Welfare in Dairy Cattle: Epidemiologic Approaches for Detection and Treatment of Lameness

by

Janet Helena Higginson Cutler

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Lameness in dairy cattle is one of the primary welfare concerns in the industry. The objectives of this thesis were to investigate the use of an accelerometer for early detection of lameness, to describe the etiology and temporal changes in hoof lesion prevalence, and to assess treatments for two types of lesions that commonly cause lameness. The Pedometer Plus™ was first validated for lying behaviour and activity measurements and determined to accurately collect data on lying and on leg movement in the cow. This system was then used to determine if changes in activity and lying behaviour could be observed during presence of hoof lesions or during lameness. Lame cows decreased their activity and increased daily lying duration compared to non-lame cows. Activity, lying duration, and lying bouts were found to be altered with particular hoof lesions compared to cows without painful lesions. Lying duration was increased in periods where cows had painful lesions compared to periods when cows had no painful lesions present on their hooves. Digital dermatitis and sole ulcers were the most commonly observed painful hoof lesions. Presence of these lesions increased the odds of a cow having that lesion later in life. Additionally, the odds of developing a sole ulcer were higher in cows that had previously had hemorrhages. A randomized clinical trial compared the use of a tetracycline hydrochloride paste to use of a bandage or no
treatment in digital dermatitis lesions. Lesion healing rates did not differ between the two treatments, while both were more effective than the negative control. An algometer was used to quantify pain at the lesion site and to verify decreasing pain responses between active, healing and healed lesions. The effect of therapeutic hoof block application on sound dairy cows was assessed, with lactating dairy cows randomly assigned to receive a block (n=10) or no treatment (n=10). Block application had little effect on the activity, lying behaviour and production of sound lactating dairy cattle. Application was associated with increased gait abnormality. These results provide potential dairy cattle welfare improvement through early identification and treatment of hoof lesions and lameness.
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Chapter 1. Introduction and Literature Review

Introduction

Pain in the limb or hoof of the dairy cow may be manifested as lameness. Lameness has been described as occurring when an animal fails to travel in a regular and sound manner on all four feet with a normal back posture and head carriage (Sprecher et al., 1997). Lameness is regarded as one of the most serious welfare concerns in the dairy industry today. The primary reason for this concern is that lameness is indicative of pain. Additionally, the prevalence of lameness is very high in the dairy industry, causing large numbers of animals to be in pain. Lameness is also an important issue in the dairy industry due to its economic impact. Recent estimates using US data, including milk loss, cost of treatment and delayed conception, show an average cost per case of $216.07US for sole ulcers, and $132.96US for digital dermatitis (Cha et al., 2010), two common causes of lameness.

Lameness can be caused by many different problems in the hoof and the leg; however the majority of cases are due to lesions or abnormalities on the hoof (Murray et al., 1996). Many types of hoof lesions can be found in dairy cattle. Descriptions of common lesions can be found in Table 1.1.

World-wide prevalence estimates of both hoof lesions and lameness (based on various scales of sound to non-weight bearing) are shown in Table 1.2. The prevalence of lesions is much higher than that of lameness, demonstrating that perhaps not all lesions are painful to the cow. Some injuries such as sole ulcers reflect damage which occurred
months before, and it is unknown if these lesions that have become visible are currently painful and/or at what time point in the past they were painful (Flower and Weary, 2006). The two most commonly found lesions causing lameness are sole ulcers and digital dermatitis.

Many risk factors contribute to the prevalence of lameness. Herd-level risk factors include housing in free-stalls, concrete flooring, having a hoof-trimming stall, presence of a footbath and various nutrition supplements (Sogstad et al., 2005; Somers et al., 2003; Amory et al., 2006). Most housing systems require cows to stand on concrete, which is believed to be important in the development of various types of lesions and disease that can cause lameness (Wells et al., 1999; Somers et al., 2003; 2005). A cow-friendly environment, which allows animals to rest adequately (Dippel et al., 2009), is also important in the prevention of lameness. Due to social or management factors, some animals may not access resting or feeding sites as often as others, which could potentially predispose them to hoof problems. In addition, factors such as season, biosecurity, housing status, claw trimming, lactation number and milk production, as well as age at first calving can impact lameness prevalence (Rutherford et al., 2009).

Lameness is also considered a significant welfare concern due to lack of detection in the industry. Producers appear to have trouble identifying lame cows, with their estimates of lameness much lower than that observed by researchers estimating prevalence. In several studies, investigators have estimated prevalence of lameness, through locomotion scoring of cows, to be 2.5 (Wells et al., 1993), 3.1 (Espejo et al., 2006) and 3.86 (Whay et al., 2003) times higher than that of farm staff. It has been suggested that this could be due to several factors, including the use of different criteria,
lack of observation of the cows or reluctance to admit a lameness problem exists (Wells et al., 1993; Whay, 2002).

**Pain**

Pain has been defined as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage” (Lindblom et al., 1986). Pain functions to signal that potential tissue damage could occur, therefore protecting the recipient from further injury (Anderson and Muir, 2005).

Two types of pain are generally described, physiologic or nociceptive pain, and pathologic pain. The elements of nociceptive pain are shown in Figure 1.1. The process of pain perception begins with a noxious stimulus, which is transduced through the firing of nociceptors. The action potentials from these nociceptors are transmitted to the spinal cord and received in the superficial layers of the dorsal horn. The action potentials are then modified by local neurons and projected to the brain where perception of the noxious stimulus occurs (Anderson and Muir, 2005).

Pathologic pain is produced when tissue or nerve damage occurs that leads to chronic pain (Anderson & Muir, 2005). This occurs due to an increase in the excitability of the neurons, allowing them to become more sensitive to stimuli at the periphery or more sensitive to sensory inputs at the level of the central nervous system.

In nociceptive and pathologic pain, both allodynia and hyperalgesia may be observed. Allodynia occurs when a painful response is elicited by a stimulus that does not normally cause pain. Hyperalgesia is an increased sensitivity to pain. These responses
can be more pronounced when an animal is already experiencing pain, such as in the case of lameness.

**Pain and Lameness**

Animals that are in pain normally show changes from their normal behaviour, specifically alterations in activity (either an increase or decrease), posture, gait and appetite (Anil et al., 2002). Changes in gait are believed to be due to pain that is associated with injuries on the hooves and legs (Whay et al., 1998). To demonstrate that lesions in the hoof were painful, Dyer and colleagues (2007) used hoof testers equipped with a pressure gauge to measure the amount of pressure tolerated by dairy cows before eliciting a limb withdrawal response. As lameness increased in the cows, the amount of pressure tolerated with the hoof tester decreased. The animals that had a normal gait demonstrated less response to pressure than those that were walking abnormally.

Research in pain due to infectious lesions has focused on the response of the cow with application of contact to the lesion. Researchers subjectively scored pain associated with digital dermatitis using a three-point scale based on reaction to water sprayed at the lesion (Hernandez et al., 1999). Pain scores were lower in cattle treated with oxytetracycline or a commercial copper formulation. An algometer has also been used to measure pain associated with diseases of the integument, such as digital dermatitis (Dyer et al., 2007), to determine the amount of force that must be applied prior to a withdrawal response. These scores were incorporated into a pain index score for the cow.

Hyperalgesia may occur when an animal is in pain; therefore it is hypothesized that if lame cows are in pain that they may show increased sensitivity to painful stimuli.
Whay and colleagues (1998) measured mechanical nociceptive thresholds in lame and healthy dairy cattle using a blunt pin that was pneumatically actuated at a constant rate, pressed against the metatarsus. There was a significant difference in the amount of force tolerated by lame and healthy cows, with the lame cows tolerating less pressure than sound cows on the day of locomotion scoring. Animals were tested 28 days later, while lame cows would tolerate increased pressure prior to observation of a leg stomp or lift, they still responded to less pressure than the sound cows. This effect was dependent on the type of lesion observed, with cows with sole ulcers and white line disease reacting to decreased pressure while those with digital dermatitis having a similar response as sound cattle.

**Perception of Lameness Pain**

Several opinion polls have begun to examine the perception of stakeholders involved in the dairy industry in relation to lameness. UK researchers polled dairy farmers to determine their opinions on lameness and their motivation for lameness reduction (Leach et al., 2010). When asked their opinion on why lameness was a problem in the dairy industry, 94% of farmers responded that pain and suffering experienced by the cow was either ‘very’ or ‘extremely’ important. Eighty-one percent of farmers responded that they felt sorry for lame cows, which motivated their action to treat lameness. These numbers are quite high, and may be biased due to the selection of farmers by institutions involved in an animal welfare project.

Cattle practitioners were surveyed to determine their perceptions of the severity of pain associated with different procedures and conditions in dairy cattle (Huxley and
Respondents reported that both treatment of sole ulcers and debriding digital dermatitis lesions were of a moderate pain level, with median scores of 6 out of 10. When asked about analgesic use in relation to treatment of lameness, 43.2% and 43.6% of respondents did not use any form of analgesic during treatment of sole ulcers and debriding of digital dermatitis lesions, respectively. An earlier survey at a cattle practitioner meeting found that sole ulcers were rated at 6.8 on a pain scale of 1 to 10 (Fitzpatrick et al., 2002). Canadian veterinarians surveyed rated acute lameness as 6.4 on a scale of 1 to 10 while chronic lameness was rated 5.2 (Hewson et al., 2007). Respondents varied in their use of analgesics for cases of both chronic and acute lameness, ranging from treating 0 to 100% of cows presenting with those conditions.

Together, these results demonstrate that those involved in the dairy industry believe that lameness is a significant problem and causes pain in these animals. While veterinarians appear to believe lameness is painful, a lack of analgesic use is apparent.

**Methods of lameness evaluation**

Pain assessment often involves measurements of general body functioning, physiological measures, or measures of vocalizations (Weary et al., 2006). These measurements are typically used, however, for short, acute painful procedures and may not be as good as indicators of chronic, or pain that persists beyond the expected healing time for an injury (Molony and Kent, 1997).

Behavioural responses to avoid recurrence of pain, protect a painful part of the body, minimize pain or assist in healing, and those that elicit assistance or prevent further pain infliction are observed when an animal is in pain (Molony and Kent, 1997).
Lameness identification and evaluation typically uses subjective methods to assess changes. However, recent advances in technology have provided opportunities for research involving more objective methods for identification.

**Subjective methods**

The most common method of lameness evaluation is through the use of locomotion or gait scoring. This process involves observing the cow walking and assigning a score based on defined parameters associated with movement. The most commonly used scoring systems are based on a 1 to 5 scale, with a score of 1 indicating a sound cow and 5 a very lame or incapacitated cow (Manson and Leaver, 1988; Sprecher et al., 1997; Flower and Weary, 2006). Descriptions of the cut-points for classifications in three of the most commonly used scales can be found in Table 1.3. The most recent scoring system contains the most detailed definitions of gait characteristics required for placement into different categories, while previous systems were more vague.

When using a scoring system, the validity must first be examined to ensure the response is accurately measuring the factor of interest. One method to validate a response measure of pain is to examine the measure during the condition and when it is absent, as well as in the presence of an analgesic known to be effective at treating the pain and without the analgesic (Weary et al., 2006). The Flower and Weary (2006) locomotion scoring system was first validated by comparing the locomotion of cattle with and without sole ulcers. Cows with sole ulcers had a mean score of $4.0 \pm 0.13$ while cows with no visible lesions had mean scores of $3.1 \pm 0.08$. Following this, validation with analgesics was then completed through the use of scoring prior to, and then again
following, an injection of local anesthetic (Rushen et al., 2007) to the limb believed to be causing lameness. Mean locomotion scores prior to injection were 3.87 ± 0.16 and decreased to 3.57 ± 0.16 ten to fifteen minutes after injection in lame cows. While a small decrease was observed, this is not very biologically significant, since they would still be considered lame. It is unknown if the observers were blind to treatment during locomotion scoring, which is very important due to the subjective nature of locomotion scoring. Full validation for the other two scoring systems outlined in Table 1.3 has not been published.

In addition to validity, the reliability of locomotion scoring must also be considered. Reliability has been defined as the repeatability and consistency of a measurement (Martin and Bateson, 1993). In subjective scoring methods, both inter- and intra-observer reliability must be examined to help to ensure accuracy of measurement. Inter-observer reliability measures the consistency between observers while intra-observer reliability measures the consistency of measurements made by a particular individual. Correlations in inter-observer reliability and intra-observer reliability are generally considered to be good if they are above 0.7 (Martin & Bateson, 1993). Reliability of observers while locomotion scoring increases with training and experience (March et al., 2007), which is expected since this method relies upon the skill of the observer to detect subtle changes in gait (Flower et al., 2005).

Values for both inter- and intra-observer reliability to locomotion scoring are not always above 0.7. Flower and Weary (2006) listed both values for the various parameters examined in their locomotion scoring system. Intra-observer reliability ranged from 0.35-0.9 and inter-observer reliability ranged from 0.38-0.83. Scores for intra-observer
and inter-observer reliability for the Manson & Leaver (1988) system were reported at 0.89 and 0.84, respectively. These high values are surprising considering the loose definitions provided, and no information on the number of observers or number of observations included in the calculations was provided.

Additionally, the type of flooring on which the animals are walking can impact their locomotion score. Softer, higher friction rubberized flooring has been shown to decrease the locomotion score slightly of sound cows and those with sole ulcers (Flower et al., 2007). Cows with sole ulcers had a mean locomotion score of 3.1± 0.1 on concrete and 2.9 ± 0.1 on a rubberized floor, while cows without ulcers had locomotion scores of 2.5 ± 0.1 on concrete and 2.4 ± 0.1 on the rubber flooring. Therefore, the surface on which cows are walking must be taken into consideration when interpreting locomotion score values.

Kinematic gait analysis, or analysis of the motion involved in gait, has also been proposed for the detection of lameness in cattle in a research setting. Flower and colleagues (2005) observed sound cows as well as those with sole injuries and ulcers from videotapes when cows had reflective markers affixed to their legs. They determined that the amount of time spent with weight on three limbs as opposed to two while walking rose dramatically from 18% to 42% in cows with ulcers. The authors suggest that the amount of time spent in a three-legged stance, could potentially be an indicator of lameness. As well, cows with sole ulcers were observed to have shorter stride length, by a mean of 0.6m, and walked at a slower speed than cows without sole ulcers.

While locomotion scoring is a valuable tool in herds where cows can be observed while walking, cows housed in tie-stalls without outdoor access cannot be easily scored.
Several methods for detection of lame cows in tie-stalls have been used with limited success. Research completed in Canadian tie-stall herds used back arch as an indicator of lameness while individual animals were standing (Zurbrigg et al., 2005), an indicator also used in locomotion scoring. In the same study, claw rotation greater than 20º from the midline was used as a measure of subclinical lameness, based on the hypothesis that cows with lesion on their lateral hind claws, the most common location, would attempt to transfer body weight to the medial claw. Further research is necessary for validation of this method.

Another method of lameness detection in tie-stalls includes examination of behavioural indicators thought to be associated with lameness. These include: regular, repeated weight shifting from one foot to another; rotation of feet outward from the line parallel to the midline of the body, standing on the edge of a step (“perching”), resting one foot more than the other and uneven weight bearing between feet when moving from side to side (Leach et al., 2009). Cows are scored as lame if two or more indicators are present. This method has been validated, with an inter-observer reliability of 0.91. Validity of the scoring system by two observers, in comparison to a 5-point locomotion score considered gold standard, ranged from 0.54 to 0.77.

Since cows are stoic animals, it is likely that behavioural changes in response to pain do not typically occur until the condition is advanced (Weary et al., 2006). Due to problems with reliability and the inability of producers to identify lame cattle, as well as the fact that a single measure in time that might not accurately reflect the lameness status or changes in lameness (Murray et al., 1996), more objective measurements for lameness detection are currently in development.
**Objective methods**

Another method of lameness detection that has been suggested is the use of force plates, which have the ability to determine the amount of weight the cow places on each leg. Initial research in this area by Neveux and colleagues (2006) demonstrated that cows experiencing discomfort in a limb transfer weight to the contralateral limb. With cows standing on force plates, uncomfortable surfaces (concrete with rocks or protruding screw heads) were placed under a limb of dairy cattle. Redistribution of weight to the contralateral limb occurred when one limb was on an uncomfortable surface.

Validation of the use of force plates was completed in the same manner as the locomotion scoring validation through the use of lidocaine on sound and lame cows (Rushen et al., 2007). The proportion of weight distribution was measured 15 minutes prior to lidocaine injection and then 15 minutes following injection. Prior to anesthetic injection, the weight distribution of sound cows was fairly evenly spread over all four limbs. In lame cows, the amount of weight placed on the lame limb was decreased and more weight was placed on the contralateral limb. Lidocaine injection did not significantly alter the weight distribution of sound cows. Lame cows placed approximately 19% of their weight on the affected limb and approximately 28% of weight on the contralateral limb, with intermediate amounts of weight on the other two limbs. Force plate technology could potentially be used in practice as Pastell and colleagues (2006) have shown. Force plates were placed in a robotic milker, which allowed for measurements on each limb several times daily. Unfortunately, throughout that study, problems arose due to heavy concentrated point loads that caused malfunction.
Advances need to be made for force plates to become a practical technology in production environments, since long-term use and stability of such devices is unknown.

Since animals in pain normally decrease their activity, the use of accelerometer devices, that measure movement and activity, have also been proposed as a method for detection of lameness. Due to the increasing use of pedometry on-farm for estrus detection, this technology is available and could potentially be useful for indicators of hoof and leg health. In a field study in Israel, 46% of the 46 lame cows examined displayed a 5% decrease in activity measured in steps per hour when compared to their average activity over the previous 10 days (Mazrier et al., 2006). The other 54% were false negatives. However, in 92% of the cows that did become lame, a decrease of at least 15% was observed, indicating that perhaps large changes in activity are better indicators of lameness. Illness is also known to reduce activity (Hart, 1988), which would be observed as decreased activity; therefore further refinement of this technology for use in lameness detection is necessary. Knowledge of the activity pattern in dairy cows with lameness due to different types of lesions could allow for the use of automated detection in the future.

Lying behaviour has also been examined when cows are lame. In a study involving 1,319 cows housed in deep-bedded stalls and fitted with accelerometers, severely lame cows spent 1.6 hours longer lying than cows that were not severely lame (Ito et al., 2010). Cows with sole ulcers have also been shown to lie for 1.5 hours per day more than cows without sole ulcers (Chapinal et al., 2009). However, lying behaviour during lameness has not been evaluated within cow to determine the changes exhibited.
Technologies that combine both activity and lying behaviour could potentially provide tools that are more accurate at lameness detection. Understanding the activity and lying pattern changes that occur during subclinical lameness (if present) and when lameness is first observed could allow for the development of algorithms for early identification of lameness in dairy cattle.

**Prevention and Treatment of Lameness**

Lameness is difficult to prevent due to its multi-factorial nature. However, many management strategies can be used to decrease the prevalence of lameness within a herd. One of the most important factors in managing lameness is proper trimming of hooves. Unfortunately, there is little standardization in trimming methods or regulation of trimmers in the dairy industry. Much work has been done on the growth of the hoof wall, which has been shown to grow at a rate of approximately 5 mm/month (reviewed in Vermunt and Greenough, 1995), however little research has been done to examine the proper way to trim this growth.

Trimming is generally recommended once to twice yearly for cows, which is based on the growth rate of the hoof wall. Recently, an epidemiological study comparing once yearly and twice yearly trimming determined that twice yearly decreased the odds of various hoof disorders (Manske et al., 2002a). In that study, cows trimmed twice yearly had a decrease in the odds of lameness incidence (OR=0.66), as well as a decrease in hemorrhages and white line disease (OR=0.86) and ulcers (OR=0.56). Additionally, hoof trimmings between scheduled trims due to lameness were more common in cows that were trimmed once yearly (OR=2.02). One study has compared two methods of hoof
trimming, the Standard Dutch flat trimming method to one where a concave surface was created in the sole (Ouweltjes et al., 2009). No difference between trimming methods was observed in claw health or locomotion on various floor surfaces, however cows were only followed for a period of 3 months. Following these cows for a longer period of time would have better reflected lesion incidence due to trimming, since lesions such as sole ulcers following trimming might not yet have been visible.

