Effects of free-choice pasture access on lameness recovery and behavior of lame dairy cattle

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ABSTRACT

Lameness is a common condition in dairy cows. Free-choice access to pasture may benefit lame cows by providing a softer and more comfortable lying and standing surface; however, the effects of this system on lameness have not yet been explored. We evaluated whether a 7-wk period of free-choice pasture access would improve lameness recovery and affect the lying behavior of lame dairy cows. Lactating Holstein cows, all clinically lame upon enrollment and housed inside a freestall barn, were pseudo-randomly allocated to 1 of 2 treatments (balancing for gait score, parity, and previous lameness history): free-choice access to pasture (n = 27; pasture) or indoor housing only (n = 27; indoor). Cows were gait scored weekly by an observer blind to treatment, using a 5-point numerical rating system (NRS 1 = sound, NRS 5 = severely lame), and hoof inspections were performed by professional trimmers at the start and end of the 7-wk period. Lying behavior was assessed using accelerometers. Cows were categorized as either having a sound period (NRS <2 over 2 consecutive weeks) or remaining lame. Cows spent, on average, 14.8 ± 10.0% (mean ± SD) of their total time on pasture, with much of this time spent outside at night. Over the 7-wk period, 42% of cows had at least one sound period (pasture: 55.6%, indoor: 26.9%), but this was more likely for cows with pasture access (odds ratio = 4.1; 95% confidence interval: 1.1–14.6%). Pasture cows also spent more total weeks sound compared with indoor cows (2.0 ± 0.34 vs. 0.81 ± 0.35 wk). Cows with pasture access lay down for less overall time than indoor cows (13.9 ± 0.29 vs. 12.7 ± 0.28 h/d) and spent more time standing on pasture (74%) than when indoors (47%). These results suggest that lame dairy cows will use pasture when provided with free-choice access, primarily at night, and that access to pasture aids in lameness recovery. We encourage future research to investigate longer-term effects on the recovery of hoof lesions and reoccurrence of lameness cases.

Key words: animal welfare, dairy cows, gait, locomotion, outdoors

INTRODUCTION

Herd-level lameness prevalence rates in North America have been estimated at 13% to 55%, and rates for severe lameness at 2% to 8% (von Keyserlingk et al., 2012; Cook et al., 2016; King et al., 2016). This presents an animal welfare concern, as lameness is a painful condition (Whay et al., 1998) with notable effects on feeding, lying, and locomotory behavior (Proudfoot et al., 2010). Lameness is also costly for farmers due to declines in reproductive performance, milk production, and effects on culling, as reviewed by Huxley (2013). Methods of reducing lameness are required to address these concerns.

A growing body of evidence suggests that pasture access can benefit hoof health and lameness recovery (reviewed by Hund et al., 2019). Pasture access is associated with reduced lameness prevalence on farms (de Vries et al., 2015; Adams et al., 2017), and zero-grazing systems are reported to have higher lameness prevalence rates compared with grazing systems (Haskell et al., 2006; Richert et al., 2013). After housing cows on pasture for a full production cycle, Olmos et al. (2009) found that pasture-housed cows had lower and less severe lesions and reduced odds of presenting as clinically lame compared with cows housed indoors. Providing even a short period of access to an outdoor paddock improved claw conformation in tiestall cows (Loberg et al., 2004), and a 4-wk period on pasture improved gait scores compared with cows housed indoors (Hernandez-Mendo et al., 2007).

These improvements to lameness may be due to a more comfortable surface on pasture for standing and lying. Cows show a preference to lie down on pasture (Charlton et al., 2013), perhaps because pasture provides more open space and allows cows to adopt outstretched lying postures (Beaver et al., 2021). Concrete flooring and poorly bedded lying surfaces are also
recognized as risk factors for lameness when cows are kept indoors (Solano et al., 2015; Jewell et al., 2019). Concrete does not provide adequate traction to allow for natural locomotion (van der Tol et al., 2005); use of softer walking surfaces and less slippery flooring is associated with reduced lameness on farms (Chapinal et al., 2013; Solano et al., 2015), and cows show improved gait when walking on pasture compared with asphalt (Alsaaoed et al., 2017). These findings highlight the importance of providing adequate lying and standing surfaces to mitigate lameness development and for lameness recovery.

Most work to date has compared cows kept indoors with those kept on pasture, yet little work has explored lameness when cows are provided free-choice access to pasture. In a free-choice system, pasture is managed for exercise and as an alternative resting area rather than for nutrition. Thus, this system provides an option for producers concerned about lack of pasture availability, grass quality, and negative effects of grazing on milk production (Smid et al., 2021) and allows cows to return indoors when motivated to do so (e.g., to feed and to avoid inclement weather; Legrand et al., 2009).

The primary objective of our study was to determine whether lame dairy cows, provided with free-choice pasture access for a 7-wk period, would show improved lameness recovery (as evaluated using gait scores) compared with cows kept indoors. Secondary objectives were to describe how lame dairy cattle use pasture when provided with free-choice access and to explore the effects of pasture access on the lying behavior of lame dairy cows.

