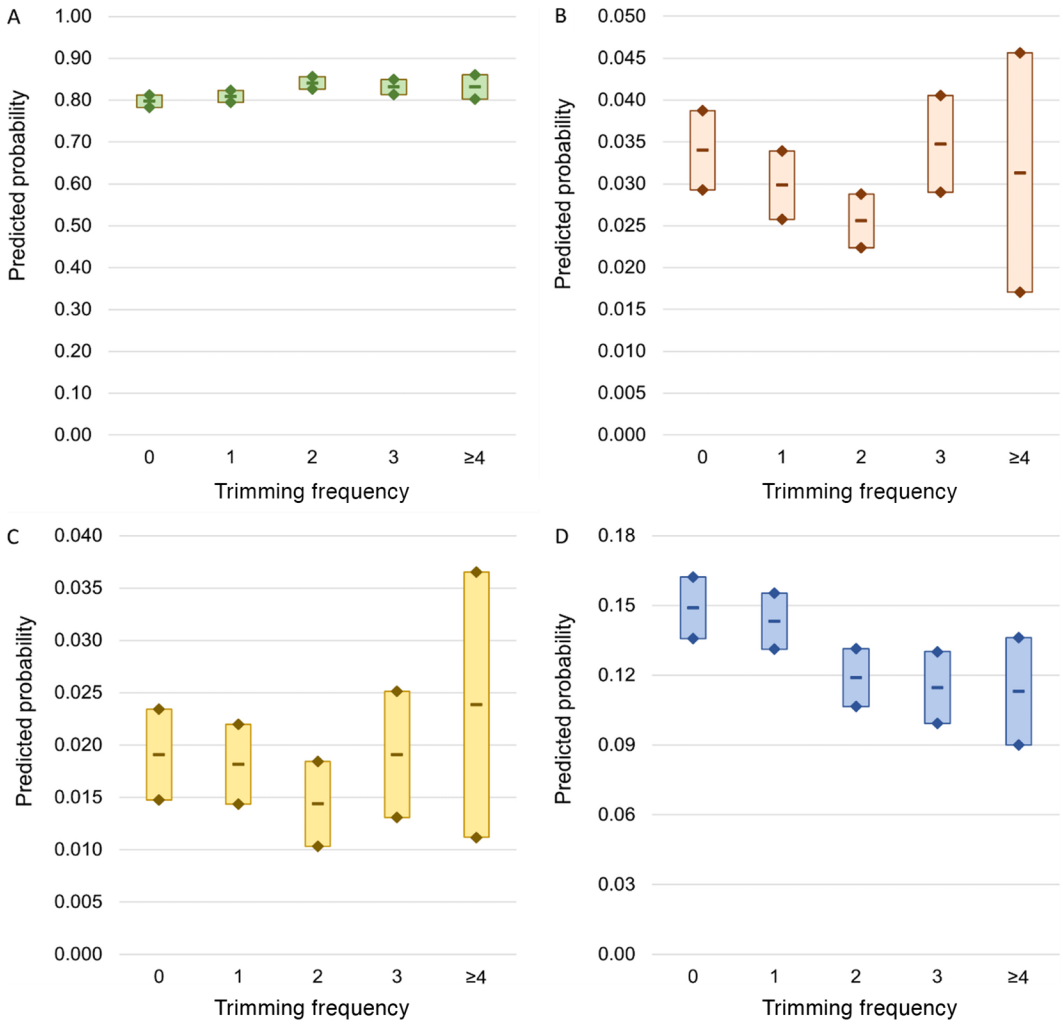

Figure 3. Mean predicted probability (line), adjusted for breed and herd effects, and 95% CI (diamonds) in the ML2 model of (A) not being culled, (B) mortality (dead or euthanized on-farm), (C) sent to slaughter with primary reason being claw and leg disorder, or (D) sent to slaughter for other reasons, in the second lactation for dairy cows with different hoof trimming frequency (0, 1, 2, 3, or ≥4 times) during the first lactation (n = 30,613 cows in 202 dairy herds). Note the differing scale on y-axis depending on the outcome.

