Finding Answers to the Critical Questions that Link Cow Comfort with Lameness in Dairy Herds

Nigel B. Cook MRCVS
Food Animal Production Medicine Group, Department of Medical Sciences, University of Wisconsin-Madison, School of Veterinary Medicine, Madison WI 53706, USA

Introduction

Whatever the housing and management system chosen to manage the dairy cow, she is entitled to be treated kindly for her work and be provided a comfortable place to rest with ready access to food and water. Poor cow comfort has long been associated with increased rates of lameness in intensively managed dairy cattle, and across many studies performed throughout the world it is common to find approximately 20% of intensively managed dairy cattle lame at any one time (Wells et al., 1993; Clarkson et al., 1996; Whay et al., 2002, Cook, 2003; Espejo et al., 2006).

The discomfort and pain associated with lameness is often underestimated and can systematically undermine the management of the dairy herd through its adverse effects on resting, walking and feeding behavior which manifest in lowered milk production (Green et al.,2000; Warnick et al., 2001; Hernandez et al., 2005a), poor reproductive performance (Garbarino et al., 2004; Hernandez et al; 2005b; Sogstad et al., 2006), and increased risk for premature removal from the herd (Collick et al., 1989; Booth et al., 2004). Differences in lameness prevalence have been reported between housing systems which are worthy of review in any discussion of the role of cow comfort in herd lameness dynamics.

Housing Systems

In some studies, grazing cattle have a low prevalence of lameness (Haskell et al., 2006), although there are well documented lameness problems specific to grazing herds (Chesterton et al., 1989; Tranter and Morris, 1991). Straw yards are popular in Europe for housing dairy cattle and are associated with significant improvements in claw health (Webster, 2001; Somers et al., 2003), and similar low levels of lameness have been identified in compost-bedded barns in Minnesota (Barberg et al., 2007). This could be due to a combination of improved resting time on a more comfortable surface, and due to a greater proportion of time spent on a softer yielding flooring surface when the cow stands between lying bouts (Singh et al., 1993a). Lower rates of lameness have been reported in tie stall herds compared with free stall (cubicle) herds (Wells et al., 1993; Bergsten and Herlin, 1996; Cook, 2003; Sogstad et al., 2005), and the intensively managed, zero-grazed free stall system appears to suffer the highest rates of lameness of all of the aforementioned production systems.

Free stall environments potentially expose cattle to adverse environmental conditions important to the epidemiology of lameness – the most obvious being the progressively greater exposure of the claw to concrete walking surfaces that are often bathed in a soup of liquid manure. An understanding of these effects and how to ameliorate them is necessary as countries move toward a greater reliance on this type of cattle housing.

Mechanisms of Lesion Development

Hoof lesions appear to develop as a result of pathological changes to the internal structure of the claw (bone, fat pad and corium) and to the external protective claw horn capsule and skin epidermis.

Changes that occur to the internal structure of the claw result from the pressure applied to the suspensory apparatus of the pedal bone while weight bearing, which causes displacement of the bone within the claw horn capsule and compression and compromise of the sole corium (Lischer et al., 2002). Increased pedal bone mobility may result from the systemic changes associated with sub-acute ruminal acidosis (Thoefner et al., 2004; Cook et al., 2004), or from hormonal changes at calving time that appear to be associated with non-inflammatory changes in the connective tissue of the corium that impair the resilience of the feet to external stresses, mediated through the activation of certain gelatinoproteases (Webster, 2001; Tarlton et al., 2002; Knott et al., 2006).

Hoof lesions may also occur due to factors which weaken the structure of the claw horn capsule and the integrity of the epidermis. Horn quality may be compromised from within by inadequate supply of macro- and micro-nutrients, such as zinc and biotin (Tomlinson et al., 2004), or by exposure to moisture (Borderas et al., 2004; van Amstel et al., 2004). The thickness and integrity of the protective horn layer of the sole and heel may be affected by excessively abrasive walking and standing surfaces (Shearer et al., 2006), or the action of infectious agents in unhygienic environments that compromise the epidermis and heel horn, weakening the structure of the claw (Berry, 2006). The role of heel horn erosion in claw horn lesion development is an intriguing area of research. Feeding of wet fermented diets appear to increase the prevalence of heel horn erosion before calving, due to increased exposure to wet slurry (Leach et al., 2005). Erosion of the heel may increase the susceptibility of the foot to claw horn lesion development post-partum – providing a link between infectious and claw horn disease.