**MATERIALS AND METHODS**

This study was conducted at the University of British Columbia’s Dairy Education and Research Centre (Agassiz, BC, Canada) between July 15 and November 17, 2020. All procedures were approved by the University of British Columbia Animal Care Committee (protocol no. A19-0299).

**Sample Size Calculation**

Power analysis was used to estimate the sample size necessary to detect a difference in lameness recovery (the primary outcome) between treatments at the end of the 7-wk study, based on the outcome of lame versus sound. We predicted 20% recovery in the indoor treatment and 60% recovery in the pasture treatment, based on a 40% expected difference according to Olmos et al. (2009) and Thomsen et al. (2019), who reported 20% recovery after a 3-wk period for cows housed in deep straw. We expected more cows to recover given our longer 7-wk treatment period. Based on these figures, we used a 2-sided sample size calculation for proportions to estimate a treatment group size of 23 animals (power = 80%, error rate = 5%). To account for the risk of some data loss (due to cow illness, equipment malfunction) we allocated 27 cows into each treatment.

**Animals and Treatments**

A total of 54 mid- to late-lactation Holstein cows were included in the study. Animals were blocked for gait score at enrollment and allocated into 1 of 2 treatments within block according to date of eligibility (by KJM), balanced for parity and DIM: free-choice access to pasture (pasture, n = 27) or housing inside a freestall barn (indoor, n = 27). The numbers of cows with previous histories of infectious and noninfectious lesions were balanced between treatments (pasture n = 12; indoor n = 12). Mean (± SD) parity was 3.4 ± 1.5 (pasture 3.3 ± 1.5; indoor 3.5 ± 1.6), BCS was 3.0 ± 0.26 (pasture 3.0 ± 0.25; indoor 3.0 ± 0.27), DIM was 172 ± 70 d (pasture 173 ± 72 d; indoor 171 ± 69 d), BW was 744 ± 76 kg (pasture 749 ± 80 kg; indoor 739 ± 73 kg), and estimated mature-equivalent 305-d milk yield was 14,037 ± 1,734 kg (pasture 13,844 ± 1,544 kg; indoor 14,231 ± 1,914 kg).

All cows had previous experience on pasture as growing heifers but were housed indoors continuously throughout their previous lactations. Some cows (n = 4) had been enrolled in previous studies investigating preference for pasture or an outdoor open pack (Smid et al., 2018, 2019, 2020). Each animal remained in the study for a minimum of 49 d in accordance with Lim et al. (2015), who report a lameness cure rate of 45 d for the majority (88%) of lameness cases.

**Housing, Management, and Diet**

**Housing.** Cows from both treatments were housed in a single experimental freestall pen (19.5 × 13.3 m; Figure 1) consisting of 36 lying stalls (2.4 × 1.2 m, Dutch-style partition spaced 1.2 m wide, neck rail positioned 1.4 m above stall; 1.7 m from inside of rear curb) bedded with approximately 30 cm of washed sand, replaced biweekly, and raked twice daily. Stalls were arranged in 3 rows of 8 lying stalls and 3 rows of 4 lying stalls. Pen and alleyway flooring was concrete; the alleyways were cleaned using an automatic scraper every 4 h, with concrete crossover alleyways manually scraped twice daily during milking. Stocking was maintained at 36 cows (1 cow per stall) throughout the study. The pen had a head-locking feed barrier (0.5 m center to center), containing 31 feeding space (0.86 spaces per cow).
All experimental cows were equipped with an SCR collar (Heatime, SCR Engineers) that provided the cows with access to the pasture (0.5 ha; lined with electric fencing) through an automatic selection gate (Lely Grazeway) located at the end of the experimental pen (Figure 1). The walkway from the barn to pasture was 19.5 × 4.3 m, lined with textured rubber mats and cleaned twice daily during milking. Pasture cows could return to the barn at any point by going through a one-way gate into the return alleyway (7.2 × 2.5 m) adjacent to the experimental pen, where cows could then return to the experimental pen through the second one-way gate (Figure 1). Indoor cows were permitted to enter the selection gate; however, they would be sorted into the return alleyway, leading back to the experimental pen.

The paddock grazing consisted of 40% orchard grass (*Dactylis glomerata L*.), 40% tall fescue (*Festuca arundinacea*), and 20% annual ryegrass (*Lolium multiflorum*) that was established in April 2015. To allow for regrowth, approximately one-third of the field was mowed and then harvested 3 wk into the experiment. As the pasture was intended to provide a softer outdoor surface for resting and exercise, the pasture area was not managed for achieving optimum forage quality. However, sward height was measured once weekly, consisting of 20 measures taken every 10 paces while walking the pasture in an S shape, using a ruler positioned...
vertical from ground level and measured at grass leaf top (looking horizontally across sward and estimating average height; O’Sullivan et al., 1987). Average sward height (± SD) was 30 ± 18 cm (range: 12–74 cm); sward height decreased from 74 cm to 13 cm over the course of the trial.