specifically, our results revealed an association between lower prevalence of severe claw horn lesions and trimming 2 or 3 times compared with trimming once or not at all. This is in line with findings by Manske et al. (2002b) and Bergsten et al. (2015) that trimming twice yearly is associated with lower prevalence of severe claw horn lesions. Concerning infectious claw lesions, our results showed an association between trimming 1, 2, or 3 times and lower prevalence of mild infectious claw lesions (interdigital dermatitis and heel horn erosion). Similarly, Bergsten et al. (2015) and Somers et al. (2005a,b) found that trimming approximately twice yearly is associated with lower prevalence of interdigital and digital dermatitis, compared with trimming less frequently. However, Manske et al. (2002b) found no such association. Somers et al. (2005a,b) found that trimming approximately twice yearly is also associated with lower prevalence of heel horn erosion, which is supported by the findings in our study. The finding that trimming ≥4 times, compared with less frequent trimming, was associated with higher prevalence of severe infectious claw lesions (digital dermatitis, foot rot, interdigital hyperplasia, chronic dermatitis/wart growth), was somewhat surprising. The severe infectious claw lesions in the present study were mainly interdigital hyperplasia (57%) and digital dermatitis (39%), and Relun et al. (2013) showed that absence of hoof trimming can strongly increase the incidence of digital dermatitis on a herd level. Somewhat similar to our results, Holzhauer et al. (2006) found a negative association between a trimming interval >12 mo and prevalence of digital dermatitis and attributed this to a herd problem with infectious claw lesions resulting in

more trimmings or the hoof trimmer spreading the infection between herds. These reasons could also explain our results. During the period from 2015 to 2018, SNDHH received information about hoof trimmings on 1,024,599 cows, of which 44% (451,106) were trimmed once, 46% (473,066) were trimmed twice, and 10% (100,427) were trimmed 3 times yearly. Based on this data, ≥4 hoof trimmings in the present study were likely performed for therapeutic reasons. However, a limitation in Swedish hoof trimming recordings is that therapeutic trimmings cannot be distinguished from routine trimmings, which should be borne in mind when interpreting our results, especially regarding ≥4 hoof trimmings. In general, our results and those of most previous studies indicate that trimming more frequently reduces the incidence of both claw horn and infectious claw lesions, making it unnecessary to adjust the trimming frequency to the type of claw lesions prevailing in the herd.

Trimming Frequency and Survival

Our results showed a lower OR and RRR of being culled in the second lactation for cows with ≥1 trimming than for cows with no trimming, and for cows with ≥2 trimmings compared with cows trimmed once. Regarding mortality, 2 trimmings in the first lactation gave the lowest RRR. In this study, 18% of the cows included were culled in their second lactation, of which 83% were sent to slaughter and 17% died or were euthanized on-farm. This reflects the proportion of cows that died or were euthanized on-farm in the total number of culled cows in Swedish dairy herds in 2018, which was approximately 18% (Växa, 2019). Lame cows may not be transported to slaughter under Swedish legislation, so these cows have to become nonlame before they can be transported to slaughter. The most common reason for cows dying or being euthanized on Swedish dairy farms is claw and leg disorders (Alvåsen et al., 2014a,b). Claw and leg disorders are also one of the most common reasons for death or euthanasia on-farm in Estonia (Reimus et al., 2020) and Denmark (Thomsen et al., 2004). In Estonia, Reimus et al. (2020) found that hoof trimming once yearly reduced herd mortality rate compared with no trimming, which is somewhat supported by the findings in our study. However, their study was performed on a herd level, whereas we had records on both hoof trimmings and culling (mortality and slaughter) on the cow level, enabling more detailed analysis. Two trimmings per year have been shown to reduce the probability of dairy cows having severe claw horn lesions (Manske et al., 2002b; Bergsten et al., 2015). Severe claw horn lesions have a high probability of causing lameness (Archer et al., 2010), which increases mortality in herds (Thomsen et al., 2004; Alvåsen et al., 2014b), so preventing claw lesions can probably reduce herd mortality, as shown in the present study.