A discussion of the roles of 'cow comfort' in herd lameness dynamics must therefore center on how different environmental conditions influence the duration and timing of standing behavior and the effect of the type of surface the cow is standing on, on the severity and location of claw horn lesions.

Critical Cow Comfort Questions

If we believe that increased time spent standing when the cow would rather be lying down, and the nature of the surface that she must stand and walk on are major factors driving differences in lameness prevalence at the herd level through effects on both lame and non-lame cows, we must find answers to three critical questions:

1. What constitutes a minimum rest period for a dairy cow each day? And what are the consequences of failing to achieve this rest?
2. When the cow isn't resting, what is the impact of the standing surface she is exposed to?

3. Do lame cows lie down more or less than non-lame cows? And what effect does this have on the duration of lameness?

What constitutes a minimum rest period for a dairy cow each day?

Normal free stall housed, TMR fed dairy cows under thermoneutral conditions spend around 4.5 h/d feeding, 0.5 h/d drinking, up to 2 h/d standing in the stall and around 2 h/d standing in alleys socializing. This leaves 24 – (4.5+0.5+2+2) = 15 hours time available for rest. A growing amount of evidence would suggest that 12 h/d should be considered the minimum amount of daily rest for a freestall housed mature dairy cow (Jensen et al., 2005; Munksgaard et al., 2005), thus any increase in milking time beyond 3 h/d, or any factor which results in an increased time standing in excess of what we view as 'normal' will compromise the time available for rest. Other time budget challenges include overstocking cows relative to stalls, poor stall design and problems related to the transition period, inadequate heat abatement and excessive time spent in lock-ups.

Time out of the pen was a significant factor for increased lameness prevalence in a recent survey of free stall herds (Espejo and Endres, 2007). As herds have expanded, group sizes have increased with little attention to the time out of pen of the last cow in the group, which often exceeds 1 hour per milking. Parlor throughput is a major limiting factor for increasing herd size and we question the logic of moving cows to and from a single milking center once a limit of around 1400 cows is reached. The problem is also an issue for large grazing herds which manage only one group of cows. Under-sized parlors result in daily milking times which exceed 3 h/d, and with early lactation primiparous cows tending to collect at the rear of the holding area, elevated standing time may exacerbate transition problems as heifers transfer from a life on pasture to commingling with mature cows on hard concrete surfaces at milking time.

In a competitive environment mixed with mature cows, heifers may lie down for as little as 6 hours per day in free stalls (Singh et al., 1993a). This reduction in stall use and rest after calving, coupled with normal behavioral changes which lead to around 3 h/d increase in standing time around the point of calving (Huzzey et al., 2005) may explain the severe claw horn lesions often observed in trials where heifers are moved abruptly from pasture to freestall housing within a few weeks of parturition (Kempson and Logue, 1993; Bergsten and Frank, 1996b), and the observed claw health benefits of segregating heifers from mature cows during the immediate post-partum period and the use of straw bedded packs up to around 30 days in milk compared to free stalls (Blowey, 2005; Webster, 2001). We will make the claim, that similar improvements can be seen in free stalls that have been designed correctly.

Overstocking reduces lying times (Friend et al., 1977; Fregonesi et al., 2007) and there is general agreement between studies that once stocking rates exceed 1.2 cows per stall, it is difficult for groups of cows to average 12 h/d of rest. Overstocking has been linked with an increased risk for claw horn lesion development - but only when lying times were extremely short, less than 5h/d (Leonard et al., 1996).

