DEVELOPMENT OF HOOF PATHOLOGIES IN DAIRY CATTLE WITH AND WITHOUT ACCESS TO PASTURE

By

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ABSTRACT

Hoof pathologies are a major concern in dairy production and lameness is considered to be one of the top three reasons for involuntary culling of lactating dairy cattle. The aim of this study was to determine the effect of a period of access to pasture before calving, versus continuous freestall housing, on the incidence of hoof lesions, dermatitis and heel erosion in dairy cattle during the months that follow calving. The hind hooves of all animals were scored for severe sole lesions, dermatitis and heel erosion pre-calving (200 to 0 days prior to calving), in early-lactation (0 to 100 DIM), and in mid-lactation (100 to 200 DIM). Over the course of the study, 42 out of 58 animals were diagnosed with severe lesions, 40 out of 58 animals were diagnosed with dermatitis, and 51 out of 58 animals were diagnosed with severe heel erosion. Multiparous cows were more affected by severe sole lesions than were primiparous animals during both the pre-calving (32 and 0 %, respectively) and mid-lactation periods (37 and 63 %, respectively). Cows housed continuously in freestalls tended to be more affected by dermatitis than were pasture animals in both early-lactation (55 vs. 32 %) and mid-lactation periods (41 vs. 24 %). There were no other effects of the pasture treatment. These results indicate that a period of access to pasture before calving has little positive effect on hoof health, and suggests that other approaches will be necessary to address these common pathologies in dairy cattle.

(Key words: lameness**,** hoof lesions, dermatitis, heel erosion**)**

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GENERAL INTRODUCTION

Hoof pathologies can lead to considerable economic loss to dairy producers through involuntary culling (Frankena et al., 1992), treatment costs (Esslemont and Peeler, 1993), reduced reproductive efficiency (Tranter and Morris, 1991), and loss in milk production (Green et al., 2002; Tranter and Morris, 1991). The welfare of an animal with hoof pathologies is also compromised as lameness and hoof injuries can cause pain (Whay, 1997). Researchers have begun to describe the development of and risk factors for hoof pathologies (e.g. Bergsten, 1994; Cook et al., 2004; Enevoldson et al., 1991a & b; Greenough and Vermunt, 1991). Measures of incidence of hoof injuries vary from study to study, but most research indicates that these injuries are common. In the United Kingdom, Clarkson et al. (1996) reported a 55% mean annual incidence of lameness in dairy cattle and Green et al. (2002) reported that over 70 % of the cows became lame at least once during their 7 month study. In a recent study on cattle in British Columbia, it was reported that 85.7 % of 624 dairy cows surveyed had at least one hoof lesion (Bell, 2004). This study reported that the 3 most common hoof pathologies were sole and white line lesions, heel erosion, and dermatitis.

The first part of this thesis will describe these 3 common hoof pathologies in more detail and review the existing literature on the risk factors for these pathologies.

Hoof Lesions

Hoof lesions commonly affect dairy cattle. Researchers from the United States, Europe and New Zealand have documented an incidence of hoof lesions ranging from 2 to 70 % (e.g. Frankena et al., 1992; Smilie et al., 1999; Tranter and Morris, 1991).

Lesions can result from several types of damage to the hoof. For example, a hoof lesion can occur when the corium is pinched between the pedal bone (distal phalanx) and the hard horn of the sole, resulting in blood being mixed with the newly produced horn. This, in turn, weakens the horn and impairs the ability of the supportive tissues to absorb shock and also reduces the quality of subsequent horn tissue. If the pinching of the corium is severe, production of new sole horn is completely interrupted and a sole ulcer is formed (Blowey, 2002). An abscess can result if the ulcer becomes infected.

Hoof lesions may occur on either the sole or white line (the junction between the sole and the wall) of the hoof (Tranter and Morris, 1991). Some researchers believe sole and white line lesions should be considered separately since the sole and white line differ in structure and function (e.g. Leach et al., 1997). Although interesting, the goal of this thesis was not to determine the relationship between hoof anatomy and susceptibility to pathologies, therefore sole and white line lesions will not be distinguished from one another and thus the term hoof lesions, or simply lesions will refer to both areas on the plantar aspect of the hoof. Hind hooves are twice as likely to have lesions as the front hooves (Manske et al., 2002 b), and the hind lateral claws tend to be more susceptible to hoof lesions than hind medial claws (Bergsten and Herlin 1996; Greenough and Vermunt, 1991; Russell et al., 1982; Leach et al., 1998). Additionally, lesions in the hind lateral claws are typically more severe than those in the hind medial claws (Leach et al., 1998; Greenough and Vermunt, 1991).

Many researchers have attempted to identify the different causes of hoof lesions in dairy cattle (e.g. Singh et al., 1993; Rowlands et al., 1985; Galindo et al., 2000; Leonard et al., 1996). Several researchers report how stage of lactation can affect the

occurrence of hoof lesions. Cows are more likely to experience hoof lesions in early-lactation than in late lactation, with the prevalence of lesions decreasing after peak lactation (Bergsten et al., 1998). Age and parity can also influence the occurrence of hoof lesions. In an extensive survey that focused on lameness in dairy cattle in the United Kingdom, Rowlands et al. (1985) found that 10 year-old cows were more than 4 times as likely to be lame compared to 3 year-old cows. This increased susceptibility to lameness was predominantly due to white line abscesses, sole ulcers and heel aberrations. Chaplin et al. (2000) found a large discrepancy in the total number of hoof lesions between two groups of animals (pregnant heifers: 16 lesions and primiparous cows: 177 lesions) housed under identical conditions. These findings correspond with Webster (2001, 2002) and Offer et al. (2000) who found that prior to calving, lesions were absent or very small in size in heifers, but after calving, most animals had both sole and white line lesions. Interestingly, heifers showed more severe haemorrhages than older cows in the period immediately following calving in a study by Greenough and Vermunt (1991). These authors found that heifers with the highest haemorrhage scores had the highest average daily weight gains. In addition, they found that haemorrhages on the hooves of multiparous cows either resolved themselves more slowly or not at all when compared to those on primiparous cows.

Feeding practices, diet composition, and feeding behaviour are known to affect hoof health (Bergsten and Frank, 1996 a & b; Manson and Leaver, 1989; Webster, 2001). For example, excessive consumption of rapidly fermenting carbohydrates (e.g. concentrates) may cause a rapid drop in rumen pH resulting in either acute or sub-acute ruminal acidosis. Ruminal acidosis can result in reduced ruminal efficiency, liver and

lung abscesses, and lameness (Stone, 2004). For many dairy cows, sub-acute ruminal acidosis, which usually goes unnoticed by the dairy producer, may be a more prevalent problem than acute acidosis. Stone (2004) explained that certain cows, particularly those around calving, with high DM intake, variable meal patterns, fed highly variable rations, or poorly fermentable or poorly formulated diets are most at risk of sub-acute ruminal acidosis. The exact link between sub-acute acidosis and hoof injuries is not known, but it has been suggested that histamine and endotoxins are absorbed through the rumen into the bloodstream. Vermunt (1992) argued that these and possibly other compounds alter circulation resulting in inflammation in the growing tissues of the hoof.

Researchers have reported that feeding a high concentrate diet may make animals more susceptible to lameness and also influence the length of time they are lame (Manson and Leaver, 1989; Bergsten and Frank, 1996 a & b). Furthermore, the method of concentrate delivery (e.g. total mixed ration or computerized grain feeder) and the feeding frequency (number of meals) may also affect hoof lesion development. For example, Bergsten (1994) reported a negative correlation between the total score of sole lesions (severity and distribution summed for all eight claws) and the number of meals of concentrate consumed per day. Another nutritional consideration that can affect hoof health is the dry matter (DM) content of the diet fed to dairy cows. Webster (2001) reported the effects of feeding a 'wet' diet (25 % DM) as compared to a 'dry' diet (60 % DM) to first-calf heifers housed in either a straw yard or a cubicle barn with concrete flooring. The 'wet' diet exacerbated the effects of housing the animals in the cubicle barn causing these animals to have more severe sole lesions for a longer duration than the animals fed the 'dry' diet.