Foot baths are commonly used in the dairy industry to assist in prevention of infectious digital diseases, such as digital dermatitis. Footbaths can contain various antimicrobial or other solutions and assist in decreasing the bacterial contamination of the hooves. For optimal effects, footbaths must be in a proper location so that they are well utilized, be large enough for the cow to step in and cover the hooves, and the solution must contain the correct concentration of chemicals and be maintained at the correct temperature (Nuss, 2006). Again, little research has examined the effectiveness of footbaths. Laven and Proven (2000) treated cows with active digital dermatitis lesions by walking them through a footbath containing erythromycin after two consecutive milkings. On the fourth day of this routine, cows that had been treated had less hoof redness, exudate, lameness and pain, compared to untreated cows. Pain in this study was described as the application of light pressure, whereby the authors noted any signs of pain. Future research on footbaths should contain more standardized and objective measures of pain to be more useful for welfare improvement.

As an addition to management for decreased lameness, genetic selection could allow for improvement in the feet and legs of dairy cattle. There has been recent interest in the dairy industry regarding selection against claw disorders in genetic improvement
programs. Heritability estimates for different limb disorders are, however, variable, ranging from <0.01 for interdigital phlegmona, or footrot, and 0.10 for digital dermatitis and interdigital hyperplasia (Van der Waaij et al., 2005). The accuracy of these numbers is questionable due to the absence of case definitions and 39 different claw trimmers recording disease status. Additionally, correlations between genetics and leg and hoof conformation traits which can predispose cows to lameness have been shown to be low; for example genetic correlations for locomotion score is 0.10 and feet and legs is 0.24 (Van der Waaij et al., 2005). This is, however, a new area of research and further information is necessary before selection and breeding programs can be used for lameness.

Treatment of any lesions should first begin with the elimination of the source of pain and then a correction of the problem. A common method of treatment for some lesions, such as sole ulcers and white line disease, is the application of a therapeutic hoof block. These blocks are applied to the healthy claw adjacent to a claw with moderate to severe lesions in an attempt to reduce pressure on the affected sole and enhance the treatment of lameness. Very little research has been done on the topic of hoof blocks, and only one study has examined their effectiveness. In that study, lameness recovery was measured in cows presenting with sole injuries in the form of wall cracks, sole ulcers, white line disease, underrun sole and sole punctures (Pyman, 1997). Cows were assigned to a wooden block, plastic shoe or bandage treatment, and lesions were examined at 3, 7 and 14 days post-treatment. Cows receiving the block and plastic shoe treatments had a higher percentage of recovery on days 3 and 7 than those receiving the bandage treatment.
Analgesics are not commonly used in the treatment of lameness in dairy cattle, however research in this area is beginning to develop. Lame cows, diagnosed through locomotion scoring, were given various doses of the non-steroidal anti-inflammatory drug (NSAID) ketoprofen (0, 0.3, 1.5, or 3.0 mg/kg of body weight) in an intra-muscular injection, and locomotion post-treatment was examined (Flower et al., 2008). Improvements in the locomotion score (completed on a 1 to 5 scale) occurred in a dose-dependent manner, with the 3.0 mg/kg BW ketoprofen dose improving the gait by 0.25 ± 0.05. The authors suggest that this was a modest improvement in gait, and that either ketoprofen did not assist in the lameness pain or that other factors were involved in the impaired gait of these cows. Similarly, another NSAID, tolfenamic acid, was randomly assigned to some cows with claw or horn disorders to determine recovery with different treatments (Laven et al., 2008). Cows that received the NSAID did not recover any faster than animals that had simply had corrective trimming. Further research is necessary to determine the mechanisms and types of analgesics that will address lameness pain.

**Conclusions**

Lameness is a very prevalent condition in the dairy industry and is a significant concern to the welfare of dairy cattle. Research into the pain caused by various hoof lesions leading to lameness has begun, however methods for evaluation are still being researched and further data collection is necessary. Locomotion scoring is commonly used for lameness detection, however concerns arise over reliability and practicality as an on-farm tool for detection. Since lameness is such a painful and prevalent condition, prevention, early detection and treatment of lameness are key to improving dairy cattle
welfare. Automated systems to help with early detection are developing, however further research to improve their effectiveness is necessary. Little research has been done in the area of lameness treatment, and further work to ameliorate recovery times and decrease pain needs to be accomplished to improve the welfare of cows that are currently lame.
**Thesis Objectives**

This thesis was written with the aim to examine early detection of lameness caused by digital dermatitis and sole ulcers, as well as to explore treatments for those lesions. Specifically, the objectives were:

1) To validate an accelerometer that measures activity and lying behaviour for use in early detection of lameness

2) To observe temporal changes in hoof lesions within individual cows and at the herd level

3) To determine if accelerometers detect changes in cow behaviour concurrent with and prior to the identification of lameness through locomotion scoring or a painful lesion

4) To determine the efficacy of digital dermatitis treatment with a tetracycline hydrochloride paste

5) To determine the behavioural, locomotion and production changes in sound cattle following application of a therapeutic hoof block
References


Flower, F., D. Sanderson, and D. Weary. 2005. Hoof pathologies influence kinematic


Table 1.1. Common hoof lesions and definitions. Adapted from Cramer et al. (2008)

<table>
<thead>
<tr>
<th>Lesion name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>White line abscess</td>
<td>Abscess in white line region, if severe, can be accompanied by swelling of affected hoof.</td>
</tr>
<tr>
<td>Deep sepsis in hoof</td>
<td>Swollen hoof with no visible exterior lesion. Drains pus when pressure is relieved.</td>
</tr>
<tr>
<td>Digital dermatitis</td>
<td>Sore, raw, sometimes hairy area on the skin around the heels and between the hooves. Can have a white rim around the lesion.</td>
</tr>
<tr>
<td>Heel horn erosion</td>
<td>Pits, cracks, or fissures in the heel area of the hoof. More extensive lesion will have V-shaped cracks on the heel.</td>
</tr>
<tr>
<td>Foot rot</td>
<td>Symmetrical swelling above the hooves, with spreading of the toes. Usually accompanied by cracked, dead, smelly skin between the digits.</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>Red or yellow discolouration of the sole or white line.</td>
</tr>
<tr>
<td>Korn or interdigital phlegmon</td>
<td>Abnormal fibrous skin growth between the digits.</td>
</tr>
<tr>
<td>White line separation</td>
<td>Breaks, separations, or fissures of the white line that can reach the corium, but that do not affect the corium or have pus associated with it.</td>
</tr>
<tr>
<td>Ulcer</td>
<td>Defect in the sole horn that exposes the corium; can be accompanied by granulation tissue. Typically occurs on the inner side of the sole, but can occur in the toe or heel.</td>
</tr>
<tr>
<td>Vertical wall crack</td>
<td>Vertical split in the wall, usually starting at the junction of the wall and skin.</td>
</tr>
</tbody>
</table>
Table 1.2. Prevalence measures of hoof lesions and lameness in dairy cows.

<table>
<thead>
<tr>
<th>Author, year</th>
<th>Measurement</th>
<th>Location</th>
<th>Housing</th>
<th>% Affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manske et al., 2002b</td>
<td>Lesions</td>
<td>Sweden</td>
<td>Tie- and free-stall</td>
<td>72%</td>
</tr>
<tr>
<td>Somers et al., 2003</td>
<td>Lesions</td>
<td>Netherlands</td>
<td>Concrete free-stall, some pasture</td>
<td>&gt;80%</td>
</tr>
<tr>
<td>Somers et al., 2003</td>
<td>Lesions</td>
<td>Netherlands</td>
<td>Straw yard</td>
<td>55-60%</td>
</tr>
<tr>
<td>Sogstad et al., 2005</td>
<td>Lesions</td>
<td>Norway</td>
<td>Tie-stall</td>
<td>48%</td>
</tr>
<tr>
<td>Sogstad et al., 2005</td>
<td>Lesions</td>
<td>Norway</td>
<td>Free-stall</td>
<td>71.8%</td>
</tr>
<tr>
<td>Cramer et al., 2008</td>
<td>Lesions</td>
<td>Ontario, Canada</td>
<td>Tie-stall</td>
<td>26%</td>
</tr>
<tr>
<td>Cramer et al., 2008</td>
<td>Lesions</td>
<td>Ontario, Canada</td>
<td>Free-stall</td>
<td>46%</td>
</tr>
<tr>
<td>Manske et al., 2001</td>
<td>Lameness</td>
<td>Sweden</td>
<td>Tie- and free-stall</td>
<td>5.1%</td>
</tr>
<tr>
<td>Espejo et al., 2006</td>
<td>Lameness</td>
<td>Minnesota, USA</td>
<td>Free-stall</td>
<td>24.6%</td>
</tr>
<tr>
<td>Rutherford et al., 2009</td>
<td>Lameness</td>
<td>United Kingdom</td>
<td>Free-stall</td>
<td>16%</td>
</tr>
<tr>
<td>Frankena et al., 2009</td>
<td>Lameness</td>
<td>Netherlands</td>
<td>Free-stall</td>
<td>24%-46%</td>
</tr>
<tr>
<td>Frankena et al., 2009</td>
<td>Lameness</td>
<td>Netherlands</td>
<td>Straw yard</td>
<td>1%</td>
</tr>
<tr>
<td>Score</td>
<td>Class</td>
<td>Behavioural criteria</td>
<td>Behavioural criteria</td>
<td>Description</td>
</tr>
<tr>
<td>-------</td>
<td>-------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>-------------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Normal</td>
<td>Cow stands and walks with level-back posture; gait is normal.</td>
<td>Minimal abduction/adduction,</td>
<td>Smooth and fluid movement</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>no unevenness of gait, no</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>tenderness</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Mildly lame</td>
<td>Cow develops arched-back posture while walking; gait remains normal</td>
<td>Abduction/adduction present,</td>
<td>Imperfect locomotion, ability to move freely not diminished</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>uneven gait, perhaps tender</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Moderately lame</td>
<td>Arched-back posture when standing and walking; gait is short-striding with one or more limbs</td>
<td>Slight lameness, not affecting behaviour</td>
<td>Capable of locomotion but ability to move freely compromised</td>
</tr>
<tr>
<td>Score</td>
<td>Description</td>
<td>Clinical Signs</td>
<td>Observations</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>-------------</td>
<td>----------------</td>
<td>--------------</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Lame</td>
<td>Arched back always evident and gait one deliberate step at a time; cow favours one or more limbs/feet</td>
<td>Obvious lameness, some difficulty in turning, behaviour pattern affected</td>
<td>Ability to move freely obviously diminished</td>
</tr>
<tr>
<td>5</td>
<td>Severely lame</td>
<td>Inability or extreme reluctance to bear weigh on one or more limbs/feet</td>
<td>Extreme difficulty in rising, difficulty in walking, adverse effects on behaviour patter</td>
<td>Ability to move is severely restricted; vigorously encouraged to move</td>
</tr>
</tbody>
</table>

1Scoring system includes definitions for 0.5 increments not included in this table.
Figure 1.1. Elements involved in nociceptive pain. (Anderson & Muir, 2005)
Chapter 2. Validation of the Pedometer Plus system

(written as a Technical Note for submission to Journal of Dairy Science)

Introduction

The use of automated behavioural technologies in livestock industries, especially dairy cattle, is increasing in popularity. For example, pedometers are often used for estrus detection on commercial dairy farms, measuring the number of steps taken by the cow, and are increasingly incorporated into dairy software programs. Benefits of automated behaviour technologies can be observed from both management and research perspectives. These technologies are less time consuming and more reliable than human observation, and their presence on farm allows for changes in behaviour to be identified quickly and easily. In addition, they eliminate the necessity of human observer presence, which could affect the animal behaviour, especially in stoic animals during illness or pain (Weary et al., 2008).

Change in activity is associated with both illness and pain. During illness, animals decrease activity and increase resting to allow for recuperation (Hart, 1988). The use of activity measures may therefore be useful measurement of both health and welfare (Rushen et al., 2008). For example, calves experimentally infected with *Mannheimia haemolytica* to induce pneumonia showed a significant decrease in activity compared to their baseline activity (Hanzlicek et al., 2010). Similarly, increased lying behaviour has been associated with lameness in cattle (Ito et al., 2010; Blackie et al., 2011). Lying behaviour of dairy cattle in deep bedded stalls was greater in cows with a numerical rating system (NRS) of 4 or greater, which indicates a lame cow, when compared to non-lame cows (Ito et al., 2010). The length and variability in duration of lying bouts were also observed to be greater in lame cattle.
The Pedometer Plus™ (SAE Afikim, Israel) is a commercially available device, marketed for use in heat detection and identification of potential negative welfare through changes in activity and lying behaviour. It is the first commercially available parlour integrated system that records lying behaviour in addition to activity. The Pedometer Plus is encased in a hard plastic shell measuring 9 cm x 7 cm and 2 cm wide. Pedometers are attached loosely to the leg of the cow above the fetlock over the metatarsus with a 38 cm by 4 cm wide nylon strap that is provided with the device (Figure 2.1). The Pedometer Plus system is typically integrated into a parlour system, and data from accelerometers are collected during milking. The Pedometer Plus device records activity and provides measurements in the form of steps per hour. Additionally, lying and standing are recorded by the device continuously through use of a tilt switch, resulting in mutually exclusive behaviour. Data output, through the herd recording software program Afimilk, includes the number of lying bouts, mean lying duration and duration of lying bouts, and mean number of steps per hour between readings of the accelerometer.

The objective of this study was to validate the Pedometer Plus (SAE Afikim, Israel) accelerometer for measurements of activity and lying behaviour. Currently, this device is commercially available, however validation of the activity and lying measures provided by the device has not been reported.

**Experiment 1**

Sixteen dairy cows were enrolled during Stage 1 and Stage 2 of this experiment, consisting of two pregnant primiparous cows, twelve non-lactating pregnant multiparous cows (mean ± SD; parity = 1.7 ± 1.2) and two early lactation multiparous cows (parity =
3.0 ± 1.4; DIM = 7.5 ± 7.8). These cows were housed in maternity pens for the duration of the validation, 2-3 days for each cow. Pens were 7.01m by 3.05m, with deep straw bedding in one half of the pen and sand bedding in the other half. Cows were fed a total mixed ration three times daily from a trough at the side of the pen, and milked twice daily in their pens if lactating.

Video cameras (Panasonic WV-CP244 Color CCTV Cameras, Heads WV-LZA61/2) were mounted above the pens to provide an overhead panoramic view and video was recorded using time-lapse VHC video recorders (Panasonic AG-RT650). One observer (author JHC) observed video and recorded behaviour continuously to determine the number of bouts and duration of lying and standing behaviour performed by each cow, using definitions from the ethogram in Table 2.1.

IceTag® (IceRobotics, UK) data was used for validation of activity measures, due to the inability to accurately view steps recorded from video data. IceTags have been validated for measurement of activity and lying adult dairy cattle (Nielsen et al., 2010) as well as in calves (Trénel et al., 2009). These devices measure lying and standing as mutually exclusive states, and activity in the form of steps as a separate measurement. The IceTag accelerometers were programmed to record information every second and output data was downloaded using IceTag Analyser software (IceRobotics, UK) following removal from the cow. Lying or standing were classified when the cow spent greater than 50% of a minute performing that behaviour.

Eleven cows were enrolled in Stage 1 of the experiment, and were fitted with a Pedometer Plus accelerometer loosely on one hind leg and an IceTag accelerometer on the lateral side of the opposite hind leg. Assignment of accelerometers to the right or left
was determined by random allotment. Data were downloaded from the Pedometer Plus accelerometers four times daily using a handheld reader which allowed for standardized timing of measurements, at approximately 0530, 1000, 1300, and 1500 providing data for a mean (± SD) of 57.4 ± 0.49 hours per cow.

As a preliminary investigation, Pearson product-moment correlations (Corr procedure, SAS 9.2, SAS Institute Inc) were calculated to determine the correlation between activity and lying measurements within each cow for the Pedometer Plus and IceTag accelerometers. The correlation between the IceTag and Pedometer Plus accelerometers for the number of steps taken was quite low (R²=0.53, p<0.0001). Casual observation of video revealed upper leg movements during lying, while the lower legs remained immobile, which could have accounted for the differences in readings from the two accelerometers. This led to an alteration in the methodology (Stage 2) as an attempt to more accurately reflect the measures of the two devices.

In Stage 2 of the experiment, an additional five cows were fitted with both Pedometer Plus and IceTag devices on the same hind leg as shown in Figure 2.1. Housing, management, video and accelerometer recordings were as described in Stage 1. Data from the Pedometer Plus and IceTag accelerometers were compared over a total period of 227 hours and 16 minutes. Correlations for the number of steps recorded by the IceTag and Pedometer Plus accelerometers were numerically higher than in Stage 1 (R²=0.67; P < 0.001; Figure 2.2). The number of lying bouts and duration of lying time were highly correlated for all cows, R²=0.96 (P < 0.0001; Figure 2.3), and R²=0.81 (P < 0.0001; Figure 2.4), respectively.
Data from video recordings for 7 animals, collected over a total of 125 hours and 21 minutes (mean ± SD = 18:22 ± 9:47 per cow) was available for analysis of lying behaviour collected during both Stage 1 and 2. Two linear regression models (Reg procedure, SAS 9.2), which included video data and cow identification number, were used to determine if the Pedometer Plus accelerometer was accurately measuring lying duration and frequency of lying bouts. Lying bouts (R²=0.81; P < 0.0001; Figure 2.5) and lying duration (R²=0.98; P < 0.0001; Figure 2.6) were highly correlated between the Pedometer Plus and video recordings.

**Experiment 2**

Due to the low correlations in activity measures observed in Experiment 1. The objective of Experiment 2 was to determine the required amount of movement by the limb for the accelerometer to record a step. Cows were housed in tie-stalls 1.88m long by 1.15m wide, with rubber mattresses (Pasture Mat®, Promat Inc., Ontario, Canada) covered with a thin layer of straw to more accurately view a single limb. Milking occurred twice daily in a parlour and a total mixed ration was fed three times daily. Following milking and when fresh feed was available, 5 lactating cows (parity = 2.3 ± 1.3; DIM = 117.0 ± 62.7) were videotaped for behavioural observations. This time period was chosen to ensure cows stayed standing for a length of time to allow for observation of leg movements. Two hand-held digital videocameras (Panasonic SDR-H85) were placed on tripods approximately 2 m behind the cows providing a posterior view of the hind-legs while cows were standing. A total of 117 minutes (mean ± SD = 38:16 ± 22:55 per cow) of video was collected while cows stood, and frequency of
behaviour was manually quantified using continuous sampling by one author (JHC), focusing on the movements of the limb attached with the Pedometer Plus (Table 2.1).

The number of leg movements observed using different combinations of behaviour were summarized by cow and compared to the corresponding output from the Pedometer Plus accelerometers using a linear regression model (Reg procedure, SAS 9.2). Cow identification was offered into all models but was removed due to lack of significance. Models were built with different combinations of leg movement, beginning with steps since it was assumed those were measured by the device. Shifts were then added due to the similarity in movement to steps, followed by leg lifts. Lying was included in a final model due to the movement of the limb while lying down. The combination with the highest coefficient of determination, an intercept closest to zero, and with a slope closest to one was considered to be the combination of behaviour associated with the Pedometer Plus output.

All leg movements listed in the ethogram in Table 2.1 were observed. Of all the leg movements measured, only 34% were classified as steps from the ethogram definition. Cut-offs using different combinations of behaviours were examined as reported in Table 2.2. The model including all leg movements and the leg movement that occurred while the cow was lying down provided the highest correlation of determination in combination with a slope close to one and intercept approaching zero. Correlation is shown in Figure 2.7.
Discussion

The results from this series of experiments suggest that the Pedometer Plus device collects both activity and lying behaviour measurements accurately. The initial validation protocol (Experiment 1) was expected to demonstrate similar activity and lying behaviour in both the Pedometer Plus and IceTag devices. However, a much lower correlation than expected was observed for the number of steps taken. Through analysis of behaviour observed from video recorded throughout the validation process, it was observed that the upper leg was moving while the lower leg was immobile when cows were lying down, likely causing the greater activity recorded by the device attached to the upper leg. Since some cows may show a lying laterality preference (Tucker et al., 2009; Ledgerwood et al., 2010; Gibbons et al., 2012), this could cause differences in the activity recordings of devices placed on different limbs. Additionally, since some of the comparison periods were short (minimum of two hours), it is possible that the cow might have only been lying on one side during that time period. Stage 2 of Experiment 1 demonstrated higher correlation between the two devices when they were measuring movement of the same limb, supporting the hypothesis that laterality preference could explain the poor correlation in Stage 1. The potential for differences in activity measurements dependent on the limb on which pedometers are attached should be taken into consideration in data interpretation. Fifty percent of the lying duration measurements that were not well correlated were from two individual cows in Stage 2. It is possible that calibration issues in either the Pedometer Plus or the IceTag devices on these two cows accounted for lack of correlation in these devices. IceTags have a
reported misclassification rate, or percent not in agreement with video analysis, of 10% was reported in adult dairy cattle (Nielsen et al., 2010)

Direct observation of behaviour, through video or live, is considered the gold standard for collection of behaviour data. Live observation is time consuming, and while video observation can be faster it is still time intensive and small leg movement may not always be observed depending on the distance from the camera to the animal and angle of the camera. Pedometers provide advantages in terms of labour required to collect data, but present risks of misclassification of behaviour due to the sensitivity of the tilt switch and algorithms used to identify lying, standing and steps.