Non-lame, high yielding dairy cows in well designed, comfortable well bedded free stalls lie down for around 12 h/d (Cook et al., 2004), but stall designs which fail to provide for the movements of lying and rising, adequate resting space, or a cushioned surface will tend to reduce lying behavior to less than 10h/d. In one study, free stalls with a concrete surface and a restrictive divider design resulted in reduced lying time, increased periods spent perching (standing half in and half out of the stall) and an increased rate of clinical lameness in heifers two months after calving compared with heifers kept in a stall with greater surface cushion and a less restrictive divider design (Leonard et al., 1994).

Once core body temperature reaches approximately 39 ^{o}C, mature Holstein cattle seek shade and stand rather than lie down (Lee and Hillman, 2007). Between four daily filming sessions that had a mean daily average temperature humidity index (THI) of between 56 and 74 in a mattress free stall barn fitted with feed bunk soakers and fans, we observed a 3 h/d increase in standing time between the coolest session and the hottest session (Cook et al., 2007). These data, together with an increased susceptibility to sub acute ruminal acidosis could explain the increase in claw horn lesion development observed in the period from September to November in many North American dairy herds (Cook, 2004; Cook et al., 2006).

Excessive time spent locked up at the feed bunk may have a detrimental effect on daily time budgets. While cows are quite capable of compensating for a 1-2 hour change in routine, if lock up is prolonged and in association with other stressors – such as overstocking, then the ability of the cow to compensate and 'catch-up' on lying time may be exceeded. Cooper et al., (2007) showed that when cows were deprived of lying for 2-4 h/d, they only managed to recover approximately 40% of the lost lying time by 40 hours after the deprivation. It is perhaps unfortunate that the cows we most commonly lock up for long periods are the fresh cows, immediately post-partum, at a time when they are most susceptible to changes in total daily standing time.

Taken together, the studies described point to the fact that a reduction in lying time – of the order of around 3 h/d can have detrimental effects on claw health. The extent of this effect will be determined by the nature of the standing surface available between lying bouts.

When the cow isn't resting, what is the impact of the standing surface she is exposed to?

In free stall environments, while cows are in the pen, they may choose to stand in the alley, or in a stall. Excessive time spent perching in stalls has been identified as a significant risk factor for interdigital and heel lesions and increased total time standing appears to significantly increase the risk for sole lesions and lameness cases (Galindo and Broom, 2000). The significance of stall standing behavior has been the subject of several studies, with some workers arguing that cows prefer to spend more time standing on a cushioned mattress bedded free stall in preference to spending time standing elsewhere (Tucker et al., 2003; Wagner-Storch et al., 2003), which suggests that this behavior has a positive effect on cow and claw health. In fact, there is some merit to this argument when we consider the impact of the surface on which the cow stands in-between bouts of lying.

For example, cows at pasture, unencumbered by poor stall designs typically have daily lying times of 8.3 to 11.5 h/d (Phillips and Rind, 2001; Tucker et al, 2007), less than the suggested minimum of 12 h/d. Grazing cattle spend longer eating than TMR fed free stall managed cows (approximately 8 h/d vs. 4.5 h/d) and may be away from pasture for prolonged periods each day when milking, so it is yet to be determined whether they have a lowered requirement for rest than free stall cows, or whether the reduced lying time is forced by stresses on the time budget. Whatever the reason, the negative consequences of reduced resting time, which would be obvious for cows on concrete, may be ameliorated by standing on a dirt surface.

We may use this argument in the free stall barn to suggest that the provision of a cushioned surface on which animals may stand – either in the stall, in the free stall alley, or outside the barn may have beneficial effects on claw health. Indeed, moving lame cows from concrete to pasture appears to improve locomotion score (Hernandez-Mendo et al., 2007). While the study was confounded by concomitant changes in diet, the improvements were observed in the absence of increased lying time. The pastured cows lay down for only 10.9 h/d compared with 12.3 h/d for the housed cattle.