Previous research has shown a relationship between lying time and hoof lesions in dairy cattle (Singh et al., 1993; Galindo and Broom. 2000). Galindo and Broom (2000), for example, studied social status and lying behaviour and found that low ranking cows that spent the least amount of time lying also had the highest incidence of lameness, mainly due to sole lesions.

In North American dairy barns, concrete is the most common choice of flooring due to its durability, availability, relatively low cost and ease of cleaning (Stefanowska et al., 2001). Since dairy cattle in the lower Fraser Valley region of British Columbia are housed almost exclusively indoors and spend approximately 10 h d^{-1} standing on concrete (Fregonesi et al., 2004), it follows that the standing surface may be a very important factor in the development of hoof problems.

Many different housing types exist and have been the focus of several studies (e.g. Faull et al., 1996; Philipot et al., 1994). Although tie stall housing appears to show fewer negative effects on hoof health than freestall housing (Bergsten and Herlin, 1996), production pressures, advancements in technology, and the restriction of movement in tie stalls all favour increased use of loose housing systems.

Housing dairy cattle in straw yards may be beneficial for hoof health. Young dairy cattle between 2.5 and 12 months of age kept in a straw yard were 40 % less likely to have sole lesions than those kept on slatted concrete floors (Frankena et al., 1992). Webster (2002) found that housing heifers in a straw yard during the periparturient period helped reduce the severity of hoof lesions compared to animals housed year-round in freestalls. Webster (2001) also compared freestall and straw yard housing for heifers and concluded that the housing systems resulted in a peak in lesion scores at different times

(week 4 versus week 8 post calving for straw- and freestall-housed cows, respectively). Webster (2001) also found that the lesions declined at different rates in the two housing systems. Sixteen weeks after calving the lesions had almost completely disappeared in heifers housed in straw yards whereas, the cumulative score (which considers both the lesion size and severity) was greatest at week 16 after calving in freestall-housed heifers. Livesey et al. (1998) compared heifers housed in freestall and straw yard housing and fed different levels of concentrates. These researchers found that all animals developed lesions post-calving; however, the problem was exacerbated in those animals that were freestall-housed with concrete floors and fed a high concentrate diet. In British Columbia straw yards are not used. Instead, producers favour freestall barns with concrete flooring and stalls bedded with sand or sawdust.

Flooring effects on hoof health may be exacerbated by the manure management that is inherent to the specific flooring type. Borderas et al. (2004) reported that cows standing in high moisture environments, such as those found in freestalls where there is considerable manure, have softer claws and have more severe claw lesions. Thus, it would follow that surfaces that allow manure to seep away quicker than solid concrete (i.e. straw packs, pasture) may be better for hoof health. Furthermore, drier environments such as that found on pasture during the summer may result in harder hooves which could provide longer term benefits by reducing the susceptibility to various hoof pathologies once the cows return to the freestall.

Dermatitis

Digital and interdigital dermatitis are two common hoof conditions in dairy cattle. For example, a United Kingdom study (Clarkson et al., 1996) reported that 8 % of all the lesions contributing to lameness were digital dermatitis. Digital dermatitis occurred on 91 % of 214 dairy farms examined in Chile (Rodriguez-Lainz et al., 1998). Frankena et al. (1992) studied 1141 young dairy heifers between 2.5 and 12 months of age, and found interdigital dermatitis in 66 % of the animals.

Some researchers believe interdigital dermatitis and digital dermatitis are separate problems (e.g. Read and Walker, 1998; Rodriguez-Lainz et al., 1998; Vokey et al., 2001) while others are of the opinion that they are manifestations of the same pathology (e.g. Manske et al., 2002 a). The lack of consensus in the literature indicates that more thorough investigations are required into the etiology of these conditions. For the purposes of this thesis, both of these ailments will be referred to as dermatitis.

Dermatitis often affects the skin midway between the heel bulbs (Blowey and Sharp, 1988). It can also develop on the soft tissue in the interdigital space. Blowey et al. (1994) described this pathology as:

> "Early lesions produce matting of the hairs which stand erect in a thick, light brown exudate, which has a characteristic pungent odour. Cleaning away superficial detritus reveals a circular, moist, red, raw and granulating area, approximately 2 to 3 cm in diameter which is extremely painful when touched."

Other clinical signs of dermatitis include inflammation and scabbing at the site of the lesion (Laven and Proven, 2000). Cows affected with dermatitis can exhibit a variety of lameness symptoms. These range from partial to complete reluctance to bear weight and bearing weight only on the toes of the affected hoof (Read and Walker, 1998), depending on the stage and severity of the lesion.

Dermatitis has typically been associated with bacterial infections (Laven and Proven, 2000; Cruz et al., 2001) and has been shown to respond well to antibiotics (Blowey and Sharp, 1988). Since moisture and manure are ideal vehicles for transmission of bacteria, housing and manure management are important characteristics of dairy production to consider when studying dermatitis. In a Californian study, an increase in the occurrence of lameness after the rainy season when cows were continually standing in mud and manure, was attributed to dermatitis (Read and Walker, 1998). Hultgren and Bergsten (2001) assessed the hoof health of dairy cows on solid or slatted floors over two years and attributed the increased dermatitis in the cows on solid floors to increased exposure to moisture and manure.

Heel Erosion

The heel is a major weight-bearing surface of the hoof (Blowey, 1990). Together with the underlying digital cushion, the heel acts as a shock absorber during locomotion (Bergsten, 2001). Degradation of the heel, commonly referred to as heel erosion or heel horn erosion, may cause a reduction in shock absorbance and a change in the weight-bearing portion of the hoof (Blowey, 1990). Heel erosion is a continuous degradation of heel tissue, resulting in major loss of heel structure (Smilie et al., 1999). Typically, it

begins as shallow irregular grooves in the heel and can progress to become deep oblique grooves. Heel erosion contributes to lameness (Bergsten and Pettersson, 1992) and can therefore have negative consequences for the comfort, welfare and productivity of the dairy cow.

Heel erosion is one of the most common chronic hoof disorders in dairy cattle (Bergsten and Pettersson, 1992). Smilie et al. (1999) examined the hooves of 203 cows in 13 herds in Ohio and found at least some heel erosion in 74 % of the heels that were examined, of which they classified 13.3 % as severe (having shallow or deep erosions that have formed grooves). In another study, Hultgren and Bergsten (2001) reported that 59 % of the 82 dairy cattle examined in their study had severe heel erosion.

A number of factors contribute to the prevalence of heel erosion. Firstly, older animals are known to be at a higher risk. Enevoldsen et al. (1991) reported that animals in their third to ninth parities were 1.7 times more susceptible to heel erosion than cows in their first or second parity.

Stage of lactation is a second factor thought to affect the prevalence of heel erosion. For example, Livesey et al. (1998) found that the prevalence of heel erosion was low in heifers before calving but increased significantly in early-lactation. Cows appear to be at greatest risk for heel erosion at peak lactation. Increased risk of heel erosion at this time has been attributed to the increased volume of manure produced at peak lactation (Bergsten and Herlin, 1996).