The ethogram in Table 1 was developed in an attempt to measure all of the movements performed by cows when standing restrained in a stall. There are no published definitions available to differentiate between walking and moving legs while standing, and it is difficult to differentiate between small leg movements while cows are standing through live or video observation. The ethogram in this study covered all of the leg movements observed over a total 177-minute period of time while five cows were standing in tie-stalls. The Pedometer Plus device appears to measure most movements made by the cow while standing on the limb on which it is placed.

Correlation for activity between the Pedometer Plus device and the IceTag were not as high as expected, which is likely due to the fact that the devices are not measuring the same form of activity. The IceTag measures the number of steps taken by cows while walking accurately (Munksgaard et al., 2006). The Pedometer Plus appears to be more sensitive to subtle movements and is measuring all movement made by the limb of the cow. This information could be very useful for detection of illness in cattle, as the
Pedometer Plus will detect increases in behaviour such as shifting, which may be a more sensitive measure of pain and discomfort. Shifting is increased in lame dairy cattle and will decrease with provision of ketoprofen as an analgesic (Chapinal et al., 2010). As well, during cases of mastitis, cows may decrease the amount of shifting they perform (Kemp et al., 2008). Use of pedometry systems sensitive to movements such as shifting could potentially allow for better detection of increased restlessness indicating pain or illness.

The Pedometer Plus device was shown to accurately measure frequency and duration of lying bouts. Almost perfect correlation for lying duration indicates that the Pedometer Plus is not misclassifying standing and lying. The correlation between the number of lying bouts was higher when compared to the IceTag accelerometers than video. This likely indicates that the accelerometers may be measuring some leg movement while lying that is misinterpreted by the device as cessation of a lying bout, increasing the count of lying bouts over a period of time.

Adoption of automated monitoring systems in the dairy industry has been widespread, especially in activity monitoring as this is commonly used for estrus detection. With the availability of such instruments, their use in monitoring for health events could assist in early identification of disease. Interpretation of data from the Pedometer Plus should take into account that ‘step’ measurements are sensitive to all motion by the leg and therefore also include weight shifting and slight motion. As a research tool, the leg on which the accelerometer is placed must also be recorded and taken into consideration for data interpretation of data.
In conclusion, the Pedometer Plus device provides accurate information on lying behaviour, including bouts and duration of lying bouts, as well as an overall activity measure of the cow, making it useful for future research.

Acknowledgments

We would like to thank Laura Wright and the staff at the Elora Dairy Research Stations (University of Guelph) for their assistance in data collection, as well as Nuria Chapinal and Amy Stanton for assistance with IceTag data management. Funding was from the Dairy Farmers of Canada.
References


Tucker, C., N. Cox, D. Weary, and M. Spinka. 2009. Laterality of lying behaviour in
Table 2.1. Ethogram of behaviour and leg movements observed through validation of the Pedometer Plus device.

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lying$^{1,2}$</td>
<td>Body in recumbent position</td>
</tr>
<tr>
<td>Standing$^1$</td>
<td>Body in upright position, with all four hooves on the ground</td>
</tr>
<tr>
<td>Step$^2$</td>
<td>Movement (backward or forward) where hoof lands &gt; 2 hoof lengths from original placement</td>
</tr>
<tr>
<td>Shift$^2$</td>
<td>Slight movement of hoof in any direction, ≤ 2 hoof lengths from original placement</td>
</tr>
<tr>
<td>Lift$^2$</td>
<td>Upward movement of leg which lands back in same location lasting &lt; 1 second</td>
</tr>
<tr>
<td>Heel lift$^2$</td>
<td>Lifting of heel only while toes remain on ground</td>
</tr>
<tr>
<td>Long lift$^2$</td>
<td>Upward movement of leg which lands back in same location lasting ≥ 1 second</td>
</tr>
<tr>
<td>Kick$^2$</td>
<td>Forceful movement upward with leg</td>
</tr>
</tbody>
</table>

$^1$ Used in Experiment 1

$^2$ Used in Experiment 2
Table 2.2. Linear regression data for activity measured using a Pedometer Plus accelerometer affixed to the hind legs of five dairy cows compared with behaviour observation from videorecordings of the same hind leg. Mean (± SD) of steps measured by the Pedometer Plus was 27.58 (± 19.85). Frequency = mean # of behaviour events (±SD).

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Frequency</th>
<th>$R^2$</th>
<th>Intercept</th>
<th>Slope</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steps</td>
<td>10.36 ± 9.64</td>
<td>0.76</td>
<td>12.54</td>
<td>1.69</td>
<td>0.0005</td>
</tr>
<tr>
<td>Steps + shifts</td>
<td>21.00 ± 15.96</td>
<td>0.83</td>
<td>3.77</td>
<td>1.13</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Steps + shifts + lifts</td>
<td>25.75 ± 18.48</td>
<td>0.90</td>
<td>1.32</td>
<td>1.02</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>All behaviours</td>
<td>26.08 ± 18.48</td>
<td>0.91</td>
<td>0.91</td>
<td>1.02</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>All behaviours except down</td>
<td>26.33 ± 18.33</td>
<td>0.90</td>
<td>0.47</td>
<td>1.03</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>
Figure 2.1. Pedometer Plus accelerometer (orange; lower) and IceTag accelerometer (green; upper) affixed to the leg of a cow during Stage 2 of the validation process.
Figure 2.2. Comparison of the mean number of steps performed by five dairy cows, as recorded between consecutive data collection points (n=40) using the Pedometer Plus and IceTag accelerometer devices affixed to the same hind leg.
Figure 2.3. Comparison of number of lying bouts between Pedometer Plus and IceTag devices (n=40), when both devices were affixed to the same hind leg. Bubble size is proportionate to the number of observations, with quantity of observations centered in bubble.
Figure 2.4. Comparison of duration of time spent lying in minutes measured by the Pedometer Plus and IceTag accelerometers (n=40), when both devices were affixed to the same limb.
Figure 2.5. Comparison of number of lying bouts measured by the Pedometer Plus device and observation of video (n=30). Bubble size is proportionate to the number of observations, with number of observations centered in circle.
Figure 2.6. Comparison of lying duration in minutes between the Pedometer Plus accelerometer and video (n=30) during Pedometer Plus validation.
Figure 2.7. Comparison of activity between the Pedometer Plus accelerometer and video over a total of 117 minutes, measured in approximately 30-minute periods.
Chapter 3. Etiology and temporal changes in hoof lesions

Introduction

Lesions in the hooves of cows are responsible for much of the lameness cases in dairy cattle (Murray et al., 1996), a huge welfare concern in the dairy industry. Estimates of lesion prevalence worldwide in a variety of housing systems have been published. In a Canadian cross-sectional study examining cows from 204 herds, lesion prevalence in tie-stalls was determined to be 26%, while a higher prevalence of 46% was observed in free-stalls (Cramer et al., 2008). Lesion prevalence estimates are higher in Europe, with estimates of 48% of cows in tie-stall herds and 72% of cows in free-stall herds in a Norwegian study examining cows in 112 farms (Sogstad et al., 2005). In another study including 101 Swedish farms, 72% of cows had at least one lesion in their hooves (Manske et al., 2002b).

Risk factors for lameness have been studied extensively, however risk factors for hoof lesions are not as well elucidated. Increased parity has been associated with interdigital dermatitis and heel horn erosion (Somers et al., 2005) as well as digital dermatitis (Holzhauer et al., 2006). The presence of solid concrete floor, restricted grazing time and long intervals between herd trimming are also risk factors for interdigital dermatitis and heel horn erosion (Somers et al., 2005). In cases of digital dermatitis, risk factors include time of peak lactation and the presence of other claw disorders (Holzhauer et al., 2006). In free-stall housing, increased alley scraping has been associated with sole ulcers, while in tie-stalls year-round access to outside and routine spraying of feet have been associated with increased digital dermatitis in the herd.
(Cramer et al., 2009). No causal relationships have been determined for these risk factors.

While not all lesions present in the hooves cause discomfort or lameness, the high prevalence is a concern. Much research has focused on the number of lesion present in cows, however the progression and change over time of lesions within cow has not been well described. Tracking of the number and type of lesions in a herd is useful for investigations of lameness problems in a herd (Guard, 2001; Mills et al., 1986).

The objective of this research was to describe the progression and temporal changes of lesions in the hooves of dairy cattle. A second objective of this paper is to determine the odds of development of lesions based on results of previous hoof exams.

Materials and Methods

Animals and Housing

All Holstein cows and close up heifers at the Elora Dairy Research Centre, Elora ON, were enrolled in the trial. The cow housing facility consists of both a free-stall and a tie-stall section, which can house 40 and 120 cows, respectively. The free-stall stocking density ranged throughout the trial period, with a mean of 78%. All animals entered the same milking parlour twice daily for milking and were fed the same total mixed ration, balanced for nutritional requirements, three times daily. Cows in the milking herd, dry cows, and close up heifers were included in the dataset. Parity and lactation information was accessed from DairyPlan C21 (GEA Farm Technologies, Naperville, IL) for data in 2009 and DairyCOMP 305 (Valley Agricultural Software, Tulare, CA) for data in 2010.
**Trimming and Data Collection**

All cows had their hooves examined every three to four months, in June 2009, September 2009, January 2010, May 2010, and August 2010, which will be referred to as Exam 1, 2, 3, 4 and 5, respectively. Cows would have their hooves trimmed every second visit, approximately 6 months apart, by a veterinarian specializing in hoof trimming and dairy cattle lameness (author GC). Cows were restrained in a hydraulic stand up chute (Comfort Hoof Care, Baraboo, WI) for hoof exam and trimming.

Anatomic location (Figure 3.1) of any visible lesions and their approximate size were recorded on data sheets using the case definitions shown in Table 3.1 based on Cramer and colleagues (2008). In order to visualize lesions present on the hooves, hooves were first trimmed. In cows not requiring trims, the sole was cleaned and if necessary a hoof grinder was used across the hoof to shave a small layer of horn to properly visualize lesions. Response to pressure from an algometer (Pain Test™ FPX 50 Algometer, Wagner Instruments, Greenwich, CT) or hoof testers distinguished between hemorrhages and sole ulcers, since corium exposure from a sole ulcer would result in a response to pressure.

Lesions requiring treatment were treated following identification. Corrective trimming was performed to ensure proper healing. Sole ulcers and cases of white line disease requiring elevation of the claw had therapeutic hoof blocks affixed to the adjacent claw, unless lesions were present on both claws of the same limb. A concurrent clinical trial for digital dermatitis treatment was ongoing throughout the treatment period (Chapter 5), therefore cases of digital dermatitis were treated with tetracycline hydrochloride wraps, paste or no treatment as a negative control. Recurrence was defined
as the same lesion type appearing in the same location on a hoof two or more times throughout the study period.

**Statistical Analysis**

Descriptive statistics were derived using the Frequency procedure (SAS 9.2). Lesion data were summarized by claw to determine recurrence. Lesion specific prevalence calculated at each exam time point. Hoof lesion prevalence was the sum of the number of lesions observed at that exam time point divided by the number of cows examined. Cow-level prevalence was calculated by the number of affected animals with the lesion of interest, divided by the total number examined. Lesions were considered to be incident cases if they were not present in that cow at the previous exam. Annual incidence rate was calculated as the number of cows with incident cases throughout the trial period divided by the unit of animal-time (number of animals examined over 1.25 years), to give annual values per 100 cow-years.

To determine if lesions were more likely to occur following the presence of other lesions at the previous exam period, the study was treated as a cohort design, where groups with factors of interest (cohorts) are followed over time to determine differences in disease development between the two cohorts. Presence of lesions by cow was determined for each exam. Logistic regression was used through the glimmix procedure (SAS 9.2) with presence of the same lesion at the previous exam, days in milk, and parity included as covariates and cow id included as a random effect. Sole ulcers and digital dermatitis were examined in detail as outcomes of interest, along with other lesions that have been shown to be associated with both ulcers and digital dermatitis in the literature.
All procedures were documented in an Animal Use Protocol (09R089) approved by the University of Guelph Animal Care Committee.

**Results**

Two hundred and thirty-nine unique cows had hooves examined, with a total of 759 hoof exams over the five exam time periods. The number of exams per cow ranged from 1 to 5 (mean ± SE: 3.18 ± 0.09) throughout the trial period. Descriptions of the animals observed at each exam time period are shown in Table 3.2.

Lesion prevalence over the five exams is shown in Table 3.3. Cow-level prevalence is shown in Table 3.4. Since many cows had multiple cases of the same lesion on different legs at the same hoof exam, lesion prevalence is higher than cow-level prevalence.

Recurrence of ulcers and digital dermatitis were examined when the same lesion was present at the same location more than once throughout the trial period. Twenty-seven cows had ulcers in the same location over 2 exam periods, 7 cows had ulcers in the same location over 3 exam periods, and 2 cows had lesions in the same location over 4 exam periods. When looking at cows with digital dermatitis with lesions present in the same location in multiple exam periods, 27 cows had lesions at 2 exams, 10 cows had lesions at 3 exams, 2 cows with 4 lesions and there was 1 cow with 5 lesions. As well, annual incidence, the number of cases per 100 cow-year, can be found in Table 3.5 for sole ulcers, digital dermatitis, hemorrhages and heel horn erosion for the duration of the trial period.
Odds ratios for various combinations of lesions at the cow level are shown in Table 3.6. The presence of sole ulcers, digital dermatitis and heel horn erosion all increased the odds of presence of the same lesion at the following exam. Hemorrhage presence did not affect the odds that a cow would have a hemorrhage at the following exam.

The presence of sole ulcers and hemorrhages were examined to determine if hemorrhages were present in the same location on the same claw as an ulcer at the Exam prior to, ulcer identification. Of the 244 ulcers observed during the trial period, 61 (25%) had a hemorrhage in the same location at the exam prior to ulcer identification. Twenty-six cases of hemorrhage in the ulcer location at the Exam following ulcer identification were also observed. The presence of digital dermatitis also increased the odds of a cow having heel horn erosion at the following exam period.

Discussion

This study was the first to track progression of all hoof lesions throughout a herd over a period of time. Since farm staff have difficulty in lameness identification (Wells et al., 1993; Whay et al., 2003; Espejo et al., 2006), examining the hooves of cows is more reflective of on-farm practices for lame cow identification.

The number of sole ulcers observed throughout the trial period was much higher than expected, three times higher prevalence than reported Canadian values (Cramer et al., 2008). The number of sole ulcers observed in this study was perhaps inflated compared to other trials since all hemorrhages in the typical sole ulcer location and identified as an early sole ulcer based on a positive withdrawal response to pressure from
hoof testers. It is unlikely that this was done in other studies, where more typically ulcers were only recorded if exposure of the corium was present.

Hemorrhage prevalence throughout the trial was also much higher than previously reported in Ontario dairy herds (Cramer et al., 2008). In the current study, all forms of hoof discolouration were included, whereas the previous study only reported moderate to severe hemorrhages, which likely increased the prevalence values.

Prevalence of digital dermatitis was very high (50%) at the first exam period compared to the Canadian reports of 8.3% (Cramer et al., 2008). Cases of digital dermatitis decreased throughout the trial period, reaching a low of 7% in the fourth exam. Through examination of potential reasons for the high prevalence at the beginning of the trial period, it was determined that the automatic footbath was malfunctioning. Once remedied, and combined with treatment of cows, the prevalence of digital dermatitis decreased to values close to those previously reported.

Prevalence values for white line abscesses and separation were similar to published Canadian prevalence data. Heel horn erosion was much higher at the beginning of the trial period; however, this decreased by the end of the trial. This reduction was likely affected by the decreasing number of digital dermatitis lesions throughout the period.

While some estimates of incidence of lameness can be found in the literature (e.g. Clarkson et al., 1996), with an annual incidence of 54.6 cases per 100 cows), no published values for incidence of lesions can be found. In order to decrease lameness in the dairy industry, incident cases must be controlled (Guard, 2001) or decreased. Further epidemiological studies examining incidence of potentially painful hoof lesions across a
range of herds should be completed to provide baseline values and set targets for improvement in the industry.

It is generally believed that hemorrhages and sole ulcers are involved in the same disease process (Leach et al., 1998; Lischer et al., 2002), but no study has examined the progression of these two lesions. Since 25% of the ulcer locations had a hemorrhage at the same location in the prior exam, it is possible that this progression was being observed. At the limb-level, those with hemorrhages had 1.61 higher odds of having sole ulcers at the following exam compared to cows without hemorrhages, suggesting a link between the two lesion types. Presence of a hemorrhage in the exam approximately 3 months after ulcer identification likely indicates scarring of the hoof or permanent damage. However, this was observed in few cases, potentially indicating more serious ulcers that had caused more extensive damage to the sole.

The odds of heel horn erosion presence was higher in cows that had previous cases of digital dermatitis. Sogstad and colleagues (2005) found a significant, although low, correlation between the presence of digital dermatitis and heel horn erosion. While no direct comparisons between lesions were made, Cramer and colleagues (2008) found similar cow-level prevalence in both digital dermatitis and heel horn erosion. Manske and colleagues (2002a) have suggested that damage to the horn-producing tissues by digital dermatitis lead to a loss of horn tissue or heel horn erosion.

Healthy claws have been shown to grow a mean of 6.2 mm/month, however wear occurs at a rate of 4.4 mm/month when cows are housed on various flooring surfaces (Vokey et al., 2001). This results in total growth of approximately 1.8 mm/month. Over the three to four month period between exams in this study, that results in approximately
5.5-7 mm of growth. Since there were 27 cows that had ulcers in the same location over 2 exam periods, it is possible that these lesions were visible as the horn had now grown out between exams.

Tracking the number and type of lesions observed on hooves at the time of hoof trimming could provide valuable information on changes in the herd, such as evaluating management changes that may impact lesion prevalence on farm. New software that allows for easy recording of lesion types and locations at the time of trimming could facilitate for efficient recording.

Conclusion

Lesion prevalence in the study herd was similar to reported values in Canada and internationally, except for the higher prevalence of sole ulcers. The presence of sole ulcers, digital dermatitis, and heel horn erosion all increased the odds of having the same lesion at the following exam period. Additionally, the presence of hemorrhage increased the odds of a cow having a sole ulcer at the following exam compared to no hemorrhage. The same was found with digital dermatitis increasing the odds of heel horn erosion at the following exam. Tracking hoof lesions at the cow-level could therefore assist in determining which cows should be observed more closely for hoof lesions and lameness.
References


### Table 3.1. Definitions of lesions used in study. Adapted from Cramer et al., 2008.

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital dermatitis</td>
<td>Sore, raw, sometimes hairy area on the skin around the heels and between the claws.</td>
</tr>
<tr>
<td>Heel horn erosion</td>
<td>Pits, cracks, or fissures in the heel area of the hoof.</td>
</tr>
<tr>
<td>Interdigital dermatitis</td>
<td>Erosions of the epidermis in the interdigital cleft (adapted from Capion et al., 2008)</td>
</tr>
<tr>
<td>Foot rot</td>
<td>Symmetrical swelling above the hooves, with spreading of the toes</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>Red or yellow discolouration of the sole or white line</td>
</tr>
<tr>
<td>Korn (interdigital hyperplasia)</td>
<td>Abnormal fibrous skin growth between the claws</td>
</tr>
<tr>
<td>White line abscess</td>
<td>Abscess in the white line area of the hoof. If severe, can be accompanied by swelling of affected hoof.</td>
</tr>
<tr>
<td>White line separation</td>
<td>Breaks, separations, or fissures of the white line that can reach the corium, but does not have pus associated with it.</td>
</tr>
<tr>
<td>Sole ulcer</td>
<td>Defect in the sole horn that exposes the corium; can be accompanied by granulation tissue.</td>
</tr>
</tbody>
</table>
Table 3.2. Description of cows examined at each Exam period through June 2009, September 2009, January 2010, May 2010, and August 2010, referred to as Exam 1, 2, 3, 4 and 5, respectively.