**Feeding and Milking Management.** All cows had ad libitum access to one self-filling water trough indoors and one outdoors. Cows were provided TMR feed indoors at approximately 0700 h and 1600 h. Feed push-up occurred at approximately 1100, 1800, and 2200 h. The diet consisted of 35.7% corn silage, 40.0% concentrate mash, 20.8% grass silage, and 2.1% straw, formulated to meet the requirements for a 659-kg Holstein producing 34 kg of milk per day, following NRC (2001).

Milking took place twice daily at approximately 0700 h and 1700 h in a double-12 parallel milking parlor; all cows, including those on pasture, were gently moved to the milking parlor during milking times.

**Experimental Design**

**Enrollment.** All lactating cows in the University of British Columbia herd (approx. 250 cows) were eligible for enrollment given that they met the following criteria: (a) gait scored as clinically lame over 2 consecutive weeks or one score of severely lame before the week of enrollment (Eriksson et al., 2020), (b) were >70 DIM at enrollment, and (c) were less than 180 d carrying calf. Lameness was defined using a 5-point numerical rating score (NRS; 1 = sound, 5 - severely lame), with a nonlame cow defined as NRS <2, clinically lame as NRS >3, and severely lame as NRS >4 (Flower and Weary, 2006). Cows were not eligible for enrollment if they were recorded in hoof trimming records as having received treatment for lameness by the hoof trimmer (e.g., having a block applied to the affected claw) within 5 wk before the date of enrollment into the study, were severely lame (NRS = 5), were actively being treated for health concerns, or had a BCS <2.

Eligible cows were enrolled into the experimental pen using staggered enrollment (i.e., new cows added weekly), with nonexperimental cows (i.e., cows that did not meet eligibility and were not used for data collection) included as fillers to maintain a constant stocking of 36 cows in the experimental pen. Within the pen, half the cows had outdoor access via the selection gate, and the other half did not have outdoor access. Initially, all 36 cows were nonexperimental filler cows, half allocated to the indoor and half to the pasture treatment. Experimental cows were enrolled and moved into the experimental pen weekly (mean ± SD of 4.5 ± 2.0 cow/wk), replacing nonexperimental cows and later replacing experimental cows that had completed their 49-d study period (cows were only removed from the pen once a new cow was enrolled and entered the pen).

**Training for the Selection Gate.** Cows were assigned to treatment before enrollment and training. The day after enrollment, pasture cows were trained to use the selection gate and the one-way gates over a period of 7 d (4 ± 2 d), with twice-daily training following a.m. (~1000 h) and p.m. (~1800 h) milking in 1-h training sessions (approx. 5–10 min/cow). Indoor cows were not trained; hence, trainers were not blind to treatment. However, indoor cows were permitted to go through the selection gate but were then sorted in such a way that they remained indoors (Figure 1).

Cows were trained in 2 phases. In the first phase, cows were guided (using grain or an experienced animal) through the selection gate to the indoor alleyway and the one-way gates. Cows that had gone through the gate without this first training (observed from video recordings) went directly into the second phase of training (n = 4). In the case where cows failed to go through the selection gate (n = 7) or were deemed untrainable (n = 1) within the first 2 d of training (or 4 training sessions), they were exchanged with a cow initially enrolled in the indoor treatment. For the second phase and remaining days of the training week (3 ± 2 d), cows were moved through the selection gate and sorted to pasture. During this week, cows were moved to pasture following a.m. and p.m. milkings, to facilitate pasture use. Cows reached the second training criteria when they went to pasture and returned indoors (as observed from video) without the experimenter present. To be eligible for continuation in the pasture treatment, the cow had to have met this second training criterion within 7 d of enrollment; all enrolled pasture cows met this criterion.

**Lameness and Other Health Measures**

**Gait Scoring.** As part of a larger and ongoing longitudinal study at the University of British Columbia, all experimental cows were gait scored once weekly. Gait scoring for animals enrolled in the current study (NRS 1–5; Flower and Weary, 2006) was performed by one experienced observer who was blind to treatment. Gait was assessed when cows left the milking parlor and walked along a straight concrete alleyway (12 × 1 m) with a slight downhill slope. The observer was initially trained using prerecorded videos of 37 cows walking in a straight line, followed by live gait scoring. Intraobserver reliability was evaluated using video scoring; the kappa values showed sufficient to excellent
agreement according to Cohen (1968; linear weighting $\kappa_w = 0.69$, 95% CI: 0.46–0.92; quadratic weighting $\kappa_w = 0.63$, 95% CI: 0.90–0.96). One cow became very lame (NRS = 5) during the study; she was removed from the experimental pen and kept on a straw bedded pack for treatment by the farm manager.