While some dairies operate barns where groups of cows have access to outside dry lots or pasture, others have looked for alternative flooring surfaces inside the barn to mimic the beneficial effects of dirt flooring. Rubber floors have become commonplace in many free stall barns and have been the subject of much interest over recent years. The initial work by Bergsten and Frank (1996), which showed that in tie stalls, rubber stall mats significantly reduced sole lesions compared to concrete supported the use of rubber in alleys – with good reason. The higher coefficient of friction of rubber, and its greater compressibility allows cows to walk with longer fewer strides at a faster speed, and slip less compared to walking on concrete (Telezenko and Bergsten, 2005; Rushen and de Passille, 2006). As confinement dairies in North America have increased in size, the problems of poor track management highlighted in grazing herds (Chesterton et al., 1989) have been mimicked as cows walk longer and longer distances on concrete transfer lanes to and from the milking center. Thin soles due to excessive claw wear have been recognized as a significant issue in these herds (Shearer et al., 2006) and the properties of rubber flooring have led to its successful use on transfer lanes to facilitate the movement of cows between pens and the milking center. However, when utilized in free stall pens, the benefits are less clear.

Vokey et al. (2001) compared a rubber feed bunk alley surface with concrete in association with combinations of sand, mattress and concrete free stall surfaces. Although some benefits of rubber were observed, there was no significant positive effect on claw health. A California study examined the effect of rubber flooring throughout a pen with free stalls bedded with manure solids with a similar pen with concrete floors. Cows that were already lame remained lame, but there was a five fold greater odds of becoming lame on concrete compared with rubber. This was associated with an increased odds of developing heel horn erosion on concrete (Vanegas et al., 2005). In contrast, a German study comparing concrete slatted floors with rubber floors in a mattress free stall barn found a negative effect of rubber on the incidence of sole ulcer and digital dermatitis, no effect on heel horn erosion, and no overall improvement in lameness (Kremer et al., 2007).

Many of the studies examining the impact of flooring on lameness demonstrate an interesting interaction between the flooring and lying surface. The reason for this may come from an understanding of the impact of rubber pen flooring on time budgets. In studies conducted with mattress free stall housing, the addition of rubber flooring resulted in increased time spent standing on the rubber alley floor, less time lying in the stalls and an increased likelihood of alley lying – changes which are more likely to be detrimental to hoof health and which reflect an aversion to lying in the stalls (Fregonesi et al., 2004; Tucker et al., 2006). It is notable that the study showing the most benefits to rubber flooring in terms of claw health used deep loose bedded stalls, rather than mattress stalls (Vanegas et al., 2005). We are therefore cautious to recommend rubber alley flooring in new free stall installations. We will use rubber in transfer lanes, holding areas and parlors, where the benefits are obvious and proven, but prefer to improve the grooving and traction of concrete in free stall pens in lieu of the use of rubber in this area. We have had several clinical experiences where rubber alley flooring in association with mattress stalls has altered the type of lesion observed (reduced white line disease, but increased sole ulceration), but failed to improve lameness overall.

We believe that the answer to the question of how the nature of the surface on which cows stand between bouts of lying impacts herd lameness can only be answered when the behavior of cows' that are already lame is understood.

Do lame cows lie down more or less than non-lame cows?