<table>
<thead>
<tr>
<th></th>
<th>Exam 1</th>
<th>Exam 2</th>
<th>Exam 3</th>
<th>Exam 4</th>
<th>Exam 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total n</td>
<td>122</td>
<td>145</td>
<td>161</td>
<td>171</td>
<td>161</td>
</tr>
<tr>
<td>N in tie-stall</td>
<td>95</td>
<td>117</td>
<td>129</td>
<td>131</td>
<td>124</td>
</tr>
<tr>
<td>N in free-stall</td>
<td>27</td>
<td>28</td>
<td>32</td>
<td>40</td>
<td>37</td>
</tr>
<tr>
<td>Mean Parity (± SE)</td>
<td>2.13 (0.04)</td>
<td>2.16 (0.04)</td>
<td>2.08 (0.06)</td>
<td>2.06 (0.07)</td>
<td>2.12 (0.05)</td>
</tr>
<tr>
<td>N in Lactation 0(^1)</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>N in Lactation 1</td>
<td>50</td>
<td>61</td>
<td>68</td>
<td>77</td>
<td>77</td>
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<tr>
<td>N in Lactation 2</td>
<td>23</td>
<td>32</td>
<td>34</td>
<td>39</td>
<td>30</td>
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<tr>
<td>N in Lactation 3+</td>
<td>39</td>
<td>42</td>
<td>47</td>
<td>44</td>
<td>50</td>
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<tr>
<td>Mean DIM (± SE)</td>
<td>172.97 (3.66)</td>
<td>200.21 (3.81)</td>
<td>184.44 (5.70)</td>
<td>161.14 (6.14)</td>
<td>173.83 (4.77)</td>
</tr>
<tr>
<td>Number of dry cows</td>
<td>0</td>
<td>9</td>
<td>22</td>
<td>25</td>
<td>16</td>
</tr>
<tr>
<td>N in Early lactation</td>
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<td>42</td>
<td>43</td>
<td>26</td>
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<tr>
<td>N in Mid-lactation</td>
<td>34</td>
<td>27</td>
<td>32</td>
<td>45</td>
<td>37</td>
</tr>
<tr>
<td>N in Late lactation</td>
<td>53</td>
<td>74</td>
<td>65</td>
<td>58</td>
<td>81</td>
</tr>
<tr>
<td>--------------------</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

1 Bred heifers
Table 3.3. Number of lesions observed at each Exam period through June 2009, September 2009, January 2010, May 2010, and August 2010, referred to as Exam 1, 2, 3, 4 and 5, respectively. Number of cows with multiple lesions shown indicated in brackets.

<table>
<thead>
<tr>
<th></th>
<th>Exam 1</th>
<th></th>
<th></th>
<th>Exam 2</th>
<th></th>
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<th></th>
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<th>Exam 4</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Front</td>
<td>Hind</td>
<td>Total</td>
<td>Front</td>
<td>Hind</td>
<td>Total</td>
<td>Front</td>
<td>Hind</td>
<td>Total</td>
<td>Front</td>
<td>Hind</td>
<td>Total</td>
<td>Front</td>
<td>Hind</td>
</tr>
<tr>
<td>Sole Ulcer</td>
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<td>16</td>
<td>15</td>
<td>33</td>
<td>19</td>
<td>14</td>
<td>54</td>
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<td>31</td>
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<td>13</td>
<td>16</td>
<td>97</td>
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<td>(5)</td>
<td></td>
<td></td>
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<tr>
<td>Digital dermatitis</td>
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<td>(4)</td>
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<tr>
<td>Hemorrhage</td>
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<td>106</td>
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<td>137</td>
<td>369</td>
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<tr>
<td>Interdigital dermatitis</td>
<td>117</td>
<td>44</td>
<td>73</td>
<td>130</td>
<td>56</td>
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<td>16</td>
<td>14</td>
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<td>0</td>
<td>1</td>
<td>13</td>
<td>2</td>
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<td></td>
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<td>(41)</td>
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<tr>
<td>Heel horn erosion</td>
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<td>219</td>
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<td>239</td>
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<td>(72)</td>
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<td>(99)</td>
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<td>2</td>
<td>2</td>
<td>3 (0)</td>
<td>1</td>
<td>2</td>
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64
<table>
<thead>
<tr>
<th>abscess</th>
<th>White line</th>
<th>2 (0)</th>
<th>0</th>
<th>2</th>
<th>13</th>
<th>6</th>
<th>7</th>
<th>0 (0)</th>
<th>0</th>
<th>0</th>
<th>1 (0)</th>
<th>0</th>
<th>1</th>
<th>8 (2)</th>
<th>1</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
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<td>(3)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of cows</td>
<td>122</td>
<td>145</td>
<td>161</td>
<td>171</td>
<td>161</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Table 3.4. Cow-level prevalence of lesions by exam period through June 2009, September 2009, January 2010, May 2010, and August 2010, referred to as Exam 1, 2, 3, 4 and 5, respectively. The number of cows with lesions at that time period (and percentage of total cows examined) are listed.

<table>
<thead>
<tr>
<th>Lesion Type</th>
<th>Exam 1</th>
<th>Exam 2</th>
<th>Exam 3</th>
<th>Exam 4</th>
<th>Exam 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole ulcer</td>
<td>24 (19.7)</td>
<td>23 (15.9)</td>
<td>40 (24.8)</td>
<td>21 (12.3)</td>
<td>58 (36.0)</td>
</tr>
<tr>
<td>Digital dermatitis</td>
<td>61 (50.0)</td>
<td>58 (40.0)</td>
<td>36 (22.3)</td>
<td>12 (7.0)</td>
<td>24 (14.9)</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>99 (81.1)</td>
<td>93 (64.1)</td>
<td>133 (82.6)</td>
<td>106 (62.0)</td>
<td>147 (91.3)</td>
</tr>
<tr>
<td>Heel horn erosion</td>
<td>88 (72.1)</td>
<td>99 (68.3)</td>
<td>45 (28.0)</td>
<td>36 (21.1)</td>
<td>30 (18.6)</td>
</tr>
<tr>
<td>Interdigital dermatitis</td>
<td>68 (55.7)</td>
<td>70 (48.3)</td>
<td>10 (6.2)</td>
<td>1 (0.6)</td>
<td>11 (6.8)</td>
</tr>
<tr>
<td>White line abscess</td>
<td>0 (0)</td>
<td>2 (1.4)</td>
<td>1 (0.6)</td>
<td>3 (1.7)</td>
<td>3 (1.9)</td>
</tr>
<tr>
<td>White line separation</td>
<td>2 (1.6)</td>
<td>10 (6.9)</td>
<td>0 (0)</td>
<td>1 (0.6)</td>
<td>5 (3.1)</td>
</tr>
<tr>
<td>Total cows examined</td>
<td>122</td>
<td>145</td>
<td>161</td>
<td>171</td>
<td>161</td>
</tr>
</tbody>
</table>
Table 3.5. Annual incidence of lesions throughout the trial period from June 2009 to August 2010. Incident cases were included if the cow had not had the same lesion at the previous exam.

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Annual incidence (cases/100 cow years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole ulcer</td>
<td>10.9</td>
</tr>
<tr>
<td>Digital dermatitis</td>
<td>7.6</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>23.6</td>
</tr>
<tr>
<td>Heel horn erosion</td>
<td>8.3</td>
</tr>
</tbody>
</table>
Table 3.6. Odds ratios and 95% CI for sole ulcers, digital dermatitis, hemorrhage and erosion based on presence of the same lesion in the same cow at the previous trim and cow included as a random effect¹.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Previous lesion presence</th>
<th>Odds ratio</th>
<th>CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole Ulcer</td>
<td>Sole ulcer</td>
<td>3.11</td>
<td>1.77, 5.46</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Digital dermatitis</td>
<td>Digital dermatitis</td>
<td>4.31</td>
<td>2.03, 3.70</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>Hemorrhage</td>
<td>1.10</td>
<td>0.63, 1.92</td>
<td>0.474</td>
</tr>
<tr>
<td>Erosion</td>
<td>Erosion</td>
<td>4.74</td>
<td>3.14, 7.14</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

¹Parity and days in milk not significant (p>0.05) in all models.
Table 3.7. Odds ratios and 95% CI for sole ulcer and heel horn erosion based on presence of prior lesion at the previous hoof exam in the same location\(^1\) or same limb\(^2\) with cow included in model as random effect\(^3\).

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Prior lesion</th>
<th>Odds ratio</th>
<th>95 % CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole Ulcer(^1)</td>
<td>Hemorrhage</td>
<td>1.61</td>
<td>1.13, 2.31</td>
<td>0.009</td>
</tr>
<tr>
<td>Heel horn erosion(^2)</td>
<td>Digital dermatitis</td>
<td>1.62</td>
<td>1.11, 2.35</td>
<td>0.01</td>
</tr>
</tbody>
</table>

\(^3\)Parity and days in milk not significant (p>0.05) in all models.
Figure 3.1. Lesion anatomic numbering system. Used with permission (Shearer et al., 2004).
Chapter 4. Early identification of dairy cattle with major hoof lesions using continuous measurement of activity and lying behaviour

Introduction

Lameness is one of the greatest welfare concerns in the dairy industry, with high prevalence reported worldwide. North American estimates of prevalence range from 21 to 25% of cows housed in free-stalls (Cook, 2003; Espejo et al., 2006). Cows are at risk throughout their lactation, however lameness incidence has been found to peak three months into lactation (Green et al., 2002). Dairy cattle lameness commonly results from lesions present in their hooves rather than injury in the leg (Murray et al., 1996). In a cross-sectional Canadian study it was observed that 47% of cows in free-stall housing and 27% of cows in tie-stall housing had lesions on their hooves (Cramer et al., 2008). In addition to high prevalence, lameness itself is an indicator of pain in the cow, causing increased concern for the welfare of these animals.

Lameness is commonly identified through the process of locomotion or gait scoring, where animals are observed while walking and various kinematic characteristics are identified. These subjective scoring systems are often based on a 5-point scale ranging from normal to severely lame (Manson and Leaver, 1988; Sprecher et al., 1997; Flower and Weary, 2006). However, detection of lame cows is difficult and farm workers appear to be unable to recognize approximately 30% of cows that are lame (Whay et al., 2003; Espejo et al., 2006). In addition to difficulties in identification of lame cows, subtle changes in cattle behaviour such as changes in locomotion are not detected until hoof injuries are advanced (O'callaghan et al., 2003). Therefore, there is a need for the
development and validation of automated methods for lameness detection. The use of accelerometers, which in cattle measure the acceleration of the limb to determine activity and lying/standing behaviour, is being investigated as a potential method for lameness and lesion detection.

The first objective of this study was to describe differences in activity and lying behaviour in cows housed in both tie- and free-stall housing, when the confounding effects of milking management were removed. The second objective was to determine if there are consistent and significant differences in activity and lying behaviour between lame and sound cows. The third objective was to determine if changes in lying behaviour and activity could be observed between cows with sole ulcers, digital dermatitis, and without the presence of painful lesions. The final objective of this research was to investigate changes in lying behaviour and activity when cows were known to have painful lesions compared to periods when no painful lesions were present, with the potential application for early detection of hoof lesions prior to clinical lameness.

**Materials and Methods**

All Holstein cows in the milking herd, dry cows and close-up heifers at the Elora Dairy Research Centre, Elora ON, were enrolled in the trial (n=239). The cow housing facility consisted of both free-stall and tie-stall sections, which housed 40 and 120 cows, respectively. Close-up heifers were housed in a separate tie-stall section of the barn. The free-stall stocking density ranged throughout the trial period from 1.0 to 0.68 cows/stall, with a mean of 0.78 cows/stall. All animals entered the same milking parlour twice daily for milking and were fed the same total mixed ration, balanced for nutritional
requirements, three times daily. Cows produced on average 33 (±2.9) L milk/day. Parity and lactation information was accessed from DairyPlan C21 (GEA Farm Technologies, Naperville, IL) for data in 2009 and DairyCOMP 305 (Valley Agricultural Software, Tulare, CA) for data in 2010. All stalls contained rubber mattresses (Pasture Mat®, Promat Inc., Ontario, Canada) covered with a thin layer of straw.

All cows had their hooves examined every three to four months, in June 2009, September 2009, January 2010, May 2010, and August 2010, referred to as Exam 1, 2, 3, 4 and 5, respectively. Cows had their hooves trimmed every second visit, approximately 6 months apart, by a veterinarian specializing in hoof trimming and dairy cattle lameness (author GC). During non-trim exam periods a thin layer of horn was removed using a grinder to facilitate identification of lesions present on the claw. Cows were restrained in a hydraulic lift table (Comfort Hoof Care, Baraboo, WI) and lifted vertically for hoof exams and trimming.

**Data Collection**

**Lesions.** Hoof lesions were identified based on standardized definitions (Cramer et al., 2008). Location, approximate shape and size of lesions were recorded onto data collection sheets. Labeled digital photographs of each hoof were taken and stored for later reference if needed. Sole ulcers and digital dermatitis are the most prevalent painful hoof horn and infectious lesions that cause lameness in dairy cattle, and therefore these were selected for inclusion and further study. Cows without painful lesions were used as controls for comparison. Digital dermatitis was defined as sore, raw, sometimes hairy area on the skin around the heels and between the claws (Gomez and Cook, 2010; Cramer
et al., 2008). Digital dermatitis was identified through visual observation, and pain was determined through use of an algometer (Pain Test™ FPX 50 Algometer, Wagner Instruments, Greenwich, CT) which was pressed against the lesion with steadily increasing pressure until the nociceptive threshold was reached, as determined by a leg withdrawal or avoidance response. Sole ulcers were defined as defects in the sole horn that exposed the corium, which could be accompanied by granulation tissue (Cramer et al., 2008). Sole ulcers were distinguished from hemorrhages by a leg withdrawal response to either pressure algometry or hoof testers, applied directly to the lesion site, indicating that the lesion was painful to the cows, and thus being classified as an early sole ulcer.

**Locomotion Scoring.** A digital video recorder (Canon DC100 DVD Camcorder, Canon Canada Inc, Mississauga, ON) was mounted on a tripod to record cows walking along a return alley, on a rubber floor. Cows were kept moving forward at an even pace by a handler walking behind them providing vocal encouragement. Cows that failed to maintain a consistent gait were cycled back through the alley and recorded again until a satisfactory transit was obtained. A minimum of two good strides was considered an acceptable recording. Video was recorded within four days prior to hoof examination, and occurred between two hours after morning milking and two hours before afternoon milking to attempt to standardize for udder fill. Locomotion was scored from video images using a 1 to 5 scoring system developed by Flower and Weary, (2006) by a trained observer (author JHC). Cows that received a score of 3 or above were considered lame and included in the lame cow dataset.
**Accelerometers.** Lying and activity data were collected using a Pedometer Plus™ unit (SAE Afikim, Israel) attached loosely to the left hind leg of each cow with a 4 cm wide and 38 cm long nylon strap. Data were downloaded from pedometers upon exit from the milking parlour twice daily. The Pedometer Plus device recorded activity in the form of mean number of leg movements (Chapter 2) per hour. Additionally, lying and standing behaviours were recorded continuously by the device through use of a tilt switch. Data output, through the herd recording software program Afimilk, included the number of lying bouts, mean lying duration and mean number of steps (leg movements) per hour that occurred since the previous reading of the accelerometer. Data were processed and summarized by cow on a daily basis through weekly backups by SAE Afikim.

**Datasets**

For all datasets, activity and lying behaviour data for the week prior to the exam period of interest had to be present for inclusion in the dataset. Locomotion scores were only used in the lameness dataset.

**Housing type.** Cow housed in both the free-stall and tie-stall facilities were included in the dataset. Exclusion criteria included presence of any lesion considered painful, through use of algometry or hoof testers.

**Lameness between cows.** Cows that had a locomotion score of 3 or greater (LAME) were compared to cows with a locomotion score of less than 3 (SOUND). LAME cows included in the dataset had either digital dermatitis or sole ulcers upon hoof exam while cows in the SOUND group had no painful lesions. Only cows housed in tie-
stalls were included in this analysis due to the small number of cows with locomotion scores housed in free-stalls.

**Lesions between cows.** Cows with sole ulcers, digital dermatitis, or a combination of the two were included in the dataset, as well as cows with no painful lesions present during an exam as controls. Cows in both housing systems were included.

**Lesions within cows.** Cows included in this data set had no painful lesions present during the first exam period but had either sole ulcers of digital dermatitis during the following exam period. A control group with no lesions during both periods was also included to ensure that differences were due to time between exam periods rather than lesion appearance.

**Statistical Analysis**

All activity, lying duration and lying bout data were summarized and reported as means for the seven days prior to an exam. Standard deviation of each measure was calculated and reported as a measurement of variation in behaviour. The day during which a cow was locomotion scored was removed from analysis due to the disruption in daily time budget that occurred and the impact that might have on activity. All analyses were completed using SAS (Statistical Analysis Software, Version 9.2). Statistical significance was set at p<0.05. Parity and days in milk of the cows were offered as fixed effects in all models, and removed through backward elimination if p-values did not reach significance. In models examining lesions (described below), housing type was also offered into models.
**Housing.** Since the facility used for the studies included both tie-stall and free-stall housing, differences in activity and lying behaviour between the housing systems that should be controlled for in lesion modeling was assessed. The effect of housing type on activity and lying measures was assessed by linear regression using the MIXED procedure, with days in milk and parity included in models to account for potential confounding.

**Lameness between cows.** To determine if lameness affected activity and lying behaviour, linear mixed models using the GLM procedure were used to compare locomotion scores for LAME and SOUND cows from the within-cow models. A separate model was created for activity, lying duration and number of lying bouts, as well as for the standard deviation of each of those values. Normality was assessed and non-normal data were log transformed.

**Lesions between cows.** To determine if digital dermatitis and sole ulcers affect behaviour differently, linear mixed models were used. A separate model was created for the outcomes activity, lying duration, and number of lying bouts, as well as one for the standard deviation of each of those values. Normality was assessed for each independent variable and non-normal data were log transformed.

**Lesions within cows.** To determine if automated activity and lying measures could be used to identify cows with lesions, comparisons between two exam periods were made. For inclusion in this part of the study, cows had no painful lesions at one exam period and then had a painful lesion (digital dermatitis or ulcer) at the following exam period. All cows without painful lesions in two consecutive exam periods were included as controls. Additionally, cows had to be housed in the same housing system between the
two periods of time for inclusion. A generalized linear mixed model was used to assess change between the two time periods with univariable output included. Multivariate linear regression was used to assess potential combinations of measures that could be used to determine differences between the two time periods. All potential two-way combinations were assessed to determine if there were significant differences between the two time periods. Three way combinations of activity, lying duration and lying bouts, as well as another model including the standard deviation of activity, lying duration and lying bouts, were assessed separately.

**Results**

**Housing type**

Seventy-seven cows over 108 exam periods in which no painful lesions were present were used for analysis. Differences were observed in activity and lying behaviour, which are summarized in Table 4.1. Activity differed between the two housing systems, with cows in free-stall housing showing increased activity and variability in activity within cow. Cows in tie-stalls, although having a similar duration of daily lying, performed a mean of 2 lying bouts a day more than free-stall cows. Since DIM could have been a confounder, this was assessed through removal of the variable from models. Changes of >25% were not observed in intercepts.
**Lameness between cows**

Eleven cows with ulcers, one cow with digital dermatitis, and three cows with both ulcers and digital dermatitis were observed lame and included in analysis. Lame cows were significantly less active and had greater lying duration compared to sound cows, as shown in Table 4.2.

**Lesions between cows**

Activity and lying behaviour differences by housing type and lesion can be found in Table 4.3. For all activity and lying measures, no interaction between lesion type (ulcer, digital dermatitis, both ulcer and digital dermatitis or no painful lesions) and housing was observed. As observed in the housing type, activity was greater and lying bouts were fewer in free-stalls compared to tie-stalls (p<0.0001). Lying duration was higher in cows with ulcers and lower in cows with digital dermatitis. However, there was no consistent effect of lesion type on lying duration behaviour, however lying bouts were decreased in cows with digital dermatitis or both digital dermatitis and sole ulcers, and activity decreased in cows with sole ulcers and digital dermatitis.

**Lesions within cows**

Twenty-two cases of ulcers, ten cases of digital dermatitis, and eight cows with both ulcers and digital dermatitis were included in this analysis. In addition, nine cows without visible painful lesions and with locomotion scores under 3 were included as controls in the dataset. As shown in Table 4.4, little difference was observed within cow between the week before a painful lesion was observed (Painful) and a week
approximately 3 months prior (Pre) when no painful lesions were present. Lying duration differed between the two time periods, with cows lying for 55 minutes more when a painful ulcer was present compared to when they did not have a painful lesion (p=0.03). As well, no combinations of measures of activity and lying behaviour measures in multivariate analysis differed between the two time periods (p>0.05).