**Hoof Management and Health.** Hooves were inspected by a professional trimmer (blind to treatment) twice during the study period: once at enrollment (d 6 ± 6 following enrollment) and once at the end of the study period (d 55 ± 7 following enrollment) to account for delayed visibility of lesions on the hoof (i.e., lesions that may take longer to present on the sole surface following disease initiation). Final hoof inspections were absent for 3 cows, as they were culled immediately following the completion of the study (n = 3), and for 2 cows during the enrollment period. Hoof trimming was recorded using Hoof Supervision Software (KS Consulting Inc.) by 3 professional trimmers (AR-PE Hoof Trimming Ltd., Abbotsford, BC, Canada). Lesion scoring and severity were both based on the Alberta Hoof Lesion Guide (Alberta Dairy Hoof Health Project, 2014) with lesion severity scored on a scale from 1 to 3 and digital dermatitis scored from M0 to M4.1 (as described by Berry et al., 2012).

Cows were retrospectively categorized into 4 different lesion categories based on trimming records: (1) noninfections (sole ulcers and hemorrhages, white line lesions, toe and periole ulcer, thin sole, interdigital hyperplasia, vertical, horizontal, and axial fissures), (2) infectious (interdigital and digital dermatitis, heel horn erosion, foot root), (3) both (both noninfectious and infectious), and (4) no lesion present. For cows affected by multiple lesions across different trimmings before and after enrollment, or over multiple hooves, the most severe lesion was considered. Hoof records at the farm, dating from 1 yr before the start of the trial, were used to retrospectively categorize cows as having or not having previous lesion history (i.e., at least one noninfectious or infections lesion, as previously defined). Lameness treatments at hoof inspections were at the discretion of the trimmer and farm manager, who were both blind to treatment, and followed standard farm protocol (UBC Dairy Education and Research Centre, 2020). All trimming treatments (e.g., if a block was applied) and corrective trimming done on cows was collected from hoof trimming records.

**Other Health Measures.** Body condition score was assessed by one experienced observer, on a scale from 1 to 5 (1 = thin; 5 = obese) according to Edmonson et al. (1989), using increments of 0.25, both at enrollment and weekly thereafter. Body weight (kg) at enrollment was an average of 2 measurements collected over the 2 d following enrollment, and 1 measure was collected after 49 d in the experiment for each cow. Hock (tarsal joint, excluding the point of the hock) and knee lesions (carpal joint) were assessed according to Gibbons et al. (2012) on a scale of 0 to 3 (0 = no swelling, no lesions or broken skin, no hair loss; 3 = major swelling, may have lesions or broken skin, hair loss) by one experienced observer who was blind to treatment. Both hocks and knees were assessed weekly during milking in the parlor at approximately 1700 h. Lesions ≥2 were considered injured, and the highest score of the 2 limbs was taken (Solano et al., 2015).

**Behavioral Measures**

Lying time was measures using electronic data loggers (HOBO Pendant G Acceleration Data Logger, Onset Computer Corporation). Loggers were attached to the hind leg of the animal with foam padding and veterinary wrap (CoFlex, Andover Healthcare) on the day of enrollment and programmed to record posture at 1-min intervals. Every 22 d, a new logger was added in the parlor during p.m. milking, and the old logger was removed for data downloading. Cow posture (lying and standing) was determined using a modified version of the UBC Animal Welfare Program (2013) algorithm, with the cutoff value validated by Ledgerwood et al. (2010) to determine the total lying time per day, number of lying bouts per day, and mean duration of lying bouts per day.

Whether the pasture cows went outdoors was determined from the electronic selection gate, which automatically recorded the time of day each cow visited the pasture. The time each cow returned to the main barn was determined using video cameras that were continuously recorded and stored using GeoVision 1480 digital recorder (USA Vision System). Four Dome cameras (WV-CW504SP, Panasonic USA) were positioned 8 m above the indoor barn and 6 m above the selection gate, and 3 Panasonic cameras (Panasonic WVCP-470, Panasonic Corporation of North America) were positioned 7 m above the feed bunk. Red lights were positioned above the experimental pen for vision during the nighttime. All animals were marked with symbols using hair dye for identification from video. A cow was considered to have returned to the barn when she passed through the first one-way gate (shoulder through the gate) into the barn (Figure 1). Time spent in the alleyway was considered indoors.

**Climatic Measures**

Climatic conditions (wind speed, air temperature, relative humidity, and rainfall) were collected from a weather station (Agriculture Canada, Agassiz, BC)
positioned approx. 400 m from the experimental barn. A temperature-humidity index (THI) was calculated as $\text{THI} = (1.8 \, T + 32) - [(0.55 - 0.0055 \, RH)(1.8 \, T - 26)]$, with $T =$ air temperature ($^\circ\text{C}$) and $RH =$ relative humidity ($\%$; Ravagnolo et al., 2000). Mean ($\pm \text{SD}$) daily temperature was 15.0 ± 5.8°C (range: 2.4–26.3°C), daily wind speed 5.7 ± 3.4 km/h (range: 2.0–23.0 km/h), and daily precipitation (present on 42% of experimental days) was 0.2 ± 0.4 mm (range: 0–1.9 mm). Average daily THI was 58.2 ± 9.3 (range: 36.1–74.3). Daily climatic conditions varied between the daytime (0700 to 1630 h) and nighttime periods (1630 to 0700 h; Table 1)

### Statistical Analysis

Statistical analysis was performed with SAS version 9.4 (SAS Institute Inc.) using cow as the experiment unit. All data were structured at the level of the experimental week, relative to enrollment for each cow. One cow was excluded from the analysis due to severe lameness (NRS = 5; indoor); no other adverse effects were identified. A total of 26 indoor cows (24 multiparous, 2 primiparous) and 27 pasture cows (24 multiparous, 3 primiparous) were used in the final analysis. Two days of data were removed due to malfunction of the electronic selection gate, and a third day was removed due to cows being mistakenly restrained in headlocks for an extended period.