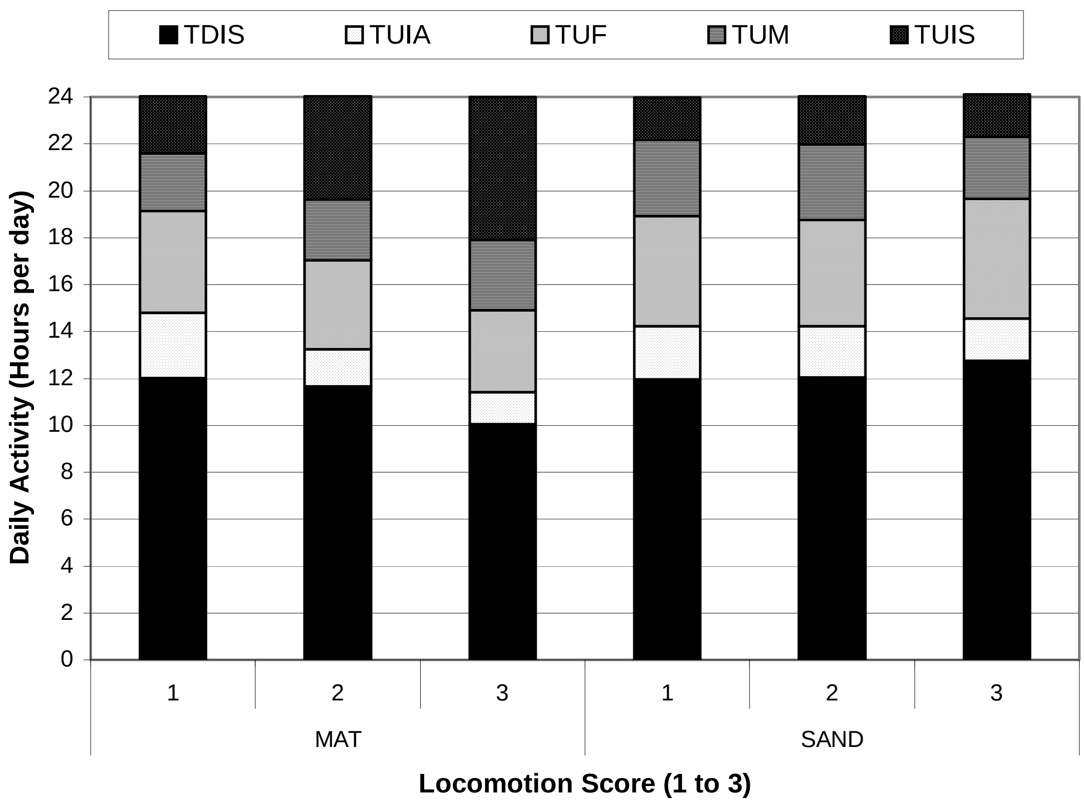
The concept that increased time spent standing on a cushioned mattress surface is beneficial to cow and claw health is challenged by the finding that an increased prevalence of lameness is observed in herds using stalls with a rubber crumb filled mattress surface compared with herds using sand bedded stalls (Cook, 2003; Cook et al., 2004; Espejo et al., 2006). Cows on rubber crumb filled mattress stalls stand in the stall for around 3.5 h/d, compared to cows on sand that stand in the stall for less than 2 h/d (Cook et al., 2004). The apparent paradox is explained by an understanding of lame cow behavior.

Surprisingly few studies have accurately documented the behavior of lame cows. Juarez et al. (2003) suggested that lame cows lay down more. However, this study only recorded the proportion of the group lying down between the morning and afternoon milking and did not report actual time budgets. Singh et al. (1993b) and Hassall et al. (1993) used the Manson and Leaver (1988) locomotion scoring system to group cows as lame (score ≥ 3) and non-lame (score < 3) and compared behavioral differences between these two groups in free stall housing and at pasture respectively. Lame cows laid down for longer than non-lame cows in stalls and at pasture, but the difference was only significant at pasture. Unfortunately, these studies failed to consider the effects of slight lameness in the 'non-lame' group, which may have confused the overall findings. We have documented behavioral changes in only slightly lame cows and this group should not be analyzed with the non-lame group.

In our work comparing the behavior of lame and non-lame cows on mattress and sand bedded free stalls, the non-lame cows behave similarly on both types of surface and, in three times a day milked herds, lie down for approximately 12 h/d and stand in the stall for approximately 2 h/d. While lame cows in sand stalls behave similarly, lame cows on mattresses do not