Discussion

Digital dermatitis and sole ulcers were included as lesions of interest due to the pain experienced by cattle with these lesions. Digital dermatitis has been shown to be painful through mechanical nociception techniques such as algometry (Chapter 5), where cows withdrew their limbs at much lower amounts of pressure when active and did not react to pressure once healed. Other pain assessments have included water sprayed at the lesion site (Hernandez et al., 1999), which caused a withdrawal prior to treatment with oxytetracycline. Changes in locomotion due to digital dermatitis infection has not been studied. Sole ulcers have been shown to cause alterations in gait which are reduced in a dose-dependent fashion with the administration of analgesics to the cow (Flower et al., 2008), indicating that pain is causing the change in gait.

Sound cow housing differences.

Activity and lying measurement comparisons between free-stalls and tie-stalls are usually confounded by management at the time of milking, since tie-stall cows are milked in their stall and free-stall cows typically go to a parlour for milking. The time required for milking in these two systems is very different, and an increase in activity due to travel
to the parlour would be observed, as well as longer disruption in standing and lying patterns. However, since cows in this study were in a unique barn design where cows in both systems go to the parlour for milking, any differences in activity and lying were due to the housing system and not the milking system or location.

Activity and standard deviation of activity were both increased in the free-stall system compared to tie-stalls, as expected. However, cows housed in the free-stall only displayed 1.4 times the activity of those in the tie-stall. This suggests that much of the difference normally observed between the two housing systems is accounted for in the milking process. Additionally, since the accelerometers used in the study measure almost all movement rather than steps (Chapter 2), shifting and steps within the tie-stall were also measured. These results indicated that cows in tie-stalls are still quite ‘active’ but don’t travel. From a welfare perspective, this has several implications. One of the main arguments against housing in tie-stalls is the lack of ability for cows to move freely. It appears that cows housed in this facility may be attempting to compensate for inability to perform locomotor movement by shifting or moving within the confines of their stall. Whether this is an indication of adaptation to the housing system or movement due to frustration of a confined space needs to be further elucidated in studies designed to examine that behaviour.

Lying duration was not different between the two housing systems, with both groups having a mean daily lying duration of just over 11 hours. Since cows in the free-stall were not required to compete for access to resting location with a stocking density above 100% throughout the trial period, which would decrease their lying time (Fregonesi et al., 2007), it is not surprising that the cows were lying for similar amounts
of time. Had competition for resting space been higher in free-stalls, this would have likely been reflected in shorter lying duration.

Average lying bout frequency was 2 bouts/day higher in tie-stalls than in free-stalls. The number of lying bouts in free-stalls were lower than frequencies of 13 bouts/day previously reported through observation of cows in 16 US freestall barns (Gomez and Cook, 2010). The results of this study also contradict those of Haley and colleagues (2000), with cows in pens having 5 more lying bouts per day than cows in tie-stalls; however, the cows in bedded pens in that study were housed individually, which likely altered their lying behaviour. Those authors suggested the increased number of lying bouts may be due ease of transitions between standing and lying (Haley et al., 2000). Krohn and Munksgaard (1993) determined that it took cows 6 seconds longer to lie down in straw bedded concrete stalls than deep-bedded loose housing system. Cows in tie-stalls may have been disrupted more often due to increased presence of farm staff in this area compared to the free-stall.

Due to the observed differences in both activity and lying behaviour, housing type was taken into consideration in all analyses.

Lame Cows

Within cow differences were expected between periods when cows were lame and when they were not lame based on locomotion scores. Changes in activity and lying duration were most obvious between the lame and non-lame cows, with lame cows decreasing their activity and increasing the duration of daily lying time. These results are consistent with other published material on lame cows. In this study, lame cows had a
decreased activity of 24% compared to sound cows. Research by Mazrier and colleagues (2006) found that 92% of the cows that developed clinical lameness had a decrease in pedometric activity of at least 15%. Lying duration has also been shown to increase in cows that are lame compared to non-lame cows (Thomsen et al., 2012; Chapinal et al., 2009; Singh et al., 1993), likely due to pain while standing.

More frequent locomotion scoring would have allowed for additional data that could have been used to better discriminate between cows when lame and not lame. Due to the changes observed between lame and non-lame cows, the use of these measures shows promise.

_Lesions between cows_

Cows with digital dermatitis and sole ulcers were compared to cows without any painful lesions to determine if there was a general change in behaviour in cows with painful lesions, regardless of their locomotion scores. In cows with ulcers, lying duration was greater compared to cows with no painful lesions. This was due to longer lying bouts since the number of lying bouts did not increase. This increase in lying duration in cows with ulcers has also been reported when compared to cows that did not have ulcers (Chapinal et al., 2009). Cows with digital dermatitis lesions had fewer lying bouts than cows with no visible lesions, as did cows with both sole ulcers and digital dermatitis. Digital dermatitis lesions can be very painful and sensitive to pressure (Chapter 5), therefore it is likely that cows were unwilling to lie down or rise, resulting in few lying bouts. In other research, more frequent lying bouts, 13.6 per day, have been observed in dairy cattle housed in large pens with mattresses and chopped straw (Haley et
al., 2000), an environment presumed to be comfortable for cows. Lying duration was also decreased in cows with digital dermatitis, likely also demonstrating a reluctance to lie down. In cows with both sole ulcers and digital dermatitis, activity decreased and the number of lying bouts decreased. If painful to move due to the presence of both types of lesions, it was expected that activity would decrease. As in cows with digital dermatitis, these cows were also likely reluctant to lie down.

Differences in behaviour between the two hoof lesions could be due to several factors. Location of lesions on the hoof is different, with sole ulcers typically appearing in the middle of the lateral claw (Rushen et al., 2008; Amory et al., 2008) of the hind limb (Whay et al., 1997; Cramer et al., 2008) while digital dermatitis typically occurs at the heel or interdigital cleft (Hernandez and Shearer, 2000). Severity of pain could also differ between the two lesions. Finally, while the etiology of digital dermatitis is still undetermined, the presence a bacterial infection is believed to play an important role (Klitgaard et al., 2008; Evans et al., 2009), which could potentially cause a sickness behaviour response in the cow if severe. Unless followed by infection, sole ulcers would cause a systemic effect and would therefore not cause sickness behaviour in cattle.

Lesions within cows

Lying duration differed between time periods, with an increase in almost an hour per day when cows had painful lesions compared to a week approximately 3 months prior when no painful lesions were present. Lying duration has been shown to increase by greater than one hour in severely lame cows housed in deep-bedded pens (Ito et al., 2010), but a difference was not observed in severely lame cows housed in mattress stalls
in the same study. The observation of changes in lying duration during lesion presence demonstrates potential for use for detection of subclinical or early onset of hoof disease.

In order to use accelerometers to flag cows that could be potentially becoming lame, changes in activity and lying behaviour within cow would need to be altered. It was expected that cows would show alterations in their activity and lying behaviour between periods when painful lesions were and were not present. However, there was great variation in these measures even within cow from day to day, making slight changes very difficult to detect.

Conclusions

Changes in activity and lying behaviour were observed when comparing cows housed in tie-stall and free-stall environments with the confounding effect of milking process removed. Activity, lying duration, and lying bouts were found to be altered with sole ulcers and digital dermatitis compared to cows without painful lesions. Lying duration was increased in periods where cows had painful lesions compared to periods when cows had no painful lesions present on their hooves. The use of these lying duration, lying bouts and activity measures for detection of cows that are lame does show promise and could potentially be used to flag cows requiring observation, however this area requires further study for behaviour within cows.
References


Table 4.1. Least Squares Mean (±SE) of accelerometer measurements\(^1\) and regression\(^2\) for cows with no painful lesions in tie-stall and free-stall housing, where all cows enter a parlour for milking. Pedometer Plus readings of activity, lying duration and lying bouts, as well as the standard deviation (SD) of each measure is presented.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Free-stall</th>
<th>Tie-stall</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parity</td>
<td>1.9 (±0.2)</td>
<td>2.1 (±0.1)</td>
<td></td>
</tr>
<tr>
<td>DIM</td>
<td>250.6 (±22.6)</td>
<td>163.1 (±12.5)</td>
<td></td>
</tr>
<tr>
<td>Activity (movements/hour)</td>
<td>128.45 (5.82)</td>
<td>90.02 (4.21)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Lying duration (minutes/day)</td>
<td>681.69 (18.10)</td>
<td>665.14 (15.02)</td>
<td>0.54</td>
</tr>
<tr>
<td>Lying bouts (#/day)</td>
<td>10.29 (0.58)</td>
<td>12.29 (0.42)</td>
<td>0.02</td>
</tr>
<tr>
<td>Activity SD</td>
<td>24.54 (3.25)</td>
<td>16.41 (1.38)</td>
<td>0.01</td>
</tr>
<tr>
<td>Lying duration SD</td>
<td>97.27 (13.48)</td>
<td>88.92 (7.37)</td>
<td>0.51</td>
</tr>
<tr>
<td>Lying bouts SD</td>
<td>2.03 (0.18)</td>
<td>2.55 (0.37)</td>
<td>0.61</td>
</tr>
</tbody>
</table>

\(^1\) Data are averaged over one week prior to hoof exam, confounding effects of DIM and parity included

\(^2\) Regression analysis performed on data averaged over one week prior to hoof exam
Table 4.2. Activity and lying behaviour in cows that were lame with ulcers or digital dermatitis and cows that were not lame (sound). Pedometer Plus readings of activity, lying duration and lying bouts, as well as the standard deviation (SD) of each measure is presented.

<table>
<thead>
<tr>
<th></th>
<th>Sound</th>
<th>Lame</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>11</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Parity</td>
<td>1.63 (±0.36)</td>
<td>1.93 (0.23)</td>
<td></td>
</tr>
<tr>
<td>DIM</td>
<td>199.22 (18.23)</td>
<td>184.93 (19.12)</td>
<td></td>
</tr>
<tr>
<td>Activity</td>
<td>113.61 (93.86-133.35)</td>
<td>80.80 (64.68-96.92)</td>
<td>0.01</td>
</tr>
<tr>
<td>Activity SD</td>
<td>28.29 (18.94-37.63)</td>
<td>14.41 (6.78-22.04)</td>
<td>0.03</td>
</tr>
<tr>
<td>Lying Bouts</td>
<td>10.89 (8.73-13.04)</td>
<td>12.50 (10.74-14.26)</td>
<td>0.24</td>
</tr>
<tr>
<td>Lying Bouts SD</td>
<td>1.93 (1.28-2.57)</td>
<td>2.64 (2.11-3.16)</td>
<td>0.09</td>
</tr>
<tr>
<td>Lying Duration</td>
<td>586.62 (514.87-658.37)</td>
<td>682.99 (627.49-738.49)</td>
<td>0.04</td>
</tr>
<tr>
<td>Lying Duration SD</td>
<td>74.69 (47.72-101.67)</td>
<td>77.53 (55.51-99.56)</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Data shown is the mean of the week prior to hoof exam, with day of locomotion scoring removed.
Table 4.3. Least Squares Means with associated confidence intervals and regression analysis of accelerometer output for lesions between cows. Lesions included non-painful lesions (No lesion; n=77), sole ulcers (Ulcer; n=53), digital dermatitis (n=78) and both ulcers and digital dermatitis (Ulcer + dd; n=32).

<table>
<thead>
<tr>
<th>Accelerometer Measure</th>
<th>Variable</th>
<th>Category</th>
<th>LS Means</th>
<th>p-value</th>
<th>Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity</td>
<td>Housing</td>
<td>Tie-stall</td>
<td>79.00</td>
<td>Referent</td>
<td>75.24-82.96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Free-stall</td>
<td>105.76</td>
<td>&lt;0.0001</td>
<td>95.69-116.55</td>
</tr>
<tr>
<td>Lesion</td>
<td>No lesion</td>
<td>97.78</td>
<td>Referent</td>
<td>90.92-105.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ulcer</td>
<td>96.93</td>
<td>0.88</td>
<td>87.98-106.80</td>
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</tr>
<tr>
<td></td>
<td>Digital dermatitis</td>
<td>91.08</td>
<td>0.15</td>
<td>84.56-98.09</td>
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</tr>
<tr>
<td></td>
<td>Ulcer + dd</td>
<td>80.87</td>
<td>0.008</td>
<td>71.14-91.94</td>
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</tr>
<tr>
<td>Lying duration</td>
<td>Housing</td>
<td>Tie-stall</td>
<td>650.93</td>
<td>Referent</td>
<td>633.59-668.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Free-stall</td>
<td>643.94</td>
<td>0.72</td>
<td>610.33-679.46</td>
</tr>
<tr>
<td>Lesion</td>
<td>No lesion</td>
<td>653.54</td>
<td>Referent</td>
<td>627.85-680.28</td>
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</tr>
<tr>
<td></td>
<td>Ulcer</td>
<td>706.77</td>
<td>0.01</td>
<td>670.28-745.31</td>
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<td></td>
<td>Digital dermatitis</td>
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<td>590.05-640.28</td>
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</tr>
<tr>
<td></td>
<td>Housing</td>
<td>Tie-stall</td>
<td>Referent</td>
<td>11.05-11.97</td>
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<td>----------------</td>
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<td>----------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>Lying bouts</td>
<td>Ulcer + dd</td>
<td>618.87</td>
<td>0.17</td>
<td>576.46-664.41</td>
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<td></td>
<td>Free-stall</td>
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<td>8.52-10.23</td>
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<tr>
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<td>No lesion</td>
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<td>Referent</td>
<td>10.57-11.94</td>
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<td></td>
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<td>0.37</td>
<td>10.86-12.62</td>
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<td>Digital dermatitis</td>
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<td>0.0002</td>
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<td>0.005</td>
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<td>12.07-14.27</td>
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</tr>
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<td>79.76-103.26</td>
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<tr>
<td>Ulcer</td>
<td>88.17</td>
<td>0.72</td>
<td>73.14-103.19</td>
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<td>72.39-96.46</td>
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<tr>
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<td>76.73</td>
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<td>56.07-97.38</td>
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<table>
<thead>
<tr>
<th>Lying bouts SD</th>
<th>Housing</th>
<th>Tie-stall</th>
<th>Referent</th>
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</table>

<table>
<thead>
<tr>
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<tr>
<td>Ulcer</td>
<td>1.89</td>
<td>0.99</td>
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<td>1.51-1.86</td>
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<td>0.02</td>
<td>1.25-1.78</td>
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</table>
Table 4.4. Within cow comparisons of activity and lying measures from the week prior to hoof exam when cows where known to have no painful lesions (pre) to the week prior to identification of a painful lesion (painful). Controls with no lesions at both time periods (No lesion; n=9) were included and compared to cows with sole ulcers (Ulcer; n=22), digital dermatitis (dd; n=12) or both ulcers and digital dermatitis (Both; n=8).

<table>
<thead>
<tr>
<th>Accelerometer Measure</th>
<th>Variable</th>
<th>Category</th>
<th>LS Means</th>
<th>p-value</th>
<th>Confidence interval</th>
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<td>Activity</td>
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<td>92.11</td>
<td>Referent</td>
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<td>Ulcer</td>
<td></td>
<td>93.97</td>
<td>0.75</td>
<td>87.56-100.37</td>
</tr>
<tr>
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<td>Dd</td>
<td></td>
<td>98.31</td>
<td>0.35</td>
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<tr>
<td></td>
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<td>81.89</td>
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<td>71.27-92.52</td>
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<td>Time</td>
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<td>Referent</td>
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<td>0.56</td>
<td>86.47-99.30</td>
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<td>No lesion</td>
<td>651.07</td>
<td>Referent</td>
<td>597.82-704.33</td>
</tr>
<tr>
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<td>Ulcer</td>
<td></td>
<td>633.63</td>
<td>0.58</td>
<td>599.59-667.72</td>
</tr>
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<td>Dd</td>
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<td>614.16</td>
<td>0.30</td>
<td>568.04-660.28</td>
</tr>
<tr>
<td></td>
<td>Lesion</td>
<td>No lesion</td>
<td>Referent</td>
<td></td>
<td></td>
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<td>--------------</td>
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<td></td>
</tr>
<tr>
<td><strong>Lying bouts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Both</td>
<td>648.24</td>
<td>0.94</td>
<td>591.75-704.72</td>
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<tr>
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<td>Pre</td>
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<td>Referent</td>
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<td><strong>Activity SD</strong></td>
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<tr>
<td>Lesion</td>
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<td>11.63-13.66</td>
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<tr>
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<td>0.20</td>
<td>11.21-12.51</td>
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<tr>
<td>Dd</td>
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<td>0.09</td>
<td>10.62-12.38</td>
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<td></td>
</tr>
<tr>
<td>Both</td>
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<td>0.10</td>
<td>10.33-12.49</td>
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<td></td>
</tr>
<tr>
<td>Time</td>
<td>Pre</td>
<td>12.17</td>
<td>Referent</td>
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<td>Painful</td>
<td>11.53</td>
<td>0.17</td>
<td>10.88-12.18</td>
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<tr>
<td><strong>Time</strong></td>
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<td></td>
</tr>
<tr>
<td>Pre</td>
<td>12.17</td>
<td>Referent</td>
<td>11.52-12.82</td>
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<tr>
<td>Painful</td>
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<td>0.17</td>
<td>10.88-12.18</td>
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<td>Referent</td>
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<tr>
<td>Lying bouts SD</td>
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<td>Referent</td>
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<td>0.55</td>
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Chapter 5. Randomized clinical trial of tetracycline hydrochloride bandage and paste treatments for resolution of lesions and pain associated with digital dermatitis in dairy cattle

(Prepared for submission to Journal of Dairy Science)

J. H. Cutler,* G. Cramer,** J. J. Walter,* S.T. Millman,‡ D.F. Kelton*
*Department of Population Medicine, University of Guelph, Guelph, ON, Canada
†Cramer Mobile Bovine Veterinary Services, Stratford, ON, Canada
‡Veterinary Diagnostic and Production Animal Medicine, Iowa State University, Ames, IA, USA

¹Corresponding author: Janet Higginson Cutler jhiggins@uoguelph.ca

Janet Higginson Cutler
Department of Population Medicine
University of Guelph
Guelph, ON, Canada
N1G 4W1
Phone: 519-824-4120 x54595
Fax: 519-763-8621
Abstract

Digital dermatitis is an infectious disease that causes lameness in dairy cattle, one of the primary welfare concerns of the dairy industry. As a painful disease, it is commonly treated with application of an antibiotic bandage that must be removed following treatment. The objectives of this randomized clinical trial were to determine if topical application of tetracycline hydrochloride in a paste would be as therapeutically effective for the treatment of digital dermatitis as a powdered form of tetracycline hydrochloride held in place by a bandage, and to quantify pain associated with digital dermatitis lesions. Two hundred and fourteen hooves with digital dermatitis lesions were randomly assigned to one of three treatments; a tetracycline hydrochloride paste, tetracycline hydrochloride powder held in place with a bandage for two days, or a negative (untreated) control. Lesions were examined at two time periods, 3-7 days post-treatment and 8-12 days post-treatment to determine healing rates. Nociceptive thresholds were measured using a pressure algometer to quantify the pain at the lesion site once the leg was restrained. The tetracycline hydrochloride paste was as effective as the powdered bandage treatment in terms of healing rates, with 47.4% and 57.1% hooves healed at 8-12 days post treatment, respectively. Both treatments were more effective than the control, in which there was no lesions healed 8-12 days following initial exam. Mean (±SE) nociceptive thresholds for active, healing and healed lesions differed, with limb withdrawal response occurring at 7.45 (±0.67) kg, 12.84 (±1.85) kg, and 25 kg (censored) of force applied, respectively. However, active lesions were not consistently associated with pain, since maximum force was tolerated when applied to 19% of active lesions, perhaps due to variability in stoicism between individual cattle or due to changes in pain
during the progression of infection. In conclusion, tetracycline hydrochloride paste was as effective as tetracycline hydrochloride bandage, eliminating the need for bandage removal following treatment application. Digital lesions can be painful during both active and healing stages, suggesting the need for treatment and husbandry interventions for pain mitigation.

**Key Words:**
Digital dermatitis, lameness, tetracycline hydrochloride, pain, pressure algometry
Introduction

Lameness is considered one of the most important animal welfare concerns for the dairy industry. This is due to many factors, including pain, impact on performance, high prevalence in the industry, as well as difficulty in both detection and treatment of causative lesions. Since first described in Italy by Cheli and Mortellaro in 1974, digital dermatitis has been a persistent problem. This infectious disease is a common cause of lameness in dairy cattle, with low healing rates as well as difficulties with treatment application.