Exposure to moisture and manure are other risk factors for heel erosion (Bergsten and Pettersson, 1992). Damp conditions increase the moisture content of the hoof, which in turn creates an environment suitable for excessive bacterial growth (Enevoldsen et al.,

1991; Bergsten and Pettersson, 1992). According to Bergsten (2001), manure macerates the skin and horn tissue, thereby creating an environment where contagious agents with an affinity for hoof horn, such as *Bacteroides nodosus*, are able to proliferate. Bergsten and Pettersson (1992) reported an increased severity of heel erosion in cows housed in stalls that contained larger amounts of manure. Susceptibility to heel erosion can also be influenced by environmental temperature, which interacts with humidity and or moisture to modulate the conditions for bacterial growth and chemical (i.e. ammonia) volatilization leading to further irritation of the hoof (Enevoldsen et al., 1991).

The amount of moisture and manure encountered by the hooves of dairy cows greatly depends on the type of housing to which the cows are exposed. Housing features that affect the amount of moisture and manure encountered by hooves are thought to influence the prevalence and severity of heel erosion (Bergsten and Pettersson, 1992; Bergsten and Herlin, 1996; Livesey et al., 1998; Offer et al., 2000). Bergsten and Herlin (1996) found that heel erosion was absent or rare in the front hooves of dairy cows housed in tie-stalls but in contrast to freestall-housed cows there was no difference between the front and hind hooves. The authors attributed these findings to the fact that the front and hind hooves of freestall-housed cows are in similar conditions whereas the front hooves of cows in tie stalls are often drier and have less contact with manure.

OBJECTIVES

This introduction has outlined 3 common dairy cattle hoof pathologies and their suspected causes. Sole lesions, dermatitis, and heel erosion are not only a problem for the individual cow but also represent a significant economic problem to the dairy producer. It is evident from the current literature that flooring is one of the primary features in the environment of a dairy cow that can have a major impact on hoof health.

It has been shown that zero-grazed cows in Kenya are 3 times more likely to become lame from foot lesions (including heel erosion and sole and interdigital lesions) than cows that are allowed access to pasture (Gitau et al., 1996). Offer et al. (2000) reported that 6 months on pasture can reduce the risk of developing hoof pathologies. However, most North American producers would find it difficult to maintain cows on pasture for as long as 6 months per year. If pasture is provided, the access is typically limited to late-lactation and dry cows and only during the summer months. However, no published research has addressed whether such access to pasture can provide benefits to hoof health.

The objectives of this thesis were to firstly determine if access to pasture for part of the summer reduced the risk of sole lesions, dermatitis, and heel erosion, particularly once cows returned to continuous housing in a freestall barn prior to calving or at the end of the summer. The second objective was to monitor the progression of the 3 pathologies and to describe their interrelationships, as this has not yet been performed in North America using the current housing comparisons.

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INTRODUCTION

Hoof pathologies such as sole lesions, white-line separation, dermatitis, interdigital necrobacillosis, interdigital hyperplasia, and heel erosion, as well as any resulting lameness, are of increasing concern to dairy producers. Animals suffering from hoof and leg pathologies are often culled due to lameness, which is now viewed as one of the 3 top reasons for involuntary culling of lactating dairy cattle (Frankena et al., 1992). Poor hoof health also results in substantial economic losses to dairy producers (Smit et al., 1986; Smits et al., 1992) through decreased production (Green et al., 2002; Tranter and Morris, 1991), reduced reproductive performance (Tranter and Morris, 1991) and treatment costs (Esslemont and Peeler, 1993). Moreover, previous research suggests that there is substantial pain associated with hoof pathologies compromising the welfare of affected cows (Enevoldsen et al., 1991a; Rushen, 2003; Whay et al., 1997).

Increases in dairy herd size and improvements in production due to feeding of high-density rations have resulted in a shift from extensive systems based on pasture to intensive indoor systems. However, concurrent with the shift to more intensive production systems is a dramatic increase in the incidence of hoof pathologies in dairy cattle. For example, a recent survey of dairy cattle in British Columbia found that approximately 86 % of dairy cows had at least one sole lesion (Bell, 2004).

Standing on concrete flooring, typical of indoor housing, is recognized as a risk factor in the development of hoof injuries (Bergsten, 1994). Given the choice, cows

prefer to stand on softer flooring surfaces (Tucker et al., 2003), and numerous researchers have suggested that access to pasture will benefit hoof health (e.g. Bergsten and Frank, 1996; Bergsten and Pettersson, 1992, Offer et al. 2000). In addition to a softer standing surface, pasture housing may also reduce prolonged periods of standing in manure slurry. This exposure to moisture is known to affect hoof hardness (Borderas et al., 2004), and exposure to pathogens in manure may increase the risk of diseases such as dermatitis.

Previous research suggests that there is a cyclic pattern to the development of sole lesions, dermatitis, and heel erosion (e.g. Offer et al., 2000). These authors report that the incidence of sole lesions increases from calving through peak lactation and then decreases. However, they also explain that older animals have more sole lesions. Heel erosion increases throughout the housing period while cows are standing in manure and on concrete. There is some evidence (Offer et al., 2000) that heels can recover from erosion, especially when cows are housed on pasture for 6 months. The number of cows affected by dermatitis increases when hooves are exposed to more moisture and manure (Rodriguez-Lainz et al., 1996), both of which are influenced by housing and management practices.

One previously published paper has compared cows with continuous access to pasture to cows housed indoors, and found that cows in the indoor group were 3 times more likely to become lame from foot lesions (including heel erosion, sole and interdigital lesions; Gitau et al., 1996). However, continuous access to pasture is not considered feasible for many North American producers due in part to the production benefits associated with feeding energy rich diets during early- to mid-lactation. Many producers are able to allow cows access to pasture when nutrient requirements are more

modest, such as during late lactation and when cows are dry. The aims of this study were to determine the effect of providing access to pasture during late-lactation and the far-off dry period on the development of hoof lesions, dermatitis and heel erosion in the subsequent lactation when cows return to indoor housing and to monitor the progression of the 3 pathologies and their interrelationships.

MATERIALS AND METHODS

The experiment was conducted at The University of British Columbia Dairy Education and Research Centre (Agassiz, British Columbia, Canada). The dates that specific animals were followed depended upon their stage of lactation at the beginning of the study in June, 2002. We began with a sample of 84 animals in late lactation (greater than 200 DIM) or a minimum of 8 weeks before calving. Once observations began animals were followed through to mid-lactation, such that the last observations were collected in May, 2003 (Figure 1).

Throughout the study cows were randomly assigned to the 2 treatments (continuous freestall housing versus a period of access to pasture), with the constraint that treatment groups were balanced for parity, estimated 305-milk production (based on current lactation) and body weight. For primiparous cows, treatments were balanced on the basis of projected calving date and body weight. Prior to the onset of this study all animals were housed indoors in a freestall barn. Unfortunately, a total of 26 animals were dropped from the data set throughout the course of the study: 1 cow aborted, 1 cow died, 1 cow was culled, 1 was not confirmed pregnant, and 22 failed to be scored at least once during each phase of the study resulting in a final number of 58 animals.

Treatment 1: Freestall Housing

A total of 33 animals were tested on this treatment, including 10 primiparous cows, 10 non-lactating, pregnant multiparous cows (mean parity = 2.0 ± 1.05) and 13 lactating multiparous cows (parity = 2.38 ± 1.39; DIM 221 ± 38). Cows were housed continuously indoors dispersed among the 225-cow lactating cow herd in a freestall barn with concrete flooring and automatic alley scrapers that ran every 4 h. Animals had access to stalls bedded with either sand or sawdust and were fed diets in the form of a total mixed ration (TMR) that varied with stage of lactation based on the recommendations outlined in NRC (2001). Dry cows and heifers had access to mineral salts (Unifeed, Chilliwack, British Columbia). The diets were fed at approximately 0600 and 1515 h along a concrete feed alley with 60 cm of feed space per animal.