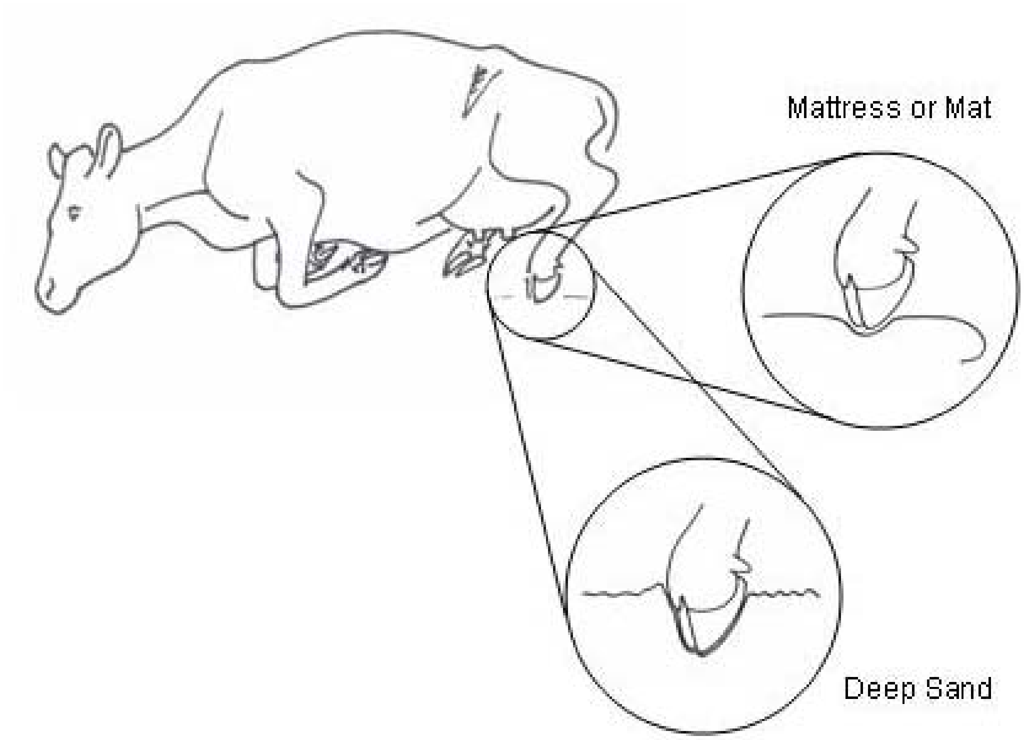
The dominant behavior change observed on firm mattresses is an increase in stall standing time from 2 h/d to around 4 h/d in slightly lame cows and to 6 h/d in moderately lame cows (with noticeable weight transfer from the affected limb). This increase in the duration of standing bouts during a stall use session leads to a significant reduction in stall use sessions from 8.5 to 4.6 per day (Cook et al., 2004). As a consequence, lying time is reduced to around 10 h/d (Figure 1).We have only tracked the behavior of one severely lame cow in a mattress stall and she lay down for only 4.2 h/d and stood in the stall for 7.5 h/d.

Figure 1. Daily time budgets for time lying down in stall (TDIS), time standing up in stall (TUIS), time up in alley (TUIA), time up feeding (TUF) and time up milking (TUM) in 73 normal (locomotion score 1), 37 slightly lame (locomotion score 2), and 10 moderately lame (locomotion score 3) cows in 6 MAT and 6 SAND herds (from Cook et al., 2004)



It is clear that when cows lie down for less time in association with increased stall standing behavior, a surface preference is not being exercised. Instead, we believe that this is a result of difficulties rising and lying down in the stall. We have proposed that behavioral responses of the cow to pain associated with lameness in the rear feet (Russell et al., 1982; Whay et al., 1998) make it difficult for cows to rise and lie down on a flat unyielding surface. We believe that sand, because of its ability to supply cushion and traction, allows cows (especially lame cows) to perform the process of rising and lying down more easily, without fear of slipping. We propose that the fear of slipping and pain associated with rising and lying on a mattress surface for a lame cow are the main reasons for extended bouts of standing in the stall during a stall use session. Note the small point of contact between the claw and the surface during the normal rising motion of the cow, compared with the cushion and traction provided by sand (Figure 2). Our recent work confirms that it is the nature of the stall surface and not other aspects of stall design that is the key to improved stall use behavior by lame cows (Marin et al., 2007).