Prevalence of digital dermatitis varies among countries. In a Canadian cross-sectional study including 204 Ontario dairy farms, 69.7% of tie-stall herds and 92.1% of free-stall herds had animals with digital dermatitis (Cramer et al. 2008). In the US, prevalence has been estimated at 43.5% of dairy herds (Wells et al. 1999). Additionally, the authors determined that 81.9% of cows with digital dermatitis lesions were lame (Wells et al., 1999), suggesting that this is a painful condition in at least some animals. However, accurate quantification of the intensity and duration of pain associated with digital dermatitis lesions has not been performed.

As reviewed by Laven and Logue (2006), treatment for digital dermatitis usually occurs at one of two levels: the herd-level in the form of footbaths, or at the individual cow level in the form of systemic antibiotic administration or topical antibiotic administration at the lesion site. Systemic antibiotic treatment of lameness is generally believed to be ineffective (Blowey and Sharp 1988), although little scientific literature is available on the subject. In a 180-cow herd case study, perenteral injection of various antibiotics (penicillin, tetracyclines, cephalaxin and sulphonamides) had no effect on
digital dermatitis lesion healing (Blowey and Sharp 1988). Footbaths appear to provide better herd-level prevention as well as some treatment of lesions (Laven and Proven 2000). These authors found footbaths containing erythromycin significantly reduced lameness within cow by 41% and pain by 55% four days after treatment when compared to untreated control cows, although indicators of pain were not defined. Topical treatments with an antibiotic bandage have been commonly used to treat lesions at the cow-level (Read and Walker 1998; Berry et al. 2010). However, if the bandage is not removed, this could cause damage to the leg of the cow. Anecdotal reports of injuries to cows from lack of bandage removal are not removed are numerous, however this finding has not been reported in published research papers. Ischemic injury from bandages has been reported in companion animals (Anderson and White 2000).

Animals in pain normally show changes in behaviour, specifically alterations in activity, posture, gait, appetite and appearance (Anil et al., 2002). These behavioral changes can also affect performance and handling during milking. Changes in gait are believed to be due to pain associated with injuries on the hooves and/or legs (Whay et al., 1998), however knowledge is lacking in this area. Quantification of pain associated with hoof lesions and throughout healing is needed to identify periods during which pain control or other interventions would be beneficial for the welfare and productivity of the cow. Previously, researchers subjectively scored pain associated with digital dermatitis using a three-point scale based on reaction to water sprayed at the lesion (Hernandez et al. 1999), and determined that these pain scores decreased in cattle treated with oxytetracycline or a commercial copper formulation.
The primary objective of this randomized clinical trial was to determine if topical application of tetracycline hydrochloride in a paste would be as therapeutically effective for treatment of digital dermatitis lesions as the current commonly used treatment, tetracycline hydrochloride held in place by a bandage. A second objective was to quantify pain associated with digital dermatitis lesions.

Materials and Methods

All procedures were approved by the University of Guelph’s Animal Care Committee (Animal Use Protocol 09R089).

Animals and Housing

This study was conducted at the University of Guelph Elora Dairy Research Station, Elora ON. Holstein cows were housed in either tie-stall or free-stall sections of the facility, with approximately 20% of the herd housed in the free-stall portion of the barn. All animals entered a single milking parlour twice daily for milking and were fed a total mixed ration three times daily. As preventive treatment for digital dermatitis all animals walked through a footbath three times weekly upon exit from the parlour as per farm protocol (twice weekly treatments of copper sulfate at 58g/L, once weekly treatments of tetracycline at 1.16g/L).

Experimental Procedure and Treatments

Cows had their hooves inspected while restrained in a hydraulic lift table approximately every 3 months, with full hoof trimming occurring every six months from
June 2009 to August 2010. Digital dermatitis lesions were scored upon visual inspection by a veterinarian (author GC) during hoof inspection at five trim dates: June 2009, September 2009, January 2010, May 2010 and August 2010. Throughout the trial, all digital dermatitis lesions were scored as active, healing, or healed by the authors (JHC and GC) at the time of hoof examination. Active lesions were raw, moist lesions with tufted or granular surfaces (Hernandez and Shearer 2000) and were typically pink-red in color. Lesions that were healing were dry and developing a scab (modified from Manske et al. 2002a; 2002b). Healed lesions showed no visible sign of moist surface or scab. Anatomic location of lesions were also recorded on data sheets using the numbering system shown in Figure 1.

Hooves with active lesions were randomly assigned to one of three treatment groups by random draw. Since hoof-level assignment of treatment was performed, one cow could be exposed to different treatments on other limbs. The paste treatment (PASTE) consisted of 175 mL propylene glycol, 175 mL vinegar and 150 g tetracycline hydrochloride (Onycin 1000, Vétoquinol Canada Inc., Lavaltrie, QC), applied directly to the lesion with a paintbrush. This resulted in approximately 2-5 g of tetracycline being applied per treatment. The bandage treatment (BANDAGE), consisted of 2-5 g of tetracycline hydrochloride (Onycin 1000, Vétoquinol Canada Inc., Lavaltrie, QC) covering a 2x2” square gauze and secured to the lesion using a bandage (Vetrap™, 3M™, St. Paul, MN). Bandages were removed from the hoof approximately 48 hours after application. The negative control (CONTROL) consisted of no therapeutic intervention. Severely lame cows, with little to no weight bearing on the affected limb,
were assigned to the paste or bandage treatment from a separate random draw as it was deemed unethical to withhold treatment to these cows.

In order to assess healing rates, a convenience sample of cows was re-examined at two time points following treatment, Exam 1 (3-7 days post-treatment) and Exam 2 (8-12 days post-treatment). Only some cows were accessible for examination following treatment due to their use in other research projects. Since bandages were removed prior to re-examinations, the observer (author JHC) was blind to treatment during these exams. At this time, lesions were classified as active, healing, or healed; digital photographs were taken, and location of lesions was recorded.

Recurrence rates were determined throughout the fifteen-month study period. A case was defined as recurred if digital dermatitis was present in the same location on the hoof at or before the following trim, usually a period of 3-4 months. Farm veterinarians examined all lame cows identified by farm staff and any digital dermatitis lesions were classified by stage of healing, as well as having digital photographs taken and having anatomic locations recorded.

Digital photographs of all hooves enrolled in the trial were taken prior to treatment. To ensure that lesion severity did not differ between treatments, initial lesions sizes were determined following the live animal trial phase of the experiment by measuring the largest diameter of the lesion from the digital photographs obtained on the day of initial treatment (Exam 0). Actual sizes were calculated based on measurement of a standardized identification tag placed below each hoof at the time of photography. Lesions sizes were then categorized into lesion scores (Hernandez and Shearer 2000) from 0 to 2, due to the potential for small inaccuracies resulting from measurement.
methodology. Lesion scores of 0 consisted of no visible lesion, lesion scores of 1 were lesions \( \leq 2.5 \) cm, and scores of 2 were lesions > 2.5 cm in diameter.

Pressure algometry (Pain Test™ FPX 50 Algometer, Wagner Instruments, Greenwich, CT) was applied to each lesion site to quantify pain at each hoof exam. The mechanical nociceptive threshold (kg force causing withdrawl of the limb from the algometer) was measured while cows were restrained in a chute with legs fastened with integrated restraints for hoof exams. The algometer tip, a 1 cm diameter flat rubber end, was pressed against the lesion with steadily increasing pressure until the nociceptive threshold was reached, as determined a leg withdrawal or avoidance response. Algometer measurements were recorded in kg of force, and single measurements were obtained for each lesion to avoid irritating the lesion. The algometer measurements were censored at 25kg, the maximum value at which the device could record pressure.

**Statistical Analysis**

Statistical analysis was completed using Statistical Analysis Software (SAS 9.2, SAS Institute Inc., Cary, NC). Descriptive statistics were compiled by examining means and frequencies. To determine if the initial lesion size differed among the three treatments, an ANOVA was performed due to the non-normality of the data. Parity, DIM, and lesion size were offered as covariates into all models. Variables potentially associated with the outcome in univariable analysis with \( P < 0.2 \) were included in final models and then removed through backwards elimination. A \( P < 0.05 \) was considered significant in final models. Model fit was assessed through the examination of residuals.
In order to determine if healing rates differed among the treatment groups, a generalized linear mixed model (PROC GLIMMIX) with a binomial distribution was used. The main effects of treatment (paste, bandage, control), the trim date (June 2009, September 2009, January 2010, May 2010, August 2010), and Exam (0-2) were included in the final model. Random effects of cow and cow by treatment were included. Additionally, the hoof on which the lesion was located was treated as a repeated measure within cow and treatment.

To ascertain if the recurrence rate differed between the two treatment groups, a separate generalized linear mixed model with a logit link was used. For recurrence data, only the paste and bandage treatments were analyzed, as those lesions assigned to the negative control group that were still active following collection of healing data may have been treated if deemed necessary. The final model included treatment and recurrence.

Finally, to determine pain associated with active, healing, or healed cases of digital dermatitis regression analysis of survival data was used (PROC PHREG) due to the presence of censored data. Repeated measures on individual animals were accounted for using robust sandwich variance estimates aggregated over cow, which allows for estimates of covariance matrix.

**Results**

The characteristics of the animals and lesions assigned to each of the treatment groups are shown in Table 5.1. Lesions were predominantly found in the hind limbs of cows, with 41.1% and 46.3% of lesions in the left hind and right hind limbs, respectively. Fewer lesions were observed in the front limbs, with 6.5% on the left and 6.1% on the
right limbs. The majority of the lesions were located in zone 10 (Figure 5.1), accounting for 73.2% of all active lesions entered into the trial. Zone 0 contained 15.5% of the lesions, and 10.8% of lesions were in zone 6. The remaining lesions (0.5%) were observed in zone 4.

Lesion sizes were successfully measured from photographs for 157/219 of the hooves entered into the trial (Exam 0); a proportion was not calculated due to poor quality of the photographs. Mean lesion scores are shown in Table 5.1.

The number of healed lesions differed by the type of treatment ($P = 0.0054$; Figure 5.2; Table 2). No difference was observed in the number of healed lesions between the paste and bandage treatments ($P = 0.2423$), and both treatments were found to have more healed lesions than the control ($P < 0.05$). Additionally, a difference was observed in the number of healed lesions among exam periods ($P < 0.0001$; Figure 5.2). Lesions were more likely to be healed during both recheck exams when compared to enrollment into the trial ($P < 0.05$). However, there was no difference in healing between the Day 3-7 and Day 8-12 post-treatment exams was not statistically significant ($P = 0.064$). Finally, the trim date at which the digital dermatitis was treated was associated with the odds of lesion healing ($P < 0.001$), with trims in January and August having more healed lesions.

Overall, there was recurrence of 33 lesions following treatment with either the paste or bandage treatments. Of these, 21 had been assigned to the paste group and 12 assigned to the bandage group. There was no difference in the recurrence rates between the two treatment types ($P = 0.42$). Numerically, the majority of recurrences were
observed following the June and September 2009 trim dates, as shown in Figure 5.3 in relation to the number of cases entered into the trial.

Algometer measurements were significantly different between lesions that were classified as active, healing, or healed \( (P < 0.0001; \text{Figure 5.4}) \). The mean \( \pm \text{SD} \) algometer measurement for lesions that were healed was 25.0kg \( \pm 0 \), the value at which measurements were censored. Lesions classified as healing had a mean of 12.84 \( \pm 10.49 \) kg of force applied and active lesions had a mean of 7.90 \( \pm 9.45 \) kg of force. Algometer measurements at Exam 0 of active lesions varied greatly, as shown in Figure 5.5, however for 50% of hooves tested withdrawal responses were provoked at 3 kg force or less. Contrast statements demonstrated that all three-way comparisons between classifications were significantly different \( (P < 0.001) \).

**Discussion**

Infectious disease cure is normally defined by an absence of the causative agent. There is still debate as to the identity of the causative agent of digital dermatitis, although the majority of experts agree that spirochetes are involved (Klitgaard et al. 2008; Evans et al. 2009). Therefore, the term ‘healing rate’ was used in this paper and was based on visual observation of an absence of an active lesion and pain response.

Our results demonstrate that treatment of digital dermatitis with a tetracycline hydrochloride paste is as therapeutically effective as application of tetracycline hydrochloride held in place with a bandage for 2 days. Healing rates of digital dermatitis were not significantly different between these two treatments. At 8-12 days post-treatment, lesions were healed in 50% and 59% of cases for the paste and bandage
treatments, respectively. These healing rates were numerically lower than those previously published. Following topical application of an oxytetracycline solution, lesions were still visible in 4/11 cows 14 days after treatment (Hernandez et al. 1999). In another study using oxytetracycline bandage application, which was repeated after 5 days, 87% of hooves were considered cured 32 days after the initial treatment (Manske et al. 2002b). However, healing rates of digital dermatitis are dependent on the location of the lesion (Hernandez and Shearer 2000). These authors demonstrated that lesions in the interdigital cleft remained visible and painful after 30 days post-treatment while lesions on the heels and dewclaws had much higher healing rates (Hernandez and Shearer 2000). A majority of the lesions from the current study were in the interdigital cleft, perhaps accounting for the lower healing rates.

Some of the lesions in the negative control group appeared to have healed during the 3-7 day post-treatment exam, however all cows examined in the negative control group had active lesions at Exam 2 (Days 8-12). Digital dermatitis lesions have been shown to heal slowly on their own without any treatment over a period of 7 to 10 days (Blowey and Sharp 1988). It is possible that these animals became reininfected between the two exam time periods, which may not have been observed in the other two treatments due to residual local antibiotic effect. Additionally, digital dermatitis lesions have been shown to frequently transition between disease states (Nielsen et al. 2012) perhaps due to the multiple symbiotic Treponema spirochete species (Klitgaard et al. 2008). This pattern was not observed in the two tetracycline hydrochloride treatment groups, with a greater number of healed lesions found in Exam 2 (Day 8-12) than Exam 1 (Day 3-7).
There is little documentation in the published literature regarding injury due to lack of bandage removal. A case series from companion animal veterinary medicine found ischemic injuries from bandages were due to direct pressure necrosis or ischemic necrosis (Anderson and White 2000), both of which are assumed to be painful conditions. The use of an antibiotic paste for digital dermatitis treatment would eliminate the need to place bandages on lesions, thus removing the chance of damage from lack of removal. Additionally, the paste option could be less costly to producers due to decreased labor involved in application and no follow-up bandage removal required.

Digital dermatitis is a multifactorial disease, therefore it is not surprising that there was no significant treatment effect on the recurrence rate of the disease. However, a post-hoc power calculation determined a need for 568 animals per group to determine a significant difference between digital dermatitis recurrence in the two treatments. Little data is available on digital dermatitis recurrence except in short time periods following infection, such as in a trial observing 742 cows over a 10-12 week period which found a mean of 1% recurrence during that time period (Nielsen et al. 2012), a much lower percentage than the 17-26% observed. Environmental contamination is very likely to occur in farms that have digital dermatitis in their herds, as evidenced by increased prevalence in environments that have muddier corrals (Rodriguez-Lainz et al. 1996). Although lesions may heal due to the treatments applied, any irritation in the skin could allow for new infections of digital dermatitis. Alternatively, if digital dermatitis lesions were deep in the skin, it is possible that the surface infection had healed and the deeper infection became visible after a period of time.
Lesion scores were calculated to ensure that treatments were exposed to similar lesion severity. There was no significant difference between the mean lesion scores for the three treatments, however the lesion scores assigned to the negative control group were numerically smaller than lesions assigned to the two treatment groups, perhaps indicating that these lesions were less severe. However, this was an artifact of the methods since severe cases of digital dermatitis causing lameness were assigned to treatment from a separate randomization chart due to ethical concerns about animal suffering, and hence preventing assignment to the negative control group.

To more accurately and empirically quantify a pain response, a pressure algometer was used to measure the nociceptive threshold at the lesion site in this randomized clinical trial. Pressure algometry has been used to quantify pain with calf disbudding by measuring mechanical nociceptive thresholds (Heinrich et al. 2010). In that research, nociceptive thresholds of calves at the site of disbudding increased (calves were less painful) with provision of a nonsteroidal anti-inflammatory drug compared to a placebo, supporting the assumption that pressure algometry is measuring pain. Nociceptive thresholds have been successfully used to measure pain in lame sheep (Ley et al. 1995) and cattle (Whay et al. 1998), when measuring hyperalgesia at locations proximal to the lesion of interest on the limb using force with a blunt pin. Flocks of sheep with high levels of lameness due to foot rot had lower nociceptive thresholds (or increased response to painful stimulus) than matched sound controls (Ley et al., 1995). Sole ulcers and white line disease were associated with lower nociceptive thresholds in cattle, on the day of treatments as well at 28 days later when compared to sound cows, while cows with acute tissue infections, including digital dermatitis, were significantly
different from sound cows on the day of treatment (Whay et al., 1998). Dyer and colleagues (2007) also used nociceptive threshold in dairy cattle with different lesions with the use of hoof testers equipped with a pressure gauge to determine claw pain and an algometer to measure integument pain, to determine a combined claw pain index. These methods combined indicated that claw pain increased in the lateral claws with increasing locomotion score, or increase in lameness, indicating more pain in lame cattle.

Nociceptive threshold measurements with the algometer may not fully reflect the amount of pain the cow experiences from digital dermatitis due to their restraint in a trimming chute during examination. Restraint for claw trimming is believed to be stressful, causing an elevation in fecal cortisol metabolites (Pesenhofer et al. 2006). Stressful events can lead to “stress-induced analgesia” (briefly reviewed in Veissier et al. (2000)), which would increase the nociceptive threshold response. In addition, physical restraint of the leg decreases the amount of movement the cow can perform, leading to a decrease in obvious leg withdrawl or avoidance response. Use of pressure algometry on areas that are less restrained, such as horn buds in Heinrich et al. (2010), allow for more movement and a potentially lower nociceptive threshold. Therefore, pain responses for the two studies would not be comparable.

The current study used pressure algometry to evaluate nociceptive threshold to evaluate at the site of digital dermatitis lesions at different stages of healing. Healed lesions did not appear to be painful, as all lesions having an algometer measurement that reached the censored value of 25kg. The algometer measurements determined that digital dermatitis lesions are painful, with cows responding to less application of force when lesions were active compared to healing or healed lesions. However, it was surprising
that pressure algometry applied to 19% of active lesions failed to provoke a withdrawal or avoidance response. In addition to restraint causing a lack of response, it is possible that different stages of disease progression cause variable amounts of pain. Future studies using a lesion severity scale in addition to algometer measurements could provide more information about pain during digital dermatitis infection. More frequent repeated measures might also provide further information about healing. Significant pain responses were also observed during the healing stages, with cows twice as sensitive to pressure on the healing lesion site than when healed, suggesting a prolonged duration of significant pain. Lameness pain is particularly important for animal welfare since cattle stimulate pain responses during activities that require them to be upright, such as during feeding and milking. To avoid pain, lame cattle spend more time lying and less time feeding (Galindo and Broom 2002), which is likely to affect performance.

Due to the pain experienced by cows with active and healing digital dermatitis lesions, treatment options should include pain management interventions. The algometer is a tool that could be used on-farm by producers to determine the amount of pain experienced by individual animals infected with digital dermatitis and determine effectiveness of intervention strategies. Further research into pain mitigation and management changes that could assist the convalescent cow are necessary for appropriate care.

**Conclusions**

In conclusion, the use of a tetracycline paste treatment was as effective as a bandage containing tetracycline hydrochloride powder in terms of both healing rates and
digital dermatitis recurrence. This indicates that paste treatments could be effectively used for the treatment of digital dermatitis and would eliminate the need for bandage removal, providing benefits for animal welfare, health and convenience. Digital lesions can be painful during both active and healing stages, suggesting the need for treatment and husbandry interventions for pain mitigation.