Cow-level and environmental variables identified as risk factors were included in models. Cow-level variables offered into models included parity (categorical: primiparous or multiparous), DIM (at enrollment, continuous), BCS (at enrollment, categorical: underconditioned <3, good condition 3.0–3.5, overconditioned >3.5), previous lesion history (categorical: at least 1 previous lesion incident reported, or none), BW (at enrollment, continuous), estimated mature-equivalent 305-d milk yield (at enrollment, continuous), whether treated during hoof inspections (categorical: yes, no), and lesion type (categorical: infectious, noninfectious, both, no lesion). Outdoor environmental conditions included THI (mean daily THI, continuous), wind speed (mean daily km/h, continuous), and precipitation (mean daily precipitation, continuous).

### Pasture Use

Time spent on pasture was summarized as total hours spent outdoors per day, averaged over the experimental period for each cow, and reported descriptively as the average percentage of time spent on pasture per day across all pasture cows. The cow’s first experimental week was excluded from analysis, to allow her time to learn to use the electronic sort gate. As cows show a preference for pasture depending on time of day (Charlton et al., 2013), we also descriptively reported percentage of time spent on pasture, separately by day (after morning milking: 0700 to 1630 h) and night (after evening milking: 1630 to 0700 h) periods. These periods follow Legrand et al. (2009), who reported that cows most often used pasture after the evening milking. The effects of lameness status (as subsequently defined) on pasture use were investigated using a mixed model, with total time spent on pasture per week as the outcome measure. Fixed effects included weekly lameness status (binary: sound, lame) and cow week. Repeated measures with cow as subject were modeled using an autoregressive covariance structure, with degrees of freedom calculated using Satterthwaite’s approximation. Environmental factors (weekly means) and cow-level factors were initially included as fixed effects, as they are reported to influence time spent on pasture (Legrand et al., 2009; Charlton et al., 2013). Stepwise elimination was used to reduce the model, only retaining variables and biologically plausible interactions with $P \leq 0.05$; no interactions were retained in the final model. Model fit was assessed through visual assessment of normality and homoscedasticity of residuals. Results are presented as least squares means and standard errors.

### Lameness Recovery Indoors and on Pasture

Two outcome measures were analyzed to explore the effect of treatment on lameness recovery. For our primary objective, the outcome measure used was overall lameness status. Cows were retrospectively categorized as either having a sound period (i.e., having had 2 consecutive weeks of NRS ≤2; Eriksson et al., 2020) or remaining lame (i.e., did not have 2 consecutive weeks

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### Table 1

Environmental conditions (mean ± SD; range) during the study period (July–November 2020; Agassiz, BC, Canada), shown separately for the daytime (0700–1630 h) and nighttime (1630–0700 h) periods

<table>
<thead>
<tr>
<th>Time period</th>
<th>Temperature (°C)</th>
<th>Precipitation (mm)</th>
<th>Wind speed (km/h)</th>
<th>Temperature-humidity index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daytime</td>
<td>16.3 ± 6.8</td>
<td>0.8 ± 0.5</td>
<td>6.7 ± 3.4</td>
<td>60.0 ± 10.6</td>
</tr>
<tr>
<td></td>
<td>(2.4–29.2)</td>
<td>(0–3.1)</td>
<td>(1.3–23.0)</td>
<td>(37.4–77.3)</td>
</tr>
<tr>
<td>Nighttime</td>
<td>13.4 ± 5.4</td>
<td>0.2 ± 0.4</td>
<td>5.0 ± 3.4</td>
<td>55.7 ± 9.2</td>
</tr>
<tr>
<td></td>
<td>(2.0–24.9)</td>
<td>(0–2.2)</td>
<td>(1.5–21.3)</td>
<td>(34.0–73.1)</td>
</tr>
</tbody>
</table>

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of NRS $\leq 2$). Cows that become sound do not always remain sound, and gait scores fluctuate (see Eriksson et al., 2020), so the total number of weeks spent sound was used as an additional outcome measure in a second model. For this second model, a weekly lameness status of sound or lame was assigned to each cow, yielding the total number of weeks spent sound throughout the trial per cow. A cow had to have scored NRS $\leq 2$ in the subsequent week for the week to be categorized as sound (i.e., if a cow scored NRS $\leq 2$ for only 1 wk, then that week would not be categorized as sound).