Figure 2. Compare the interaction of the claw with the stall surface at the point that the weight bearing rear foot loads as the cow rises in the stall for a mat or mattress surface, compared with deep sand. Sand provides cushion and traction compared to the small surface area of contact with a mattress, making it easier for lame cows to rise in the stall.



Whether or not the stall standing behavior involves standing with all four feet up on the stall platform, or standing with the rear feet in the alley and the front feet in the stall (perching) is perhaps immaterial – both behaviors represent loading modifications to the claw at a time when the cow would rather be lying down. We suggest that this loading of the claw may have a deleterious effect on lameness recovery and this difference, at least in part, may explain the average 42% lower prevalence of lameness observed in sand compared with mattress free stall barns (Cook, 2003; Espejo et al, 2006). Evidence that sand promotes lesion healing has recently been presented in a comparison of claw health between cows managed on sand bedding and cows managed on straw bedded free stalls. After 21 weeks, number and lesion score was significantly more reduced in cows on sand (Norring et al., 2008). Interestingly, these workers were puzzled by the results – because they found that cows lay down longer on straw then on sand. However, they failed to identify lying times in lame compared with non-lame cows - where we have found the most profound differences in behavior. That said, other benefits of sand, such as increased traction in the alleys cannot be over-looked.

Conclusions

In this discussion, we have tried to find answers to the key questions that relate cow comfort to lameness. Firstly, we have made the case that the milking dairy cow needs to rest for around 12 h/d, and when this rest is compromised – through poor stall design, overstocking, heat stress, via challenges to the time budget such as increased time spent milking or in lock-ups, there is evidence to suggest that there is a negative impact on hoof health. Secondly, the extent of the impact of reduced rest on hoof health is determined by the nature and properties of the flooring surface that the cow is exposed to between bouts of rest. It would appear that the structural damage caused by increased time spent weight bearing, may be ameliorated by standing on a soft giving surface – such as pasture or a deep loose bedded straw or sawdust pack. While rubber surfaces have some advantages in terms of reducing wear and trauma to the claw surface in transfer lanes, they may have negative effects on claw health when cows must choose between standing on rubber in an alley rather than using an uncomfortable stall for rest. Thirdly, the understanding that lame cows behave differently to non-lame cows, even when they are only slightly lame is paramount. Sand bedding allows lame cows to rest and recuperate while maintaining lying times above the required threshold, by providing cushion and support and traction.

References

Barberg, A.E., Endres, M.I., Salfer, J.A., Reneau, J.K. 2007. Performance and welfare of dairy cows in an alternative housing system in Minnesota. Journal of Dairy Science 90, 1575-1583.

Bergsten, C., Herlin, A.H. 1996. Sole hemorrhages and heel horn erosion in dairy cows: The influence of housing system on their prevalence and severity. Acta Veterinaria Scandinavia 37, 395-408.

Bergsten, C., Frank. B. 1996. Sole hemorrhages in tied primiparous cows as an indicator of periparturient laminitis: Effects of diet, flooring and season. Acta Veterinaria Scandinavia 37, 383-394.

Berry, S.L. 2006. Infectious diseases of the bovine claw. In: Proceedings of the 14th International Symposium on Lameness in Ruminants, Uruguay, November 8-11, pp. 52-57.

Blowey, R.W. 2005. Factors associated with lameness in dairy cattle. In Practice 27, 154-162.

Booth, C.J., Warnick, L.D., Grohn, Y.T., Maizon, D.O., Guard, C.L., Jansen, D. 2004. Effect of lameness on culling in dairy cows. Journal of Dairy Science 87, 4115-4122.

Borderas, T.F., Pawluczuk, B., de Passille, A.M., Rushen, J. 2004. Claw hardness of dairy cows: relationship to water content and claw lesions. Journal of Dairy Science 87, 2085-2093.