Treatment 2: Pasture

A total of 25 animals were tested on the pasture treatment, including 10 primiparous cows, six non-lactating, pregnant multiparous cows (mean parity = 2.5 ± 1.87), and nine late lactation multiparous cows (mean parity = 3.1 ± 1.76, DIM = 215 ± 23). Cows were on pasture for an average of 94 ± 40 d (mean ± SD) from June 15, 2002 until the last cows were moved off pasture on November 1, 2002. Lactating cows were brought into the freestall barn twice daily for milking at approximately 0630 and 1530 h.

The 8 ha pasture was in a flat area, seeded in May 2001 with approximately 5 ha of Festuolium (tall fescue/rye grass cross) and 3 ha of "Profile" orchardgrass (*Dactylis glomerata* L.). The pasture was divided into 41 plots (average size: 1,500 m^2) plus

corridors for moving cows from paddock to paddock. All paddocks had water troughs and mineral salts (Unifeed, Chilliwack, British Columbia). Animals were managed using a rational grazing system (Voisin, 1974). Lactating cows were allowed access to a fresh paddock every day. Following removal of the lactating cows, the pregnant animals were given access to the same paddock. Representative pasture samples from each plot were analysed bi-weekly for the first 4 months and monthly until the completion of the pasture phase of the experiment. Four different quadrants in each plot were analysed using near infrared reflectance spectroscopy for DM, ADF, NDF and CP. The nutrient composition was then used to calculate the approximate yield of nutrients from the pasture. Resulting calculations indicated that the lactating cows on pasture required, on average, 15 kg supplemental concentrate per cow per day in order to equalize the energy and protein intake with that of the freestall-housed cows. Dry heifers and dry cows on pasture did not receive any supplementary feed in addition to the mineral salts.

Concentrate for lactating cows on pasture was provided in 3 equal portions throughout the day. Prior to each of the 2 daily milkings, cows could access concentrate spread along the concrete feed alley (with approximately 60 cm bunk space per cow). The total time in the milking parlour and in the feed alley was approximately 80 min per milking. The third concentrate allotment was distributed along a strip of pasture 16 m X 0.15 m at 2000 h.

Hoof Health

Hooves of all subjects were scored approximately every 7 weeks (52 ± 8 d), since this represents the approximate time for any visually identifiable haemorrhages to appear

on the sole surface after an injury to the corium (Bergsten and Frank, 1996). As all animals were scored during a single visit by the hoof trimmer, the number of times each animal was scored during each period was somewhat variable: 2.25 ± 0.89 (mean ± SD) times pre-calving, 1.85 ± 0.36 times in early-lactation (0-100 DIM) and 1.19 ± 0.40 times in mid-lactation (100 – 200 DIM). Due to the decision to group observations, after the data were collected, into pre-calving, early-lactation, and mid-lactation, one primiparous cow was only scored in her pre-calving and early-lactation periods. Thus, the resultant data set included 58 animals in the pre-calving and early-lactation observation periods and 57 animals in the mid-lactation period.

Lesion scoring. At each observation, the soles of the hind hooves were pared minimally by a trained hoof trimmer to expose a clean surface. The hoof was divided into 6 zones following Greenough and Vermunt (1991). Lesion severity was scored by 2 trained individuals as haemorrhages or ulcers based on colour and extent of damage to the hoof, using the method of Leach et al. (1998). Haemorrhages were scored on a scale from 1 to 5 (1 = diffuse red or yellow; 2 = stronger red; 3 = deep dense red; 4 = port coloration; 5 = red, raw, possibly fresh) and ulcers were scored from 6 to 8 (6 = corium exposed; 7 = severe ulcer, major loss of horn; 8 = infected ulcer). Hooves were only correctively trimmed in situations when an ulcer or abscess was present. Throughout the study, only 4 cows had ulcers with one of these cows also having an abscess at the same time on the opposite hoof. These cows were correctively trimmed on the affected hoof and remained part of the study.

Dermatitis scoring. Hind hooves of each cow were inspected for the presence of digital dermatitis and interdigital dermatitis. Manure was scraped from the interdigital

space and the area between the heel bulbs. If there was evidence of a raised area of skin with or without odour and hair-like projections, pressure was applied to the area. If the cow withdrew her hoof dermatitis was recorded as active and was treated by the hoof trimmer.

Heel erosion scoring. The hind heels of each cow were scored according to the criteria outlined by Smilie et al. (1999). Specifically, we noted if grooving appeared on the 4 claws (medial and lateral or the left and right hind feet), and if these groves were irregular or oblique.

Statistical Analysis

For sole lesions and heel erosion, scores were collapsed into categories of severe and not severe as we felt this more accurately described the true importance of the pathologies. Dermatitis was considered present if it was deemed "active". Any claw with lesions scored as a 3 or higher was considered to have severe lesions following Bergsten et al. (1998). Any heel with erosion scored as a 3 or 4 was considered severe following Smilie et al. (1999). Preliminary analyses indicated there were no differences between left and right hooves or lateral and medial claws with respect to any of the 3 hoof pathologies studied. Odds ratios were calculated to determine the likelihood of having pathologies on one or both claws and one or both hooves, but all other analyses reported below are on a per cow basis. Binomial tests were performed to determine if more animals improved or worsened between observation periods. Preliminary graphical analysis showed that differences due to treatment and parity varied between observational periods. Thus all statistical comparisons were pair-wise, comparing treatments and

parities (multiparous versus primiparous) within periods, and vice-versa using the Fisher exact test.

RESULTS

Sole Lesions

In the pre-calving observation period, a higher proportion of pasture animals had severe lesions than did those in the freestall group (Fisher Exact $P = 0.049$) (Figure 2 a). This difference had disappeared by early-lactation when cows were housed indoors for the remainder of the study. However, the 2 groups diverged again in mid-lactation with the pasture cows again tending to have more lesions than freestall cows (Fisher Exact $P = 0.08$).

Within the freestall treatment group, the proportion of cows with severe lesions increased from pre-calving to early-lactation (Fisher Exact $P = 0.0005$) but not from early- to mid-lactation (Fisher Exact $P = 0.11$). Within the pasture group, there was no significant change in the proportion of cows with severe lesions either from pre-calving to early-lactation (Fisher Exact $P = 0.12$) or from early- to mid- lactation (Fisher Exact $P = 0.19$).

Approximately one-third of multiparous cows had severe lesions during the pre-calving period, but these lesions were absent in primiparous cows during this period (Figure 2 b; Fisher Exact $P < 0.01$). In early-lactation this difference between the parity groups had disappeared, with 50 % of both groups affected. However, by mid-lactation, more primiparous cows were affected with severe hoof lesions than multiparous cows ($P < 0.05$).

There was a significant increase in the number of multiparous cows with severe lesions in early-lactation compared to the pre-calving period (Fisher Exact $P = 0.05$), but multiparous cows tended to be less likely to have severe lesions in mid-lactation compared to those in early-lactation (Fisher Exact $P = 0.095$). There was also a significant increase in the number of primiparous cows with severe lesions in the pre-calving to early-lactation periods (Fisher Exact $P = 0.0002$), however, there was no difference between the early- and mid-lactation periods (Fisher Exact $P = 0.18$).

Table 1 shows that from pre-calving to early-lactation more animals worsened than got better with respect to severe lesions. There was no evidence of such a difference from early- to mid-lactation.

Sole lesions varied by zone of the claw (as it is divided in the claw map agreed upon at an international symposium (Greenough and Vermunt, 1991)): 7.1 % of the lesions were in zone 1, 16.7 % in zone 2, 11.6 % in zone 3, 52.2 % in zone 4, and 12.4 % in zone 5. Considering the white line separately we found no difference between treatments or parities. Thus, differences seem to be driven by lesions in the zones of the sole (zones 4 and 5).