ACKNOWLEDGEMENTS

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References


Table 5.1. Characteristics of Holstein cows assigned to paste, bandage and negative control treatments in a randomized clinical trial examining tetracycline hydrochloride paste treatment efficacy. Exam days listed are relative to day of treatment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Paste</th>
<th>Bandage</th>
<th>Control</th>
<th>$P$ - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. enrolled at Exam 0 (Day 0)</td>
<td>79</td>
<td>70</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>Exam 1 (Day 3-7)</td>
<td>25</td>
<td>27</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>% healed</td>
<td>22.2</td>
<td>42.9</td>
<td>14.3</td>
<td></td>
</tr>
<tr>
<td>Exam 2 (Day 8-12)</td>
<td>22</td>
<td>22</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>% healed</td>
<td>47.4</td>
<td>57.1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Recurred lesions (%)</td>
<td>26.6</td>
<td>17.1</td>
<td>-</td>
<td>0.43</td>
</tr>
<tr>
<td>Parity (mean ± SD)</td>
<td>1.8 ± 0.14</td>
<td>1.6 ± 0.12</td>
<td>1.9 ± 0.14</td>
<td>0.32</td>
</tr>
<tr>
<td>DIM (mean ± SD)</td>
<td>188.1 ± 13.0</td>
<td>169.6 ± 13.0</td>
<td>158.9 ± 13.7</td>
<td>0.28</td>
</tr>
<tr>
<td>Nociceptive threshold, kg force (mean ± SD)</td>
<td>10.0 ± 10.5</td>
<td>10.9 ± 11.0</td>
<td>11.2 ± 10.3</td>
<td>0.44</td>
</tr>
<tr>
<td>Lesion score (mean ± SD)</td>
<td>1.05 ± 0.71</td>
<td>1.03 ± 0.80</td>
<td>0.80 ± 0.69</td>
<td>0.09</td>
</tr>
</tbody>
</table>
Table 5.2. Odds ratios (OR) and confidence intervals (CI) for healing rates for the three treatment groups (paste, bandage and negative control) in the randomized clinical trial.

<table>
<thead>
<tr>
<th></th>
<th>OR</th>
<th>CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandage&lt;sup&gt;1&lt;/sup&gt;</td>
<td>referent</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Paste&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.183</td>
<td>0.010-3.253</td>
<td>0.24</td>
</tr>
<tr>
<td>Control</td>
<td>&lt;0.001</td>
<td>&lt;0.001-0.049</td>
<td>0.0014</td>
</tr>
</tbody>
</table>

<sup>1</sup>Treatment consisted of 2-5 g of tetracycline hydrochloride covering a 2x2” square gauze and secured to the lesion using a bandage.

<sup>2</sup>Treatment consisted of 175 mL propylene glycol, 175 mL vinegar and 150 g tetracycline hydrochloride, resulting in approximately 2-5 g of tetracycline being applied per treatment.
Figure 5.1. Lesion anatomic location numbering system. Used with permission (Shearer et al. 2004)
Figure 5.2. Percent of observed lesions that were healed for the three different treatments (paste, bandage, and negative control) by exam time periods; Exam 1 (Day 5-7 of the trial), and Exam 2 (Day 8-12 of the trial). All lesions at Exam 0 (Day 0) were active. Columns containing different subscripts are significantly different (P<0.05).
Figure 5.3. Number of cases entered into trial (white bar) and number of recurrences following paste or bandage treatment (horizontally lined bar) at each trim time period in the randomized clinical trial. Lameness cases occurred throughout the trial period.
Figure 5.4. Frequency of observation in which cows responded at different nociceptive thresholds (kg force) applied by an algometer to digital dermatitis lesions, by healing status in a randomized clinical trial assessing use of tetracycline hydrochloride paste treatment for digital dermatitis.
Figure 5.5. Survival curve for proportion of responses by nociceptive threshold (kg of force causing withdrawal of limb from the algometer) of active digital dermatitis lesions at Exam 0.
Chapter 6. An observational study of the effects of therapeutic hoof blocks on the locomotion, behaviour, and production of healthy dairy cattle.

(Prepared for submission to Journal of Dairy Science)

J. H. Cutler,*1 J.K. Shearer,† D.F. Kelton,* G. Cramer,‡* P. Gorden,† S.T. Millman†

* Department of Population Medicine, University of Guelph, Guelph, ON, Canada
† Veterinary Diagnostic and Production Animal Medicine, Iowa State University, Ames, IA, USA
‡ Cramer Mobile Bovine Veterinary Services, Stratford, ON, Canada
§ Agriculture and Agri-Food Canada, Agassiz, BC, Canada

1Corresponding author: Janet Higginson Cutler jhiggins@uoguelph.ca

Janet Higginson Cutler
Department of Population Medicine
University of Guelph
Guelph, ON, Canada
N1G 4W1
Phone: 519-824-4120 x54595
Fax: 519-763-8621
Abstract

Therapeutic hoof blocks have been recommended for treatment of sole ulcers in dairy cattle, however they are underutilized in the dairy industry. Twenty lactating Holstein cows were randomly assigned to the following treatments: wooden hoof block applied to the medial claw of the left hind (n=5), to the right hind (n=5) or no hoof blocks as a negative control (n=10). Block retention was measured daily and hoof wear weekly throughout the trial. Accelerometers were affixed to both hind legs of 10 blocked and 5 control cows and recorded steps, number of lying bouts, and lying bout duration. Locomotion scores were determined on days -1, 1, 2, 3, 7, 14, 21 and 28 relative to treatment assignment, based on a five point scale with higher numbers reflecting increasing abnormality in gait. Daily milk production was recorded. Mixed models were constructed to determine effects of block application on activity, lying behaviour, milk production and locomotion scores. Of the ten blocks applied, six were retained at the end of the trial, with lost blocks occurring on days 5, 20, 22 and 25 relative to application. Block wear increased throughout the trial, with wear on the cranial end much higher than the caudal end of the block. The number of steps taken by cows changed by day, with cows being most active on day -1. A limb by treatment interaction was observed, where cows with blocks attached to their right hooves showing increased activity on the pedometers affixed to the right leg than the left. The mean number of daily lying bouts did not differ by treatment but was altered by day. Lying bout duration did not change with block application or by day of trial. Locomotion score was altered by block application and day. Cows with blocks had higher locomotion scores on days 1, 2 and 3 compared to their baseline levels on day -1. Control cows showed no alterations in
locomotion throughout the trial. Milk production differed by parity and day of trial, but no difference between the two treatment groups was observed. In conclusion, although block application affected locomotion, it did not appear to adversely affect the behaviour or milk production of sound dairy cows.
Introduction

Lameness is considered one of the largest welfare concerns in the dairy industry (Rushen et al., 2008). Lameness is a behavioural indicator of pain in the leg or hoof of the cow (Whay et al., 1997), making it a welfare concern for these animals. Lameness is also very prevalent, affecting a large number of animals. North American estimates include a high prevalence of hoof lesions in Ontario cattle with 46.3% of free stall and 25.6% of tie-stall cows having at least one lesion (Cramer et al., 2008). In Minnesota, 24.6% of freestall cows were deemed lame (Espejo et al., 2006), while in Wisconsin 21.1% and 23.9% of cows observed in the summer and winter, respectively, housed in various systems were lame (Cook, 2003). However, little research has explored appropriate treatment for lame cows and for mitigation of pain.

One of the common causes of lameness is the presence of sole ulcers. Sole ulcers occur when the corium is exposed through a defect in the sole (Collick et al., 1997). Sole ulcers typically develop on the lateral claws (Rushen et al., 2008; Amory et al., 2008) and have been found at levels four times higher in the hind limbs than the front (Whay et al., 1997; Cramer et al., 2008). The lateral claw of the hind limb is responsible for 70-80% of the total force exerted by the hind limb (Van Der Tol et al., 2004), explaining the increased potential for damage to the sole in these claws.

Therapeutic hoof blocks have been recommended for treatment of lesions in the hoof, such as sole ulcers and white line disease (Espejo et al., 2006; Toussaint Raven et al., 1985). These blocks are applied to the healthy claw adjacent to the diseased claw in an attempt to prevent further mechanical injury and to reduce pressure on the affected sole, thereby reducing pain. However, widespread use of therapeutic hoof blocks does
not occur on commercial farms. In a cross-sectional study of 204 Canadian dairy farms, the combined prevalences of ulcers and white line abscesses recorded by hoof trimmers were 11.3% in free-stalls and 5.3% in tie-stalls (Cramer et al., 2009; 2008). Only 2.2% and 0.3% of all cows received blocks in that trial for free-stalls and tie-stalls, respectively, and was suggested that this decreased use could be due to cost (Cramer et al., 2008). Additionally, efficacy of therapeutic blocks has not been well documented. Only one published paper examined the efficacy of hoof block application for ulcers. This clinical trial examined different block types and found a recovery rate of 65.8% six days after placement of a wooden block as determined by elimination of lameness, compared to 32.3% for cows that received bandaging without block application (Pyman, 1997). No information is available in the literature on the effects that blocks may have on the behaviour, locomotion and milk production of cattle, and these concerns of producers need to be addressed for hoof blocks to be incorporated into regular treatment protocols for hoof lesions.

The objective of this study was to determine the effects of therapeutic hoof block application on locomotion, behaviour, and milk production of cattle. To avoid confounding effects of lameness, sound cattle were used for this study.

Materials & Methods

Twenty lactating Holstein cows were used for this experiment. Cows were housed in a free-stall barn in a group of approximately 45 cows at the Iowa State University Research Centre during June and July 2010. Stalls with mattresses were bedded with sawdust. Cows were milked twice daily in a parlour and fed a total mixed
ration twice daily, balanced for nutritional needs. Water was freely available at two self-filling troughs. Head-gate spaces were restricted to a stocking density of 11 for every ten cows. Forty-eight stalls were available in the pen.

At the day of enrolment, cows were lifted on a tilt table and hooves were trimmed by one of the authors, a veterinarian experienced in hoof trimming and hoof care (JKS). Exclusion criteria for enrolment included lameness or the presence of ulcer, digital dermatitis, white line disease or injury to the hooves of the cows. Cows were assigned to experimental treatment by random draw, with 10 control cows (no blocks) and 10 cows receiving hoofs blocks. Of the 10 cows receiving the block treatment, 5 cows had blocks placed on the medial claw of the right hind leg, and 5 on the medial claw of the left hind leg. Wooden blocks (Agriviv Inc, WI, USA) measuring 2.2 cm high and 13.3 cm long were affixed using Bovi-Bond™ (Bovi-Bond, CA, USA), such that the cranial end of the block lined up with the cranial end of the claw, and the caudal end of the block aligned with the heel bulb to provide proper heel support. The abaxial edge of the block was aligned with the abaxial edge of the claw. A grinder was used to prepare the contact surface of the claws receiving blocks and it was also used to decrease the length of the block at the caudal end for cows with shorter claws. The angle at which the block was placed was measured by the angle between the surface of the block on which the cow would walk and the dorsal wall of the claw, with an aim of angles of approximately 45°, the angle of a normal claw (Kloosterman, 1997). Cows remained in their experimental group for 28 days, after which any remaining blocks were removed.
Data Collection

**Block wear and retention.** All cows with blocks attached were checked daily throughout the trial period to record any missing blocks to determine the length of block retention. Block wear was measured while cows were standing at the feed bunk or in a stall on days 7, 14, 21 and 28 post-application. The caudal end of the blocks was measured on both the axial and abaxial sides from the point where the block was affixed to the sole to the bottom of the block. The cranial end of the block was measured on the abaxial side, with no measurements on the axial side due to the difficulty in accurately recording measurements in that physical location while cows were standing.

**Locomotion Scoring.** A digital video recorder (Canon DC100 DVD Camcorder, Canon Canada Inc, Mississauga, ON) was used to record cows walking along a diamond cut grooved concrete alley opposite the feed bunk in their pens. Cows were encouraged to walk at an even pace with a handler walking behind at a steady pace. Cows were recorded walking in two directions to ensure video images were available from both the right and left sides of the cow. Cows that failed to maintain a steady consistent gait were recorded walking the same passage again. A minimum of two good strides was recorded for a passage to be acceptable. Video was recorded on Days -1, 1, 2, 3, 7, 14, 21, 28 in relation to treatment assignment. Gait was scored from video images based on a numerical rating system developed by Flower and Weary (2006) and the trained observer (author JHC) was blind to treatment.

**Activity.** Accelerometers (IceTag 3Ds, IceRobotics Ltd, UK) were attached with Velcro straps to both hind legs above the fetlock over the metatarsus for 15 cows on day -5 (five right limb block, five left limb block and five control cows). Two cows assigned
accelerometers presented with digital dermatitis upon hoof inspection on day 0, so the accelerometers were assigned to two additional cows that only have data from Day 0 onward. IceTags recorded the number of steps taken, lying bout duration, and number of lying bouts. The position of the cow (lying or standing) was recorded every minute. IceTag data from Day -3 until Day 28 in relation to treatment assignment was used for analysis.

**Statistical Analysis**

All statistical analysis was completed using SAS (Statistical Analysis Software, version 9.2). All fixed effects were included in the model and removed through backward elimination. Descriptive statistics were derived from frequencies and means, and analysis of variance (PROC ANOVA) was used to determine if cows assigned to the different treatment groups were significantly different. Biologically significant interactions were assessed in models and the lowest covariance structure was used. Model fit was assessed through the examination of residuals.

To examine if locomotion score changed by treatment, a mixed model (PROC MIXED) was constructed using cow within treatment as a repeated measure. Any cows that lost their blocks throughout the treatment period were removed from the model for the days where no block was present. Treatment, day of trial, parity, days in milk and weight were included in the model as fixed effects. The interaction between treatment and day was also assessed in the model.

Total daily milk production was used for analysis. To measure the effect of block application on milk production, a mixed model (PROC MIXED) was built with cow
within treatment as a repeated measure. Treatment, parity, day of trial, and days in milk on Day 0 of the trial were offered into the model, as well as a treatment by day interaction.

Activity and lying behaviour measurements were summarized by day for analysis. Three treatment groups were used for analysis, cows assigned to blocks on the left hind, right hind, and controls, due to the differences that might be observed depending on the limb to which the blocks were applied. Day of treatment assignment (Day 0) was removed from all analyses due to the large disruption in behaviour due to trimming and other measurements taken on this day. Activity data was modeled separately for number of steps taken, mean lying duration and number of lying bouts per day. All outcomes were modeled using a mixed model (PROC MIXED) with cow as a repeated measure. Treatment assignment, day of the trial and a treatment by day interaction were all tested in the models. The limb on which the accelerometer and a limb by treatment interaction were also assessed to determine if there were differences between measurements on the limbs to which block were affixed. Treatment was forced into the model regardless of significance.

All procedures were approved by the Institutional Animal Care and Use Committee at Iowa State University.
Results

Characteristics of the cows assigned to different treatment groups are shown in Table 1.

**Block Wear and Retention.** Blocks were placed at a mean angle of 43.9° (range 39° to 50°). Of the ten blocks affixed to claws, six were removed from the claws at the end of the trial. The other four blocks came off at 5 (right hind), 20 (left hind), 22 (right hind), and 25 (right hind) days post-application. During block removal at the end of the trial it was observed that one of the cows had developed a white thick liquid between the block and the claw, however no lesions were observed on the claw and this cow was not lame. Block wear increased numerically over time, as shown graphically in Figure 1, with block height decreasing over the 28 day period.

**Activity.** The number of steps taken daily by cows in the three treatment groups differed (p=0.04). Cows in the control group performed a mean (±SE) of 1969.5 (±25.2) steps/day throughout the trial period while cows with blocks on their left limb and cows with blocks on their right limb performed 1897.5 (±46.2) and 2153.8 (±32.0) steps/day, respectively. The number of daily steps was altered by day of trial (p<0.0001; Figure 2), with day -1 having the highest level of activity (p<0.05) compared to all days following treatment assignment. Additionally, the limb to which the accelerometer was attached altered the activity reading depending on treatment group (p<0.0001). Cows with blocks affixed to their right hind leg showed differences in activity readings dependent on placement of pedometers, with those on the right recording a higher number (least
squares means ± SE) of steps (223.77 ± 68.9) than those on the left (194.2 ± 68.9) (p<0.0001). This difference was not observed in blocks on the left hind limb (p=0.80).

**Lying.** Lying behaviour did not differ by treatment group as shown in Figures 3 and 4. Cows assigned to receive blocks on their left and right hind legs were therefore grouped together as a block treatment for analysis and reporting. Mean daily lying bout duration (±SE) for control cows was 75.89 (±4.98) minutes and for blocked cows was 64.71 (±1.61) minutes (p=0.48). The day of trial did not alter the lying bout duration performed by cows (p=0.12). The mean number of daily lying bouts (±SE) for control cows was 9.62 (±0.27) and for blocked cows was 11.38 (±0.25). Number of daily lying bouts was affected by day of trial (p=0.02; Figure 4). No differences were observed in lying duration or lying bouts between the two limbs.

**Locomotion Scores.** All cows included in the trial were sound, with no evidence of abnormal gait (locomotion score ≥ 3) on Day -1. Four cows lost their blocks throughout the trial. Of those that lost their blocks, the subsequent locomotion score increased by 1 for one cow (block lost on day 22), remained the same for two cows (blocks lost on days 20 and 25), and decreased by 1.5 for one cow (block lost on day 5). Locomotion score was affected by an interaction between treatment and day (Figure 5). Cows with blocks on both their left hind and right hind legs had higher locomotion scores on days 1, 2, and 3 compared to their baseline locomotion scores on day -1 (p<0.05). No differences were observed during the same time periods for the control cows (p>0.05).
One cow assigned to the block treatment, that had a block affixed to her limb the entire trial, became quite lame (locomotion score 4) during the trial. Initial lameness was noted on day 14 of the trial, with a locomotion score of 3, which progressively increased to a locomotion sore of 4 by day 28. A veterinarian (author JKS) completed a lameness and hoof examination on day 16, determining that the lameness was due to an upper leg injury rather than a lesion in the hooves or due to discomfort of exposed glue from the block. Hoof pain under the block was measured through sharp quick taps with closed hoof testers on the surface of the hoof block. No treatment was given, however the cow was carefully observed throughout the remainder of the trial and following block removal to ensure removal to a hospital pen was not necessary.

**Milk production.** Milk production varied by day of trial (p < 0.0001), with production levels decreasing throughout the trial period (Figure 6). Milk production increased with higher parity (p = 0.01). Primiparous cows produced a mean (±SE) of 73.97 (±0.79) lbs/day of milk throughout the trial period. Second parity cows produced 85.21 (±1.17), third parity cows 94.56 (±0.76), and fifth parity cows 121.44 (±1.80) lbs/day. No difference was observed between cows with blocks attached to their limbs or controls (p=0.69; Figure 5), although numerically cows in the block treatment group had higher milk production (Figure 5).

**Discussion**

Little is known regarding the length of time blocks should remain affixed to the claw for appropriate ulcer healing. Collick and colleagues (1997) recommended that
blocks should remain affixed to the claw for a maximum of six weeks. More recently, research into the healing of the claw has been conducted. Healthy claws have been shown to grow a mean of 6.2 mm/month and wear at 4.4 mm/month when dairy cows are housed on a variety of flooring surfaces (Vokey et al., 2001). Examination of claws with mild ulcers that were treated with a therapeutic block revealed a solid layer of horn covering the ulcer sites when examined 50 days following treatment (Lischer et al., 2002). These results suggest that blocks could likely be removed at or prior to this time, since exposure of the corium is likely no longer a concern. However, the length of time necessary for appropriate healing to the point where elevation of the claw should be removed is still unknown and requires further investigation.

For cows that had blocks removed at the end of the trial, block wear was inconsistent throughout the block, with the majority of the wooden block at the cranial end wearing off. When walking, the heel region is the area of initial contact in the hind limb, with the lateral claw landing prior to the medial claw (Schmid et al., 2009). Although initial contact does not occur at the cranial end of the hoof where block wear was most apparent, the amount of force exerted on the caudal end of the hoof during walking is less than the cranial end. When measuring the maximum pressure exerted on the ground by the claw, a study has shown that the push off phase exerts 180-200 N/cm² compared to heel strikes which generates 90-100 N/cm² of pressure (Van Der Tol et al., 2003). The increased pressure and friction at the toe during the push off phase likely accounted for this increased wear at the cranial end of the block. The wear in these wooden hoof blocks also suggests that the efficacy of these blocks in relieving pressure on the sole ulcer decreases over time. Unbalanced wear could also potentially affect gait
and likelihood of slips and falls, which warrants further study. Other materials such as plastic blocks may not wear as quickly, and could be used for lesions or injuries that require an increased length of elevation, however these do require removal to prevent further injury.

Activity has been shown to decrease in lame cows (O'callaghan et al., 2003), and discomfort due to block application was expected to be reflected in decreased activity. A difference was observed between the three treatment groups, with cows in the control group having a mean number of steps/day between those cows assigned to the left and right hind block groups. Cows receiving blocks on their right hind leg showed increased activity on their accelerometers affixed to the same limb, suggesting that perhaps these cows were kicking or shaking that leg, since the accelerometers will pick up leg lifting while standing (Nielsen et al., 2010). The same pattern was not observed in cows with hoof blocks affixed to their left hind legs.