For the first outcome, the effects of treatment on overall lameness status were explored using multivariate logistic regression, fitted with lameness status (binary: lame = 0, sound = 1) as the outcome and treatment as a fixed effect. For the second outcome, the effect of treatment on the total number of weeks spent sound was explored using a multivariate general linear model with the number of weeks sound as the outcome and treatment as a fixed effect. Cow-level variables (as previously outlined) identified as risk factors for lameness (Solano et al., 2015; Jewell et al., 2019) were screened in univariate models and variables $P \leq 0.05$. Two were retained (Dohoo et al., 2009) for further testing in the model. The final model was built using stepwise elimination, first removing variables with $P < 0.1$ and then only retaining variables with $P \leq 0.05$. All variables were tested for collinearity through variance inflation factor and collinearity diagnosis; no collinearity was found (variance inflation factor $< 2$ for all variables). All biologically plausible interactions were tested in the model and retained if $P \leq 0.05$. Previously excluded variables were checked as confounders if estimates changed by $>30\%$; if so, and if model fit was improved, then variables were assessed for retention in the final model. Model fit and outliers were assessed through visual assessment of normality and homoscedasticity of residuals. All means are presented as least squares means and standard errors.

Because assessing the effect of location (i.e., pasture vs. indoor) on lying behavior was not a primary aim, this was assessed descriptively. For pasture cows only, daily lying behavior was split according to cow location and then summarized by day and week separately for when cows were indoors or on pasture. Mean daily lying time (h/d), number of lying bouts (no./d), bout duration (min/bout), and proportion (%) of daily lying time relative to time spent on pasture versus indoors are reported.

**RESULTS**

**Pasture Use**

Cows provided with pasture access spent, on average (± SD), 14.8 ± 10.0% of their time outdoors (range: 0.0–36.9%). As expected, cows spent more time on pasture at night than during the day (1630 to 0700 h vs. 0700 to 1630 h; 22.9 ± 15.5% vs. 2.5 ± 3.0%, respectively). Weekly lameness status was not related to time spent outside on pasture ($F_{1,147} = 0.10$, $P = 0.75$): cows categorized as sound spent, on average, a total of 25.6 ± 3.9 h/wk on pasture compared with lame cows, which spent 24.5 ± 3.2 h/wk on pasture. Environmental conditions influenced time spent outside: for every 1-unit increase in THI, cows spent 0.8 ± 0.3 more hours per week on pasture ($F_{1,132} = 5.96$, $P = 0.02$), and for every 1-mm increase in precipitation, pasture use decreased by 1.5 ± 0.5 h/wk ($F_{1,102} = 7.15$, $P = 0.01$). No other cow-level or environmental variables were associated with pasture use.

**Descriptive Results: Hoof Lesions and Leg Health**

Many cows (43%) had noninfectious lesions, but some had infectious lesions (13%) or a combination of infec-
tions and noninfectious lesions (11%); the remaining cows (32%) had no visible lesions. Lesion type varied between treatments (Table 2); descriptively, more cows with pasture access presented with infectious lesions compared with cows housed indoors. Over the 7-wk study, 18.9% of cows had at least one occurrence of injured hocks (pasture: 22.2%; indoor: 15.4%), and 94.3% of cows had at least one occurrence of injured knees (pasture: 92.6%; indoor: 96.2%). At enrollment, 42.3% of cows had at least one occurrence of injured knees (pasture: 22.2%; indoor: 15.4%), and 94.3% of cows had at least one occurrence of infectious lesions (11.5%; indoor: 11.5%), and both wrapping and blocking together (pasture: 3.7%; indoor: 3.8%).

Lameness Recovery

Descriptive Results. Overall, 42% of cows had at least one sound period during the study (pasture: 55.6%; indoor: 29.6%). For cows that became sound, the number of weeks (± SD) from enrollment to first sound week was 2.2 ± 1.7 wk (pasture: 2.1 ± 1.5 wk; indoor 2.5 ± 2.2 wk), and the mean duration of each sound bout was 3.5 ± 1.5 wk (pasture: 3.6 ± 1.6 wk; indoor 3.0 ± 1.3 wk).

Overall Llameness Status. The multivariable analysis revealed an effect of treatment and lesion history on lameness status (Table 3). Cows with pasture access had increased odds of having a sound event relative to cows housed only indoors (P = 0.03), and cows with no previous history of a lesion had increased odds of having a sound event compared with those with previous lesion history (P = 0.01). Other cow-level and hoof health factors were not associated with the odds of a sound event.

Total Number of Weeks Sound. Multivariable analysis revealed an effect of treatment and lesion history on the number of weeks cows were sound. Cows with pasture access spent more weeks sound than cows housed only indoors (pasture: 2.0 ± 0.34 wk; indoor: 0.81 ± 0.35 wk, P = 0.02; Figure 2), and cows with no previous lesion history spent more weeks sound than cows with previous lesion history (no lesion history: 2.1 ± 0.34 wk; yes lesion history: 0.77 ± 0.35 wk, P = 0.01). No other cow-level or hoof health factors were associated with total weeks sound.

Lying Behavior. On average (± SD), cows with free-choice pasture access spent 53.0 ± 8.9% (range: 25–69%) of their time indoors lying down compared with 26.3 ± 17.1% (0 to 57%) of their time on pasture lying down. Descriptively, cows spent less time lying down and had fewer and shorter lying bouts when on pasture compared with indoors (Table 4).