Digital Dermatitis

Freestall-housed animals tended to be more likely to have dermatitis in all 3 periods, but these differences failed to reach significance (Figure 3 a; Fisher Exact $P = 0.15$, 0.051 and 0.097, for pre-calving, early-lactation and mid-lactation respectively). The number of freestall-housed animals with dermatitis increased from pre-calving to early-lactation (Fisher Exact $P = 0.016$) and showed a marginal decline in mid-lactation

(Fisher Exact P = 0.11). Cows on pasture showed a similar pattern, but neither the increase in early-lactation nor the decrease in mid-lactation was significant (Fisher Exact P = 0.11 and 0.20, respectively).

During the pre-calving period, multiparous cows tended to have more dermatitis than primiparous cows (Fisher Exact P = 0.07; Figure 3 b), but there was no evidence of such a difference during the subsequent periods. The number of multiparous cows with dermatitis increased from pre-calving to early-lactation (Fisher Exact P = 0.049) and this number tended to decline again in mid-lactation (Fisher Exact P = 0.07). The number of primiparous cows with dermatitis showed a similar increase from pre-calving to early-lactation (Fisher Exact P = 0.028), and no difference from early- to mid-lactation (Fisher Exact P = 0.25).

Although only 4 animals had dermatitis at the outset of the study, 40 of the 58 were diagnosed with this ailment during at least one scoring session. However, once cows were treated, they normally showed no re-occurrence; only 15 animals were scored for dermatitis in more than one observation period. Individuals with dermatitis tended to improve between the early- and mid-lactation (Binomial P = 0.08; Table 1).

Heel Erosion

There was no difference between freestall and pasture animals in the proportion with severe heel erosion either pre-calving or in early-lactation (Figure 4 a; Fisher Exact P = 0.21 and 0.21, respectively), but there tended to be fewer pasture animals with severe heel erosion by mid-lactation (Fisher Exact P = 0.1). The number of freestall animals with severe heel erosion showed little change from pre- to early-lactation (Fisher Exact P

= 0.12), but did increase in mid-lactation (Fisher Exact P = 0.0006). Pasture cows showed a similar pattern with little change from pre-calving to early-lactation (Fisher Exact P = 0.19), followed by an increase from early- to mid-lactation (Fisher Exact P = 0.048).

More multiparous cows than primiparous cows had severe heel erosion in each observation period (Figure 4 b). This difference was greater when cows were in the pre-calving and early-lactation periods (Fisher Exact P = 0.0005 and P = 0.00005, respectively) than in the mid-lactation period, due to an increase in number of primiparous cows with severe heel erosion in mid-lactation (Fisher Exact P = 0.004). Multiparous cows were also more likely to be diagnosed with severe heel erosion in mid-lactation compared to early-lactation (Fisher Exact P = 0.0065). Both primiparous and multiparous cows also showed some increase in heel erosion from pre-calving to early-lactation, but these differences were not significant (Fisher Exact P = 0.30 for primiparous and P = 0.09 for multiparous cows).

No improvement in severe heel erosion was observed in any of the animals from early- to mid-lactation (Table 1). At the end of this study, 50 out of 57 animals were diagnosed with severe heel erosion.

Interrelationships between pathologies

Table 2 shows the interrelationships between claws (medial and lateral) and hooves (left and right). In the pre-calving and mid-lactation periods, if a cow had a severe lesion on one hoof (left or right), it was more likely to have severe lesions on both hooves (O.R.> 6, Fisher Exact P = 0.001 and 0.003). A similar interrelationship existed between

claws (medial or lateral) in early-lactation (O.R. = 23, Fisher Exact P = 0.001). In all 3 periods, if an animal had dermatitis on one hoof, it was more likely to have it on both hooves (O.R.> 5, Fisher Exact P = < 0.001 to 0.009). Since dermatitis affects the hoof and not individual claws, claw comparisons were not made here. In each period, if an animal had heel erosion on one claw or one hoof it was more likely to have the pathology on both claws or hooves (O.R. > 5, Fisher Exact P < 0.01).

In the pre-calving period, all interrelationships between hoof pathologies were significant. Animals with severe lesions were more likely to have dermatitis than were animals with no severe lesions (O.R. = 6; Fisher Exact P = 0.02), and those with severe heel erosion were more likely to have severe lesions than were animals without severe heel erosion (O.R. = 21; Fisher Exact P = 0.0005). Animals with severe heel erosion also tended to be more likely to have dermatitis than those without severe heel erosion (O.R. = 3; Fisher Exact P = 0.06).

By early-lactation these interrelationships were less pronounced (lesions and dermatitis, O.R. = 1, Fisher Exact P = 0.6; heel erosion and lesions, O.R. = 1.5, Fisher Exact P = 0.4). However, cows with severe heel erosion were still more likely to have dermatitis than those without severe heel erosion (O.R. = 5; Fisher Exact P = 0.006). By mid-lactation there were no significant interrelationships between the hoof pathologies (severe lesions and dermatitis: O.R. = 0.5, Fisher Exact P = 0.2; severe heel erosion and severe lesions: O.R. = 1.1, Fisher Exact P = 0.6; severe heel erosion and dermatitis: O.R. = 3, Fisher Exact P = 0.3).

DISCUSSION

Sole Lesions

Previous work has indicated that time spent standing on concrete can increase the risk of hoof lesions (e.g. Bergsten, 1994; Singh et al., 1993). Bergsten and Frank (1996) discussed the potential benefits of providing cows with a soft, comfortable standing surface. They postulated that a more yielding surface (compared to concrete) would decrease the biomechanical forces on the corium of the hoof. For this reason, keeping cows on pasture was predicted to improve hoof health in general, and more specifically reduce the risk of developing sole lesions. However, in the current study the only effect of housing was on the proportion of hoof lesions during the pre-calving period, and this difference was in the opposite direction to that predicted. This difference may have been due to chance differences between treatment groups at the outset of the experiment. We made no attempt to balance groups for the presence of lesions, as it takes approximately 2 months after the onset of inflammation of the corium to be able to visually identify haemorrhages on the sole surface (Bergsten and Frank, 1996). Differences between the pasture and freestall cows may also have been due to the changes in the plantar surface of the hoof in pasture animals. Hooves of pasture cows were gradually cupped out, whereas the hooves of freestall cows tended to be flat. This cupping out may have differentially affected our ability to identify lesions in the two groups. For these reasons, our results cannot be used to meaningfully assess the immediate effects of pasture on sole lesions. However, the results do indicate that access to pasture during the pre-calving period has little effect on the risk of animals developing lesions once they return to indoor housing after calving.

The increase in severe lesions from pre-calving to early-lactation, followed by a decline from early- to mid-lactation, was similar to the results reported by Bergsten et al.

(1998) and Offer et al. (2003). These authors found that cows were more likely to experience hoof lesions in early-lactation (< 100 DIM) than in late lactation (> 200 DIM) and that the occurrence of sole lesions peaked at 4 months post-calving. The subsequent decline in severe lesions could be attributed to the decreased milk production, demand for energy (concentrates) and manure produced at this time of the lactation cycle. The large increase in the number of primiparous cows with severe lesions in early-lactation compared to the pre-calving period corresponds with the findings of Webster (2001, 2002) and Offer et al. (2000). These earlier studies reported that prior to calving, lesions were largely absent in heifers, but after calving most animals had both sole and white line lesions. Our results are also consistent with those reported by Chaplin et al. (2000) who found a large difference in the total number of hoof lesions between pregnant heifers and primiparous cows housed under identical conditions.

The pre-calving and early-lactation periods are obviously critical times in terms of hoof health in primiparous cows, and many researchers believe that once hoof health is compromised an animal will be more susceptible to subsequent injuries (e.g. Offer et al., 2000). Movements to new housing conditions and new social groups combined with changes in diet may account for the increased risk of lesions after calving (Greenough and Vermunt, 1991).