The number of daily steps taken by cows in the trial stayed fairly consistent throughout the trial period except for Days -1 and +1. Day -1 was the first day that locomotion scoring occurred in the pen, and increased the general activity of all of the animals in the pen. In addition, many of the study cows had to be videotaped walking the same path multiple times, due to speed of gait or unwillingness to travel in the desired direction. Habituation to locomotion scoring occurred throughout the trial period, with the videotaping process taking less time and the majority of cows only needing to walk through the alley once later in the trial, which was reflected in activity patterns closer to the baseline levels. Livestock species, including cattle, habituate to fearful stimuli by showing less behavioural responses, which is reviewed in Forkman et al. (2007).
Cows assigned to the block and control treatment groups did not show any differences in the number of daily lying bouts or lying bout duration. Lame cows have been shown to show differences in lying behaviour compared to sound cows, with severely lame cows housed in deep bedded stalls having longer lying bouts than sound cows (Ito et al., 2010). In that study, cows that were lame (locomotion score of 3 or 3.5) showed no alteration in lying behaviour. Therefore, it was expected that any extreme discomfort due to block application might have altered lying behaviour, due to difficulty in lying or standing versus pain.

Locomotion scoring systems have been developed to identify cows with abnormal locomotion due to pain in one of their limbs. The scoring system developed by Flower & Weary (2006), used in this trial, was developed using cows with sole ulcers. In the process of validation, elimination of abnormal gait was observed with analgesic treatment, suggesting that abnormal gait measured through this system was due to pain caused by the lesion. In the present study, a gait alteration was observed in the cows that had blocks affixed to their claws. While cows receiving the negative control treatment showed very little change in locomotion score throughout the trial period, those receiving the block treatment showed an increase in their locomotion score following block application, or increase in the abnormality of their gait. This alteration in gait was likely due to the physical elevation of one claw, rather than an indication of pain, since no lesions were observed when hooves were examined at the end of the trial. To confirm that this was not an indication of pain analgesics would need to be given and observe no change in locomotion score. If block application was causing pain, it would be expected that locomotion would become worse throughout the trial period due to the chronic effect.
of abnormal weight bearing on the affected limb, however this was only observed in one cow that had an injury in the upper leg. The physical increase in length of the limb from block application likely caused the differences in locomotion scoring. Locomotion scores decreased numerically by Day 7 of the trial in the cows with blocks affixed to their limbs, suggesting habituation to the block over time. Locomotion scores for animals in the block group increased slightly again by Day 28, however this was driven by one lame cow as all other cows in that group had no differences in locomotion scores between days 21 and 28.

While the one cow that did become lame did not have any lesions in her hooves an upper leg injury was determined to be the cause, and it is unknown what caused the injury or if it was due to block application. Slips and falls have been a concern regarding block application. In sound animals, slipping and falling predisposes cows to upper leg injury (van Amstel and Shearer, 2006). Casual observation while locomotion scoring noted quite a bit of slipping in the free stall by all cows. Concrete flooring has been shown to cause more slipping than rubber flooring (Rushen and de Passillé, 2006), with wet, slurry covered flooring causing more slipping than a dry surface.

In contrast to our observations, shoes placed on sound horses have been shown to improve gait (eg. Willemen et al., 1997). Horseshoes are however typically made of metal, not as high as hoof blocks, and are placed on more than one limb. Additionally, cow hoof blocks are only placed on one claw rather than the whole hoof as in horses. Placing a block on only one limb at a height of 2.2 cm, could alter the kinetics of cattle gait.
Milk production was examined due to concerns that block application might decrease the ability of the cow to compete for food at the bunk, which would be reflected in decreased milk production. Milk production has also been shown to decrease significantly in lame cows by 0.5 kg/day or more (Warnick et al., 2001). The results from this trial showed no decrease in milk production following hoof block application to sound cows, suggesting that block application itself likely had little effect on competition at the bunk when 1.1 headgates per cow was available, however behavioural analysis or feed intake data would be necessary to test this hypothesis. Since no data was available in the literature for sample size calculations, these were not performed prior to the trial. A post-hoc power test revealed that sample sizes of approximately 80 cows per group to determine a difference in milk production between the two treatment groups. The cows with blocks had numerically higher milk production throughout the trial period compared to the control cows.

Decreased milk production in both treatment groups throughout the trial period could have been due to increasing days in milk throughout the trial period. Another potential contributing factor to decreased production was ambient temperature increases due to the time of year. The decrease in dry matter intake and resulting decrease in milk production during heat stress has been reviewed by West (2003).

**Conclusions**

Application of a therapeutic hoof block appeared to have little effect on the activity, lying behaviour and production of sound lactating dairy cattle. Application was associated
with an increase in locomotion score, or increase in gait abnormality, however this could be due to an increase in the physical length of the limb or uneven walking surface with one claw elevated, rather than injury or pain in the hoof. One cow that had a block applied became lame during the trial period, and further examination of the likelihood of slips or falls associated with hoof blocks merits further study. Six of ten blocks applied were retained for the 28 days of the study and wear occurred unevenly over the block surface, suggesting that identification of appropriate block materials for commercial flooring surfaces needs further study. The results from this study provide data that can be used for sample size calculations for further study in block efficacy on lame cows. Due to the minimal effect on behaviour and production in dairy cattle, further study on efficacy of block application for the treatment of hoof lesions such as sole ulcers is warranted.
References


Table 6.1. Mean (±SE) values of characteristics of cows that were enrolled into trial by randomly assigned treatment group, either negative control or application of a therapeutic hoof block to the medial claw of the hind leg.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>LH Block</th>
<th>RH Block</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (n)</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>.</td>
</tr>
<tr>
<td>Parity</td>
<td>1.6 (±0.40)</td>
<td>1.8 (±0.37)</td>
<td>1.4 (±0.24)</td>
<td>0.93</td>
</tr>
<tr>
<td>DIM</td>
<td>203.6 (±31.5)</td>
<td>213.0 (±35.3)</td>
<td>191.4 (±40.3)</td>
<td>0.83</td>
</tr>
<tr>
<td>Wt (kg)</td>
<td>653.86 (±22.24)</td>
<td>621.36 (±15.26)</td>
<td>655.91 (±34.32)</td>
<td>0.62</td>
</tr>
<tr>
<td>Locomotion Score</td>
<td>1.65 (±0.08)</td>
<td>1.80 (±0.12)</td>
<td>1.70 (±0.12)</td>
<td>0.58</td>
</tr>
<tr>
<td>Milk production (kg/day)</td>
<td>37.43 (±3.76)</td>
<td>42.78 (±3.94)</td>
<td>40.43 (±3.28)</td>
<td>0.63</td>
</tr>
</tbody>
</table>

1 Data collected from Day 0 of trial.

2 Data collected on Day -1 of trial
Figure 6.1. Mean block height (cm) of three areas of the block, measured weekly throughout the trial period to determine block wear. Day of trial relative to block application and number of blocks (n) included in the mean is shown on the x-axis.
Figure 6.2. Mean number of steps performed by cows in the control group (n=10), cows with therapeutic hoof blocks affixed to their left hind limb (LH; n=5) and cows with blocks affixed to their right hind limb (RH; n=5) by day of trial relative to block application. Data from day 0 omitted due to disturbances from treatment assignment.
Figure 6.3. Mean number of lying bouts for cows in the control group (n=10) and therapeutic block group (n=10) by Day of trial relative to block application. Data from day 0 omitted due to disturbances from treatment assignment.
Figure 6.4. Mean lying bout duration (minutes) for cows in the control group (n=10) and therapeutic block group (n=10) by Day of trial relative to block application. Data from day 0 omitted due to disturbances from treatment assignment.
Figure 6.5. Least squares means (SE) of locomotion score for cows assigned to the control group, or having a block affixed to their left hind (LH) or right hind (RH) by day relative to treatment assignment. Locomotion was scored on a five-point scale (Flower & Weary, 2006), with cows having scores <3 considered sound. Cows in the block treatment group were removed from analysis following block removal.
Figure 6.6. Mean milk production (lbs/day) by group (n=10 per group) throughout the trial period. Treatment assignment occurred on Day 0, with cows receiving a trim and therapeutic hoof block application (block) or a trim as a negative control (control).
Chapter 7. Discussion

General Discussion

Since lameness is one of the most important welfare concerns in the dairy industry due to associated pain and high prevalence, improvements in prevention and treatment are essential. Sole ulcers and digital dermatitis are the two most commonly found painful lesions, which led to their focus in this thesis. The two main goals of this thesis were to determine if early detection of lameness through hoof lesion presence could be completed using a commercial accelerometer system, and to examine treatments for digital dermatitis and sole ulcers. A commercial system was chosen in an attempt to utilize readily available technology for the producer, with hope that this application could be used on farm. The treatment chapters focus on the two most common treatments for both digital dermatitis and sole ulcers.

To use a commercial system for early detection of lameness, a first step was to ensure that the accelerometer was accurately measuring activity and lying behaviour. Therefore, the first objective in this thesis was to validate the accelerometer to be used for research in early detection of lameness (Chapter 2), the Pedometer Plus accelerometer. This device measures both activity and lying behaviour. Validation was completed with both video recordings and a previously validated IceTag device. The Pedometer Plus was determined to accurately measure lying bouts and duration between both the IceTag devices and video. The number of steps taken was poorly correlated to output from the IceTag device, however the accelerometer output did correlate well with video analysis. This could potentially be due to the fact that the two devices were measuring different leg
movements, however further analysis would be required to examine this. The Pedometer Plus consistently measured higher activity that the IceTag device, suggesting increased sensitivity to movement of the limb. This was further examined to determine that the Pedometer Plus measured all hoof movements that the cow makes, including shifting and kicking of the limb. The Pedometer Plus provides an accurate measurement of activity and lying behaviour, and could be used for future research. In addition, accelerometer placement must be taken into account when interpreting data, as results may depend on the limb on which the device is affixed.

Following validation of the accelerometer, potential use for early identification of lameness in dairy cows could then be evaluated (Chapter 3). Through this objective, a comparison of activity and lying behaviour in free-stall and tie-stall housing at the facility used was completed. Due to the unique design of the facility, where all cows enter a parlour for milking, this allowed for comparison of activity and lying behaviour in the two systems eliminating the confounding effect of changes due to travel to a parlour for milking and effects of time spent milking. All cows, housed in free-stall and tie-stall systems, were required to travel to the parlour for milking twice daily. Activity was greater in free-stalls whereas the number of lying bouts was lower in comparison to tie-stalls. Housing type was therefore included in models examining activity and lying behaviour in relation to the presence of hoof lesions and lameness. When comparing cows without painful lesions to cows with digital dermatitis lesions or with sole ulcers, some behavioural changes were observed, dependent on lesion type. However, to determine if an accelerometer system could flag cows becoming lame, lying behaviour and activity would need to be significantly different between periods when a painful
lesion was present and absent within a cow. While the use of a combination of lying and activity was unable to detect differences, lying duration was sensitive enough to detect increased lying duration when cows had a painful lesion, with increases of approximately one hour per day. When examining animals with painful lesions that were lame, changes in both activity (mean decrease of 33 steps/hour) and lying duration (mean increase of 97 minutes/day) were observed compared to time periods when those cows were not lame. Changes in behaviour during lameness are therefore more obvious than changes when cows had digital dermatitis and sole ulcers, however these results show promise for future use for early detection of lameness, or at least detection of lameness, in dairy herds.

Throughout the process of evaluating the use of accelerometers for early identification of lameness, detailed hoof lesion data was collected. This lead to an observational study examining the etiology and temporal changes of lesions in dairy cows (Chapter 4). While many assumptions have been made regarding the progression of hoof lesions within individual cows, no literature examines the temporal changes within the hoof. This research showed that the presence of a lesion increases the odds of that same lesion being present approximately 3 months later (in sole ulcers, digital dermatitis and heel horn erosion), suggesting that once a cow develops a hoof lesion she is likely to continue to have lesions. Additionally, the presence of a hemorrhage did increase the odds that a sole ulcer would be present at the same location three months later compared to no hemorrhage presence, supporting the theory that some hemorrhages are early ulcers or indications of defects in the sole.

When examining treatments for lameness, the most common infectious lesion (digital dermatitis) and physical defect (sole ulcer) were addressed. Firstly, the efficacy
of an tetracycline hydrochloride paste for the treatment of digital dermatitis was assessed (Chapter 5). Debate is still present on the causative agent(s) of the digital dermatitis. While much work needs to be done on prevention of this infectious disease, having simple treatments could help to reduce the amount of time that cattle were infected and in pain. Since the application of bandages can cause damage to the limb if not removed, an alternate form of treatment that would not require further action by the producer would be beneficial. A tetracycline hydrochloride paste, containing glycol and vinegar and applied to the hoof without a wrap or bandage, was assessed in a clinical trial in comparison to tetracycline hydrochloride bandages and untreated negative controls. Digital dermatitis lesion healing and nociceptive threshold at the lesion site were appraised. At 8-12 days post-treatment, both paste and bandage treatments results in greater healing rates than untreated controls and the paste and bandage treatments did not differ. As well, nociceptive threshold, measured through the use of an algometer, differed between active lesions and lesions that were healing and healed, with cows with active and healing lesions being more sensitive to pressure than those with healed lesions. Pressure algometry could therefore be used by hoof trimmers or in research to differentiate between stages of healing in digital dermatitis lesions.

Finally, the effect of the application of therapeutic hoof blocks on the behaviour, locomotion and production in dairy cattle was assessed (Chapter 6). Since previous research had identified a lack of use of therapeutic hoof blocks in the treatment of painful lesions, the effect of application on cows was examined. Sound cows, identified through locomotion scoring, were assigned to hoof block or control (no hoof block) treatments. Hoof block application increased the locomotion score of cows, a measure of increased
lameness, on days 1-3 post-application, likely due to kinematics associated with the physical elevation of the claw rather than pain. No difference was observed between cows assigned to either treatment group in terms of lying behaviour or activity, measured through IceTag devices. It has been suggested that producers are unwilling to use hoof blocks due to concerns over their ability to lie down and rise and to successfully compete for access to the feedbunk once a block was applied. Since milk production did not differ in the two treatment groups, it is unlikely that feed access is a concern. However the power of this pilot study to detect differences in milk production was low. Lying behaviour also did not differ between the treatment groups, suggesting that sound cows with hoof blocks were able to lie down and rise with no greater difficulty than cows without blocks, or that any difficulty present did not affect their standing and lying bouts and duration.

**Strengths/weaknesses**

Many exciting and promising results for the welfare of lame dairy cattle arose from this research. Examining the research completed retrospectively, there are also several aspects of methodology I wish had been done differently.

This is the first validation of the Pedometer Plus system, allowing for confidence in further use of this system in research and in commercial applications. The sensitivity of the Pedometer Plus to small leg movements will allow for application for detection of subtle movements by the cow. Initially, the Pedometer Plus was going to be validated
against the IceTag device, however validation against a gold standard is the best approach, which was also completed.

Since activity and lying behaviour have both been shown to alter in lame cows, the use of an accelerometer for early detection of lameness using both activity and lying behaviour was evaluated. This research demonstrated that changes in both activity and lying behaviour were both useful for detection of differences between sound and lame cows. While changes in cows that had hoof lesions were not as obvious, evidence of changes was found, warranting further research in this area.

Many difficulties arose when attempting to videotape cows for locomotion scoring, resulting in missing data. Several locations throughout the barn at Elora Dairy Research Centre and methods were tested during the first couple of exam periods until an appropriate system in the return alley from the parlour was developed. Very few locomotion scores were successfully assigned to passages until the final methodology was developed. However, all areas used throughout the trial were selected due to the presence of a surface that would be relatively non-slip and therefore should provide similar locomotion scores. Both locomotion scores and lesion information was available for a subset of cows, a strength which allowed for distinction between pain at the lesion site itself and pain while the cow was bearing weight on the limb, both of which I believe are important to the welfare of the cow. Having a complete dataset of locomotion scoring would have increased the sample size and strength of the research.

Additionally, locomotion scoring cows between exam time periods would have captured more lameness and increased the amount of data to compare accelerometer measurements within cow. If I were to design such another study to examine the use of
accelerometers for early identification of lameness, I would locomotion score the cows much more frequently, at least monthly. This would allow for more accurate timing of onset of lameness, which could then be compared to accelerometer data.

The two treatment chapters both provided promising results. The use of a paste formulation for digital dermatitis that is inexpensive, allows for quick and easy application, and does not require bandage removal was shown to be as effective as the current standard bandaging treatment. Due to these factors, potential for faster treatment and therefore recovery of digital dermatitis is possible. The study examining the application of hoof blocks to sound dairy cattle demonstrated little change to the cow when observed without the confounding effect of a painful lesion on the hoof. Cramer and colleagues (2008) observed that hoof blocks were rarely used in their cross-sectional study. Therefore, alleviating the concerns of producers, such as increased slips and falls and decreased ability to compete for food at the feedbunk, could increase their use in the dairy industry. The research in this thesis determined that few behavioural changes were observed following hoof block application and that no alteration in milk production resulted from block application. This study provides information which can be used for future clinical trials to examine the efficacy of therapeutic hoof block application on lesion healing and/or on alleviation of pain when applied to cows suffering from digital dermatitis.

The use of severity scoring for different lesions would have added to the quality of research, especially for the digital dermatitis project (Chapter 5). For example, Holzhauer and colleagues (2008) used a 5 point scale which included information about the stage and severity of the lesion observed. This would have assisted in validation of
the algometer as a tool for pain quantification in digital dermatitis. This would have also
allowed for clearer definitions of the healing process of digital dermatitis. The digital
dermatitis treatment project was originally intended to be a small side project, however a
digital dermatitis outbreak at Elora Dairy allowed for a much greater sample size than
expected.

**Future Research**

Many future research ideas have resulted from the completion of this thesis. Firstly, the early detection of lameness through use of accelerometers should be completed in other commercial farms to determine if these results are consistent between farms.

The ability of the Pedometer Plus to detect very slight movements could be very valuable in detection of other diseases in cattle, since an increase in shifting or other subtle movements might assist in detection of pain. Combining this data with lying behaviour could be very beneficial in early detection of pain and illness, since activity and rest patterns are altered in both painful and ill animals. Evaluating commercially available accelerometers would make use of systems that are already being used and prevent the necessity of producer purchase of more equipment. However, having equipment that is time-stamped would allow for more detailed investigation of behaviour and determine if cows are altering the patterns or timing of activity and lying.

Since this research showed few behavioural changes with the application of therapeutic hoof blocks, further research in this area should proceed. No literature exists
on healing rates of ulcers with block application. Since producers have raised concerns about block application and ability to compete at the feed bunk, determination of feed intake in cows with sole ulcers and blocks should be examined. Due to the many flooring surfaces found in dairy cattle barns, finding a block that would provide the best traction would also be beneficial. Observing locomotion of cows closely to evaluate the frequency of slips and falls in cows with hoof blocks compared to unblocked cows would provide more information on the ability of the cow to compensate for alterations in both height of the claw and in traction on that claw. Although there are estimates for the amount of time required for the sole to grow over an ulcer, which has been used to argue the length of time blocks should remain affixed, more information is needed in this area. The effect of block wear and retention should also be assessed in cows with sole ulcers, since this could impact their healing. Finally, since the application of a hoof block results in only one claw being elevated this could potentially cause strain to other areas of the limb, which should be examined to ensure that block application is not causing damage to other areas of the limb.

In addition to future research questions that expand on the research completed in this thesis, other questions also arose through completion of these projects. Through observation of several different trimming styles and review of the literature throughout the completion of this thesis, the variability in trimming methods in the dairy industry became obvious. The development of standardized methods of trimming could be beneficial to the industry, to ensure that hooves were being trimmed to minimize potential for hoof lesions and ensure that hooves allowed for appropriate balance and movement for cows. With many other flooring options now available, such as rubber,
that result in less hoof wear (Telezhenko et al., 2009), trimming will only become more important for hoof health.

Conclusions

Lameness is one of the most important welfare concerns in the dairy industry. Both early identification of lameness or hoof lesions and prompt effective treatment will help to decrease the incidence of severe cases and duration. The Pedometer Plus has been validated for use in dairy cattle and accurately measures both activity and lying behaviour. The use of this accelerometer in dairy cattle for identification of lameness and hoof lesions shows promise, with more obvious changes in behaviour observed through data from lame cows. Following the hoof lesion history of cows allows for ability to predict the potential of future lesions or identify cows which should be observed more closely for development of lesions. Efficacy of a tetracycline hydrochloride paste for the treatment of digital dermatitis and lack of negative effects from the use of therapeutic hoof blocks, both show promise for resolution of some hoof lesions.
References