Overall Lying Behavior by Treatment. Cows with pasture access spent about 1 h/d less time lying down than did cows kept indoors (13.9 ± 0.29 vs. 12.7 ± 0.28 h/d, F1, 50.7 = 9.48, P = 0.003; Figure 3) and tended to have fewer lying bouts per day when provided with pasture access than if housed only indoors (11.5 ± 0.52 vs. 10.3 ± 0.50 no./d, F1, 55.6 = 3.19, P =

Table 2. Number and percentage of cows affected by each type of hoof lesion, as identified during pre- and post-enrollment hoof trimming; results are shown separately for cows provided with free-choice pasture access (pasture: n = 27) and those housed only indoors (indoor: n = 26) over a 7-wk period

<table>
<thead>
<tr>
<th>Type of lesion</th>
<th>Pre-enrollment</th>
<th>Post-enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Indoor</td>
<td>Pasture</td>
</tr>
<tr>
<td>Infectious</td>
<td>2 (8)</td>
<td>7 (26)</td>
</tr>
<tr>
<td>Noninfectious</td>
<td>7 (27)</td>
<td>6 (22)</td>
</tr>
<tr>
<td>Both</td>
<td>2 (8)</td>
<td>2 (7)</td>
</tr>
<tr>
<td>No lesion visible</td>
<td>15 (58)</td>
<td>12 (44)</td>
</tr>
</tbody>
</table>

1Lesions identified during inspection and trimming by 3 professional hoof trimmers and based on the Alberta Hoof lesion guide (Alberta Dairy Hoof Health Project, 2014). Noninfectious lesions were classified as sole ulcers and hemorrhages; white line lesions; toe and periople ulcer; thin sole; interdigital hyperplasia; vertical, horizontal, and axial fissures; and corkscrew claw. Infectious lesions were classified as interdigital and digital dermatitis, heel horn erosion, and foot root. Both classified animals as having at least one case of infectious and noninfectious lesion. In cases where an animal had multiple lesions, the most severe lesion was considered as the primary lesion.

2Lesions at pre-enrollment were identified at the start of the study period; post-enrollment lesions were identified following the 7-wk experimental period.

Table 3. Cow-level variables associated with having a sound event1 in the final multivariable logistic regression model; results are shown for cows provided with free-choice pasture access (pasture: n = 27) or cows housed only indoors (indoor: n = 26) over a 7-wk period

<table>
<thead>
<tr>
<th>Variable</th>
<th>Category</th>
<th>Coefficient</th>
<th>SE</th>
<th>OR</th>
<th>95% CI</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>Pasture</td>
<td>1.40</td>
<td>0.65</td>
<td>4.1</td>
<td>1.1–14.6</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Indoor</td>
<td>Referent</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Previous lesion history2</td>
<td>No</td>
<td>0.87</td>
<td>0.33</td>
<td>5.7</td>
<td>1.6–20.4</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Referent</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

1Lameness was assessed by weekly gait scoring using a numerical rating system (NRS: 1 = sound, 5 = severely lame). Sound event defined as NRS ≤ 2 over 2 consecutive weeks (Eriksson et al., 2020). OR = odds ratio.

2Any incident of a previous infectious or noninfectious lesion, as collected from farm trimming records.
variables, DIM (F1, 56.3 = 6.15, P = 0.02) and mature-equivalent 305-d milk yield (F1, 50.9 = 4.60, P = 0.04) were found to increase and decrease daily lying time, respectively. No other cow-level factors were found to be associated with lying behavior.

**DISCUSSION**

**Pasture Use and Lying Behavior**

Cows in the current study spent about 15% of their time on pasture, with greatest time spent outside at night (3% daytime vs. 23% nighttime) and with increasing THI. Cows may have preferred a cooler outdoor environment during the night compared with that inside the barn (Shock et al., 2016). Most previous studies assessing free-choice pasture access in lactating dairy cows reported greater time spent outdoors, from 54% to 90% of time (Legrand et al., 2009; Smid et al., 2019). We speculate that the results of the current study may be due to lame cows spending less time walking (Walker et al., 2008), likely due to associated pain. The sand bedding provided in current study may have also offered a comfortable lying location indoors, compared with other studies that report higher usage of pasture but provided cows with only mattresses indoors (e.g., Charlton et al., 2013). Furthermore, our experimental design (whereby half of the group always remained indoors) may have reduced the number of cows outdoors due to group synchronization (Stoye et al., 2012). It is important to note that our study was not designed as a preference test; further research is encouraged, to differentiate between the effects of lameness status and social and environmental factors on pasture preference.