Dermatitis

It has been postulated that the occurrence of digital dermatitis varies in relation to the lactation cycle and that this cycle reflects the cleanliness of the environment in which animals are housed (Manske et al., 2002). Our data support this claim, with the highest

level of dermatitis observed in early-lactation when animals are believed to produce the most manure, although manure production was not measured in the current study. The trend for pasture-housed cows to show a reduced risk of dermatitis may also be partially explained by the differences in exposure of the feet to manure during the pre-calving period.

We found no effect of parity on dermatitis. This is in contrast to Bergsten et al. (1998) who found that digital dermatitis decreased with age. They attributed their findings to an increase in resistance to dermatitis causing pathogens arising from previous exposure. It is not clear why we did not find the same relationship between parity and dermatitis.

Heel Erosion

The proportion of animals with severe heel erosion increased over the course of the study. Livesey et al. (1998) also reported a low prevalence of heel erosion before calving, followed by a large increase 6 weeks after calving regardless of housing system (freestall vs. straw yard). Bergsten and Herlin (1996) suggested that increased exposure to manure in early- to peak lactation could increase the risk of heel erosion. We found little evidence of improvement in heel erosion in pasture cows in our study. However, Offer et al. (2000) reported that with a longer period on pasture (6 months) cows could show improvement in heel erosion.

Only a small proportion of primiparous cows had severe heel erosion in the pre-calving period. This proportion increased by mid-lactation but remained low compared to multiparous cows. This result corresponds well with the findings of Bergsten et al. (1998)

and Enevoldsen et al. (1991b) who also found that heel erosion was more common in older cows. In our study, the heels of most animals deteriorated from the onset of the study and none improved after early-lactation. Bergsten and Pettersson (1992) suggest that it takes approximately 2 to 3 months for animals to recover from heel erosion, and that heels can show evidence of recovery during summer grazing. However, little is known about how this recovery may occur.

Interrelationships between pathologies

We found that cows with severe sole lesions were more likely to have dermatitis. Similarly, Frankena et al. (1992) suggested that interdigital dermatitis can affect the integrity of the claws, contributing to the formation of sole ulcers. However, Hultgren and Bergsten (2001) reported no evidence of this interrelationship. The reason for the difference between these studies is not clear.

We found that heel erosion and sole lesions were related in the pre-calving period. One explanation for this is the presence of an eroded heel may alter the weight-bearing surface of the hoof so that additional weight falls on the solar region and causes the toe of the hoof to deviate dorsally and the pedal bone (phalange 3) to rotate (Blowey, 1990). After calving we found no relationship between sole lesions and heel erosion. Bergsten and Herlin (1996) also reported a similar finding when they examined hooves in the first 2 to 4 months post-calving. We found that animals with severe heel erosion also had dermatitis, suggesting that either pathology may predispose animals to the other, or that the 2 pathologies are caused by similar conditions. Enevoldsen et al. (1991b) reported mixed results with respect to the relationship between heel erosion and interdigital

dermatitis. They suggested that the 2 pathologies might be manifestations of the same disease in first lactation cows, but not in multiparous cows. The only explanation they offer is that first lactation cows undergo abrupt environmental changes, possibly in association with a specific environmental pathogen, and therefore experience heel erosion linked to interdigital dermatitis.

After early-lactation, the interrelationships between these different pathologies weakened or disappeared. The reasons for this may be due to differing aetiologies. Sole lesions and heel erosion followed the same pattern of development at the beginning of the trial, however, after calving this pattern differed. One explanation may be that heel erosion results from a constant environmental impact such as exposure to manure. On the other hand, sole lesions can develop as a result of nutritional insults. Dermatitis and heel erosion were interrelated through pre-calving and early-lactation probably due to the commonalities of their causes as both pathologies are influenced by manure and moisture.

CONCLUSIONS

A period of access to pasture before calving has little effect on the risk of developing sole lesions, dermatitis, and heel erosion in dairy cattle after calving when all animals are housed in freestalls. However, the high incidence of all 3 pathologies suggests the need for continued work in this area. Specifically, we need to understand what types of housing systems can both reduce the risk of developing these pathologies, and help affected animals recover. It is likely that any positive effects of housing will be most apparent during the treatment period than in the months that follow. Previous work has shown that extended periods on pasture can have positive effects, but new research is

required on the effects of housing and especially flooring in situations where extended access to pasture is not practical.

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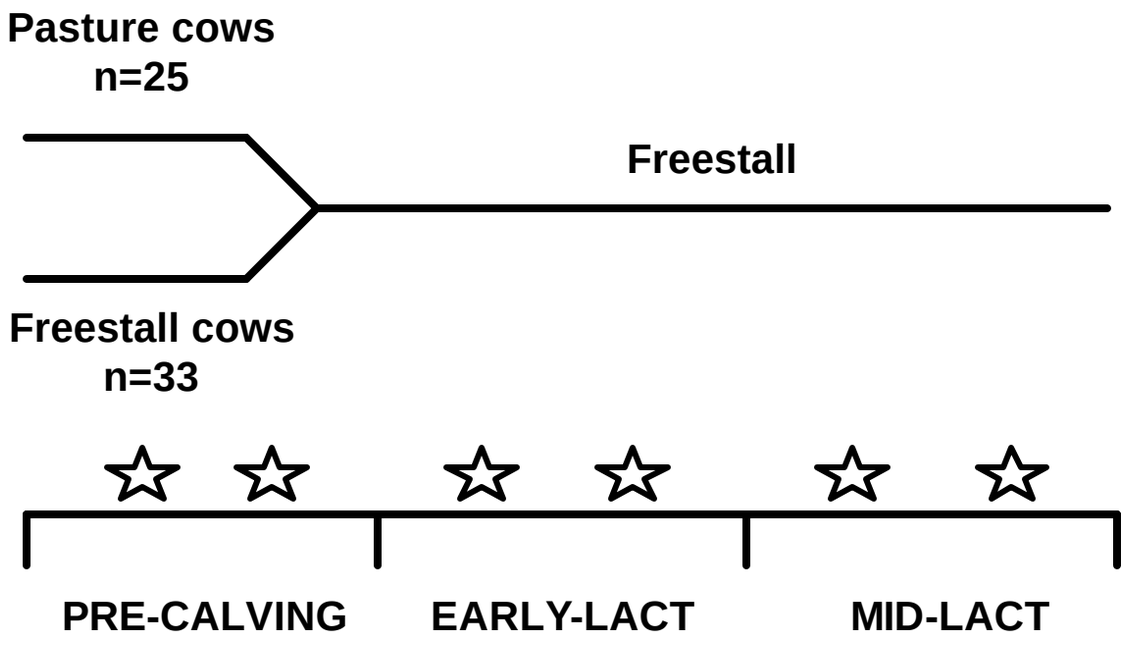
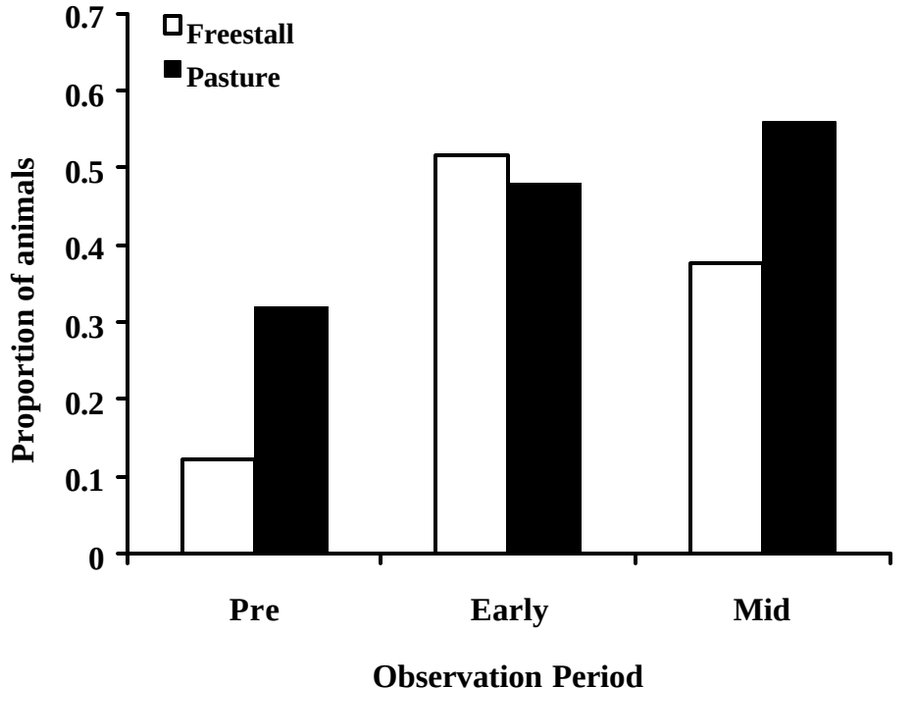