Claw or leg disorder was reported by farmers as the primary reason for slaughter of 11.5% of cows in the present study, which is slightly higher than the national average of 7% (Växa, 2023a). In contrast to expectations, we found no association between trimming frequency and being sent to slaughter for the stated reason "claw and leg disorder." However, the reason given for sending cows to slaughter may be inaccurate, because farmers must state a reason, but cows may not be lame when transported to slaughter.

We observed a significantly higher RRR of being slaughtered for reasons other than claw and leg disorder if the cow had no or 1 trimming compared with 2 or more trimmings in the first lactation. This may indicate that claw lesions affect parameters such as fertility (Charfeddine and Pérez-Cabal, 2017) and udder health (Singh et al., 2018), or that these have joint causal factors. Problems with fertility, udder health, and low milk yield are the most common reasons for slaughter reported by farmers in Sweden (Växa, 2023a).

Our finding that cows with claw lesions at the first trimming in the esecond lactation had a higher probability of being culled than cows without claw lesions, irrespective of trimming frequency in the first lactation, is in line with findings by Manske et al. (2002b).

Breed

Our results showed an association between dairy cow breed and prevalence of claw lesions at first trimming and culling in the second lactation, irrespective of trimming frequency in the first lactation. In general, the results were in line with SNDHH data and with findings in previous Swedish studies that SR cows have better hoof health (fewer recorded claw lesions) than SH cows (Manske et al., 2002a; Bergsten et al., 2015). More specifically, our results showed that SH cows had a significantly higher probability of claw horn lesions, and SR cows had a significantly higher probability of mild infectious lesions and other lesions. Holzhauer et al. (2006) observed higher prevalence of digital dermatitis in herds with a higher percentage of Holstein-Friesian cows. Moreover, our results showed that mortality was higher in SH cows than SR cows, which was a logical finding because a higher proportion of SH cows had a high probability of suffering severe claw horn lesions in early second lactation. Similarly, Thomsen et al. (2004) found higher mortality for cows of the Danish Holstein breed compared with cows of the Danish Red breed. However, when we examined the association between breed and slaughter, we found that SR cows had higher OR of being sent to slaughter due to claw and leg disor-

ders or for other reasons than SH cows. This was probably because a higher proportion of SH cows could not be transported to slaughter because of more severe claw horn lesions. In Sweden, health aspects have long been included in the breeding index for dairy cattle, particularly the SR domestic breed. Breeding of SH animals has involved greater use of international Holstein bulls and health aspects have not been considered for as long as for the SR breed, which might explain the differences we observed between the breeds. Swedish Holstein cattle are in many aspects similar to other national Holstein breeds, so the results found in this study are probably applicable to Holstein cows in other parts of the world.

Hoof Health in Sweden

In Sweden, routine hoof trimming is most commonly performed twice a year (Växa, 2023a) and observed claw lesions are recorded digitally by hoof trimmers in a common Nordic software program, the Nordic Claw App (Nordic Cattle Genetic Evaluation, 2020). Therefore Swedish cows generally have good hoof health, and consequently a relatively low incidence of lameness (Manske et al., 2002a; Sjöström et al., 2018), which may explain why we did not see a stronger association between hoof trimming frequency and claw lesion prevalence. Other possible reasons for the good hoof health in Swedish dairy cattle are that Swedish legislation requires all dairy cows to be out on pasture in summer (Swedish Riksdag, 2019; Animal Welfare Act), generally good animal health (Växa, 2023a), and relatively high production level (Växa, 2023b). A welfare reimbursement called "Claw Coin" introduced in Sweden in 2016 to promote hoof trimming of dairy cows at least twice yearly with at least 3 mo in between has been shown to have had a positive effect, with fewer claw lesions in general on a national level (Åkerström et al., 2019). In Swedish dairy herds receiving "Claw Coin" reimbursement, all cows must be taken into the trimming chute and the foot must be examined from the sole side, even if no trimming is needed. This increases the probability of detecting and treating lesions before clinical lameness is evident, thereby improving general hoof health.

Methodological Considerations

In general, the precision/reliability of this retrospective cohort study based on over 30,000 observations can considered high, and the estimated probabilities of claw lesions and cullings due to hoof trimming can be considered accurate. When using a large dataset, small numerical differences can be significant without having relevance, but we consider our consistent finding that trimming 2 or 3 times reduced the odds of claw lesions or being culled by 10% to 41% is a biologically relevant reduction, and not just a statistically significant difference.