We found that cows with free-choice pasture access lay down for less time (12 vs. 13 h/d) and tended to have fewer lying bouts (10 vs. 12 bouts/d). These results are within the range of previously reported lying times in freestall systems (10–12 h/d; Gomez and Cook, 2010; Ito et al., 2010) and are in line with studies suggesting that cows kept on pasture lie down for less time (8–10 h/d; Thompson et al., 2019). However, cows in our study lay down more indoors compared with

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**Table 4.** Descriptive statistics for mean ± SD (range) daily lying time, daily number of lying bouts, and daily lying bout duration; results are shown separately for cows provided with free-choice pasture access (pasture: n = 27) or cows housed only indoors (indoor: n = 26) over a 7-wk period

<table>
<thead>
<tr>
<th>Lying behavior</th>
<th>Indoor</th>
<th>Pasture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lying time (h/d)</td>
<td>11.0 ± 2.4 (5.9–16.0)</td>
<td>1.8 ± 1.5 (0.0–4.9)</td>
</tr>
<tr>
<td>Number of lying bouts (no./d)</td>
<td>8.6 ± 2.8 (4.0–18.0)</td>
<td>1.9 ± 1.4 (0.0–5.0)</td>
</tr>
<tr>
<td>Lying bout duration (min/bout)</td>
<td>88.4 ± 17.6 (51.0–137.9)</td>
<td>47.1 ± 26.1 (0.0–84.8)</td>
</tr>
</tbody>
</table>
when on pasture (53% of time indoors, 36% of time on pasture), contrasting with previous studies reporting cows to use pasture primarily for lying (Legrand et al., 2009; Charlton et al., 2013), suggesting the need for further work on the behavior of cows within free-choice pasture systems.

Lameness Recovery

Cows with free-choice pasture access spent less time lame and had increased odds of having a sound period compared with cows housed indoors. To our knowledge, this study is the first to report effects of free-choice pasture access on lameness recovery, but our results are consistent with a larger body of literature showing protective effects of pasture on lameness (e.g., Haskell et al., 2006; de Vries et al., 2015) and hoof health (e.g., Olmos et al., 2009). Pasture may have benefited lame cows by providing a softer surface, reducing the mechanical strain on the claw (Ouweltjes et al., 2011), increasing activity and blood flow to the claw for improved hoof and leg health (see discussion by Shepley and Vasseur, 2021), or reducing joint stiffness and improving overall joint motion (also see Hernandez-Mendo et al., 2007). Our study was not powered to investigate differences in hoof health, and hoof overgrowth was unlikely an issue, as cows were trimmed before enrollment, but previous studies have found that increased exercise improves hoof health, conformation (Loberg et al., 2004), and wear (Black et al., 2017). We encourage future research on these factors when free-choice pasture access is provided.

Cows that became sound may have spent more time outdoors when lame, perhaps due to a preference for the softer surface (Telezhenko et al., 2007), or an initial recovery may have promoted greater use of pasture due to reduced pain when walking; we cannot disentangle these effects in the current study. Furthermore, dairy cows are highly motivated to access pasture (von Keyserlingk et al., 2017) and may use pasture regardless of their lameness status. The current study may have failed to detect an effect of lameness status on pasture use, as we simply had few cows recover (58% remained lame), or because weekly gait scoring was not sufficiently sensitive to detect short bouts when cows were lame or sound. We encourage future work to monitor lameness status daily; we expect that the development of automatic lameness detection systems will provide better longitudinal data on the development and recovery of lameness cases.

Another limitation of our study was that lesions may have presented outside of the 7-wk inspection period, and we did not have the power to detect an effect of lesion type on lameness status. We expect that pasture access is more beneficial for cows with noninfectious compared with infectious lesions, as a softer surface for standing and resting, such as pasture, reduces strain on the claw (see Cook and Nordlund, 2009). However, under some conditions (e.g., if cows are required to walk through slurry or mud), pasture may increase the risk of certain infectious lesions, as reported by Solano et al. (2016b), who found cows on farms with exercise lots to have a higher prevalence of infectious lesions, perhaps due to wet and unhygienic surfaces. Furthermore, recovery time can differ depending on lesion type and severity (Huxley et al., 2014), a factor our study was not powered to assess. We encourage future research with larger sample sizes to investigate the role of free-choice pasture access on the recovery of specific hoof lesions.
Our study excluded “untrainable” cows from the pasture treatment, but no assessment of trainability or similar exclusion was applied to the indoor treatment. We do not have any reason to expect that trainability relates to lameness recovery, but readers should be aware of the confound. Finally, we found that not all cows use pasture similarly; individual preferences and motivations to be on pasture could have differing effects on lameness recovery. Providing pasture access during the night, to cows with previous experience, and with a short distance from the barn on a soft track surface may improve pasture use for lame dairy cattle. Continued on-farm research is also required, to better understand the effect of free-choice pasture systems on hoof health, lameness development, and recovery under different management and farm conditions.

CONCLUSIONS

Lame dairy cattle provided with a 7-wk period of free-choice pasture access were more likely to recover (i.e., to spend at least 2 consecutive weeks sound), and to spend more overall time sound, compared with cows kept indoors only. Cows used pasture primarily at night and spent most of their time on pasture walking or standing. More research is required to understand the longer-term effects of free-choice pasture access on the development of and recovery from lameness and on hoof and leg lesions.

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REFERENCES


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