Figure 1: Graphical representation of the type of housing provided throughout the study and the approximate number of times within the pre-calving (-100 to 0 DIM), early-lactation (0 to 100 DIM), and mid-lactation (100 to 200 DIM) observation periods that hoof scoring (✍) took place.

a)



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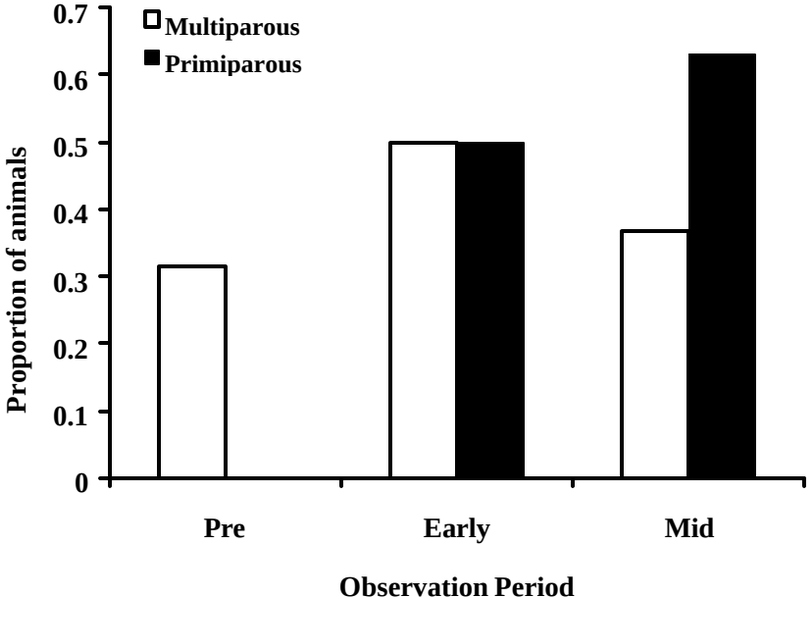
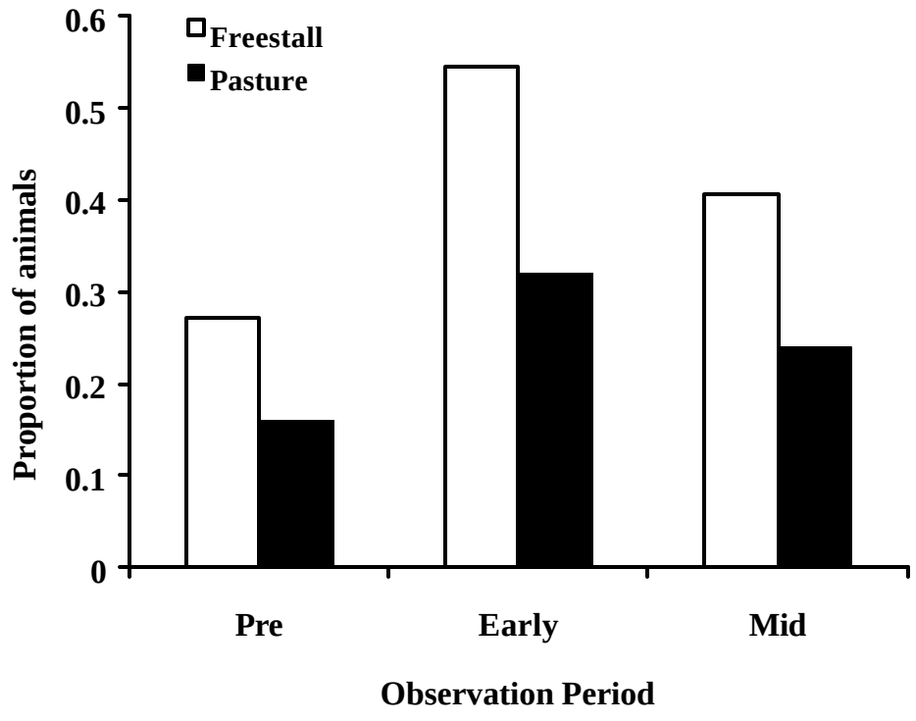


Figure 2: Proportion of animals with severe sole lesions by treatment (a) and parity (b) for the pre-calving, early-lactation, and mid-lactation observation periods.

a)



b)

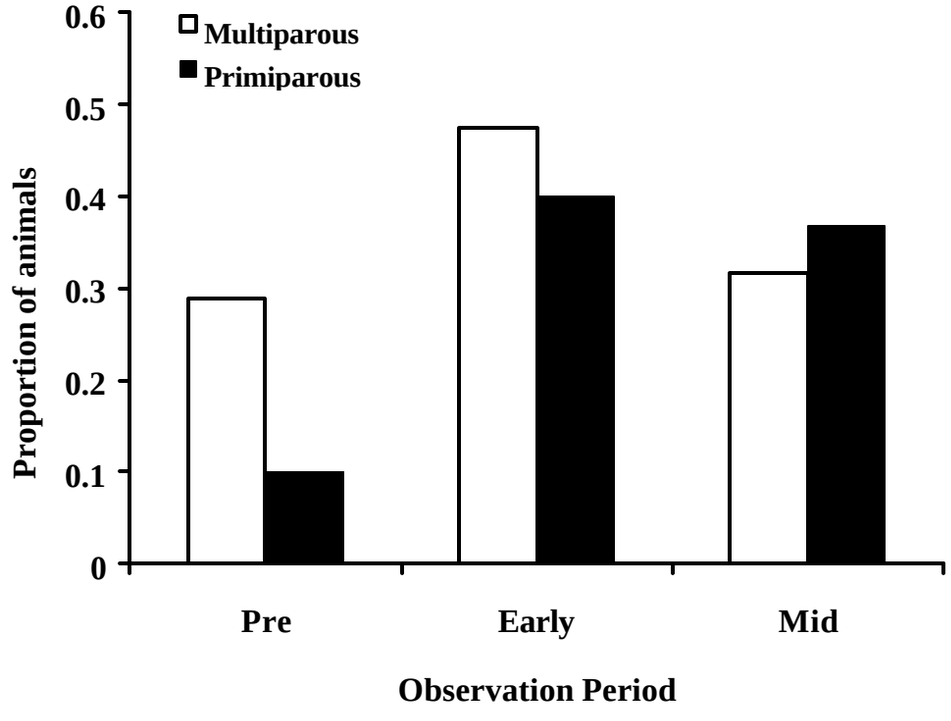
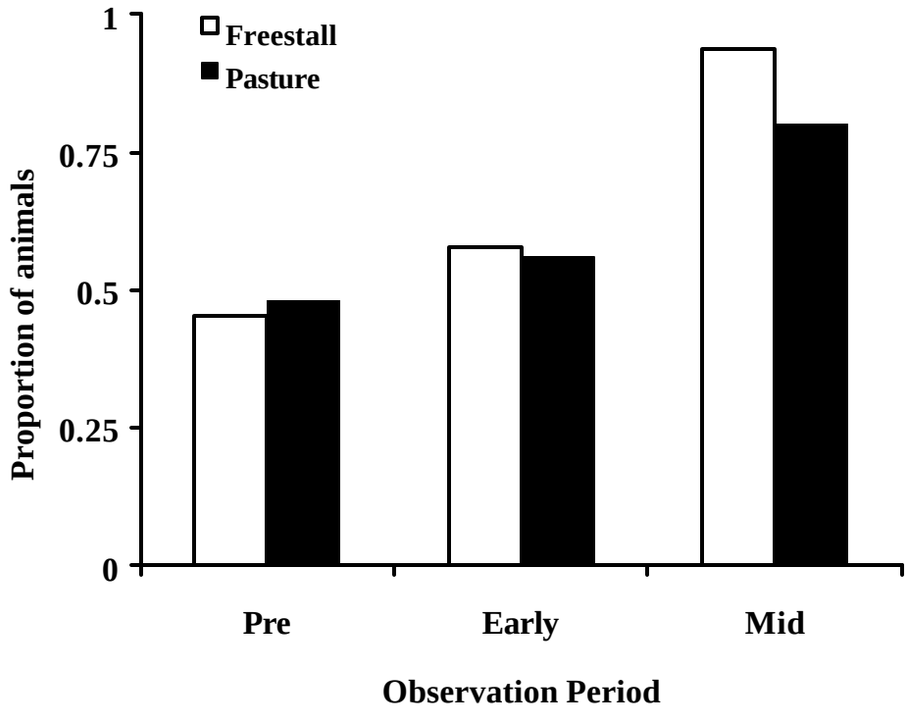