Concerning validity of the results for the target population (primiparous cows in large herds in Sweden), there may have been some selection bias due to the different inclusion criteria we applied. One of these was that the primiparous cows had to have a hoof trimming occasion within 90 d in their second lactation. This interval should have been suitable for revealing the preventive effect of trimming frequency in the first lactation because most claw disorders appear within this time frame (Bergsten and Frank, 1996; Leach et al., 1997; Green et al., 2002). A longer follow-up period could have increased the risk of other intervening and confounding factors, which we could not control for, influencing the results. If we had chosen a shorter period, the number of observations would have been reduced and we would have been less likely to find any differences. Several previous studies have chosen a similar time frame in lactation to assess the prevalence of claw lesions (Bergsten and Frank, 1996; Smilie et al., 1999; Wilhelm et al., 2015), so we believe that within 90 d was an appropriate choice. However, we cannot draw conclusions on whether hoof trimming frequency in the first lactation will have the same association with claw lesions at a later stage in the second lactation or in later lactations, and further studies are needed.

Another limitation of our study is that we only included primiparous cows and therefore cannot draw conclusions on whether the results apply to cows in higher parities. We made this choice to decrease potential bias from cows being affected by factors other than hoof trimming frequency because multiparous cows have experienced more lactations and are more likely to have suffered from claw lesions in a prior lactation. A limitation is that we cannot be sure that all primiparous cows were healthy before they were enrolled in the study because we did not have any information about claw lesions before first calving.

Despite these limitations, we believe that the external validity is sufficiently high to allow the results to be applied to primiparous cows in all Swedish dairy herds with 200 cows or more because our study population represented approximately two-thirds of all Swedish dairy herds with >200 cows and such herds will have similar housing and milking systems and management regimens. The results may not be equally applicable to smaller dairy herds, although we see no reason why this should be the case, as shown by Manske (2002). The decision was made to limit the study to primiparous cows in herds with >200 cows because they are more representative of a future dairy herd and in a global perspective (Barkema et al., 2015).

All hoof trimming recordings in this study were made by Swedish hoof trimmers. According to previous stud-

ies in Sweden (Manske et al., 2002a; F. Åkerström, C. Bergsten, and A. Nyman; Quality assured hoof health records; Växa, Stockholm, Sweden; unpublished data), the accuracy of hoof trimming records is higher for severe claw lesions, such as sole ulcer, digital dermatitis, and interdigital hyperplasia, than for milder claw lesions, such as heel horn erosion and mild dermatitis. A similar difference was seen by Capion et al. (2021) on investigating the accuracy of Danish hoof trimming records. Hence, the association between trimming frequency and the RRR of mild claw lesions at first trimming in the second lactation might be less valid than the association with more severe claw lesions.

CONCLUSIONS

Trimming frequency during the first lactation was associated with hoof health at first trimming in the second lactation, with 2 or 3 trimmings being most beneficial for hoof health and cow survival in the second lactation. Presence of claw lesions at first trimming in the second lactation increased the probability of a cow being culled, irrespective of trimming frequency in first lactation. There were breed differences in the probability of claw lesions at first trimming in the second lactation and the probability of culling during the second lactation. However, trimming 2 or 3 times may not be optimal on all farms, and the optimal hoof trimming frequency must be determined at the individual farm level, taking other farm-specific factors into consideration, because many different factors affect hoof health in a dairy herd.

NOTES

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Nonstandard abbreviations used: L1 model = multivariable mixed-effect logistic regression model for hoof health at first trimming; L2 model = multivariable mixed-effect logistic regression model for culling in the second lactation; ML1 model = multivariable multinomial logistic regression model for association between categories of claw lesions; ML2 model = multivariable multinomial logistic regression model for associations between reasons for culling; OR = odds ratio; RRR = relative risk ratio; SH = Swedish Holstein cattle; SNDHH = Swedish National Database on Hoof Health; SOMRS = Swedish Official Milk Recording Scheme; SR = Swedish Red cattle.

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