Figure 3: Proportion of animals with dermatitis by treatment (a) and parity (b) for the pre-calving, early-lactation, and mid-lactation observation periods.

a)



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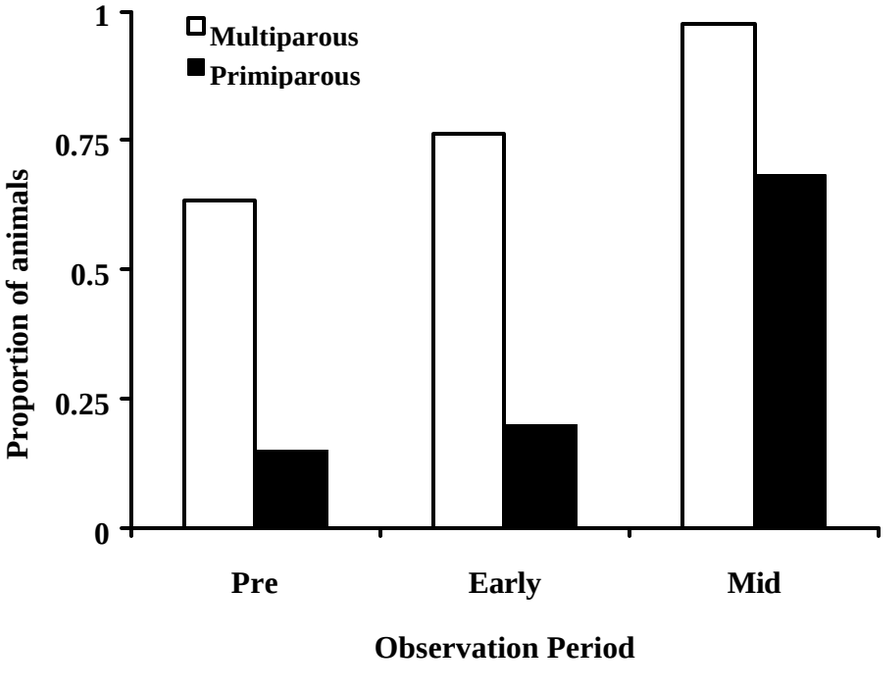

Figure 4: Proportion of animals with severe heel erosion by treatment (a) and parity (b) for the pre-calving, early-lactation, and mid-lactation observation periods.

Table 1: The number of animals that worsened (i.e. unaffected to affected) or improved (affected to unaffected) from pre-calving to early-lactation and from early-lactation to mid-lactation. Results are shown separately for the severe sole lesions, active dermatitis, and severe heel erosion between observation periods.

Observation Periods	Pathology	n	# worsened	# improved	Binomial *P*
From pre-calving to early-lactation	Sole Lesions	58	21	4	< 0.001
	Dermatitis	58	19	6	0.005
	Heel Erosion	58	10	4	0.061
From early-lactation to mid-lactation	Sole Lesions	57	9	11	0.16
	Dermatitis	57	12	18	0.081
	Heel Erosion	57	18	0	< 0.001

Table 2: Interrelationships of pathologies by hoof and claw. The odds ratio (O.R.) and associated Fisher-Exact *P* value for the association between hooves (i.e. left and right) and claws (i.e. lateral and medial), shown separately for the pathologies (severe sole lesions, active dermatitis and severe heel erosion) and the 3 observation periods. Claw associations cannot be tested for dermatitis as this pathology does not affect the claw.

		Pre-Calving		Early-Lactation		Mid-Lactation	
Association	Pathology	O.R	Fisher Exact p	O.R	Fisher Exact p	O.R	Fisher Exact p
Hooves							
	Sole Lesions	19.2	0.001	1.4	0.8	6.3	0.003
	Dermatitis	27	< 0.001	5	0.009	16.3	< 0.001
	Heel Erosion	5.3	0.006	27.4	< 0.001	9.1	0.003
Claws							
	Sole Lesions	23	0.001	0.4	0.2	3.1	0.08
	Dermatitis	n/a	n/a	n/a	n/a	n/a	n/a
	Heel Erosion	8.5	0.001	108.3	< 0.001	48.1	< 0.001

GENERAL CONCLUSION

This study monitored the hoof health of dairy cows housed either continuously in a free stall barn or maintained on pasture for a period of time before re-entering the freestall barn. The objectives were to compare the two treatment groups with respect to sole lesions, dermatitis, and heel erosion from the pre-calving period through mid-lactation and to monitor the progression of the 3 pathologies and their interrelationships.

Although there were only minimal effects of housing on the occurrence of sole lesions, dermatitis, and heel erosion in dairy cattle, the high incidence of each of these diseases indicates the necessity for continued research in this area. These results indicate that a relatively short duration on pasture does not decrease the incidence of sole lesions, dermatitis, and heel erosion. In contrast Offer et al. (2000) found that an extended period on pasture resulted in improved hoof health.

The results of this study also accentuate the need to protect animals from hoof pathologies early in their productive life and early in their lactation cycle. Most primiparous cows in the pre-calving period experience little or no hoof pathologies but we observed an increase in pathologies throughout their first lactation. Our data shows that these primiparous cows will most likely continue to have a higher incidence of hoof pathologies in subsequent lactations, which is in accordance with previous work (Offer et al., 2000).

More work is required in determining an objective method of scoring and analysing hoof health that best describes the development of hoof pathologies. Clearly, one of the most important tasks for future research is to determine the relationship between the severity of sole lesions, dermatitis, and heel erosion and lameness. One

possible way this can be achieved is through the use of gait scoring in conjunction with frequent hoof scoring (only paring the hoof minimally to reveal lesions on the surface).

Although, North American dairy production systems typically do not utilize pasture, it is important to determine whether long-term access to pasture can reduce the severity of these hoof pathologies. Such improvements could have positive economic implications for producers by reducing the involuntary culling rate of dairy cattle suffering from hoof injuries. Furthermore, the high incidence rates of the 3 hoof pathologies in the animals used in this work necessitates the need for research focused on developing alternative flooring surfaces to provide practical solutions to improve hoof health.

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