Chesterton, R.N., Pfeiffer, D.U., Morris, R.S., Tanner, C.M. 1989. Environmental and behavioral factors affecting the prevalence of foot lameness in New Zealand dairy herds – a case control study. New Zealand Veterinary Journal 37, 135-142.

Clarkson, M. J., Downham, D. Y., Faull, W. B., Hughes, J.W., Manson, F.J., Merritt, J.B., Murray, R.D., Russell, W.B., Sutherst, J.E., Ward, W.R. 1996. Incidence and prevalence of lameness in dairy cattle. Veterinary Record 138, 563-567.

Collick, D.W., Ward, W.R., Dobson, H. 1989. Associations between types of lameness and fertility. Veterinary Record 125, 103-106.

Cook, N.B. 2003. Prevalence of lameness among dairy cattle in Wisconsin as a function of housing type and stall surface. Journal of American Veterinary Medical Association 223, 1324-1328.

Cook, N.B. 2004. Lameness treatment rates in Wisconsin dairy herds. In: Proceedings of 13th International Ruminant Lameness Symposium, Maribor, Slovenia, pp. 50-51.

Cook, N.B., Bennett, T.B., Nordlund, K.V. 2004. Effect of free stall surface on daily activity patterns in dairy cows, with relevance to lameness prevalence. Journal of Dairy Science 87, 2912-2922.

Cook, N.B., Banks, R.J., Bennett, T.B., Burgi, K. 2006. Season associated changes in infectious and claw horn lesions in a free stall housed dairy herd. In: Proceedings of the 14th International Symposium on Lameness in Ruminants, Uruguay, pp. 163-164.

Cook, N.B., Mentink, R.L., Bennett, T.B., Burgi, K. 2007. The effect of heat stress and lameness on time budgets of lactating dairy cows. Journal of Dairy Science 90, 1674-1682.

Cooper, M.D., Arney, D.R., Phillips, C.J.C. 2007. Two-or-Four-hour lying deprivation on the behavior of lactating dairy cows. 2007. Journal of Dairy Science 90, 1149-1158.

Espejo, L.A., Endres, M.I., Salfer, J.A. 2006. Prevalence of lameness in high-producing Holstein cows housed in freestall barns in Minnesota. Journal of Dairy Science 89, 3052-3058.

Espejo, L.A., Endres, M.I. 2007. Herd-level risk factors for lameness in high-producing Holstein cows housed in freestall barns. Journal of Dairy Science 90, 306-314.

Fregonesi, J.A., Tucker, C.A., Weary, D.M., Flower, F.C., Vittie, T. 2004. Effect of rubber-flooring in front of the feed bunk on the time budgets of dairy cattle. Journal of Dairy Science 87, 1203-1207.

Fregonesi, J.A., Tucker, C.B., Weary, D.M. 2007. Overstocking reduces lying time in dairy cows. Journal of Dairy Science 90, 3349-3354.

Friend, T. H., Polan, C.E., McGilliard, M.L. 1977. Freestall and feed bunk requirements relative to behavior, production and individual feed intake in dairy cows. Journal of Dairy Science 60, 108- 116.

Galindo, F., Broom, D.M. 2000. The relationships between social behaviour of dairy cows and the occurrence of lameness in three herds. Research in Veterinary Science 69, 75-79.

Garbarino, E.J., Hernandez, J.A., Shearer, J.K., Risco, C.A., Thatcher, W.W. 2004. Effect of lameness on ovarian activity in postpartum Holstein cows. Journal of Dairy Science 87, 4123-4131.

Green, L.E., Hedges, J., Schukken, Y.H., Blowey, R.W., Packington, A.J. 2002. The impact of clinical lameness on the milk yield of dairy cows. Journal of Dairy Science 85, 2250-2256.

Hassall, S. A., Ward, W.R., Murray, R.D. 1993. Effects of lameness on the behavior of cows during the summer. Veterinary Record 132, 578-580.

Haskell, M.J., Rennie, L.J., Bowell, V.A., Bell, M.J., Lawrence, A.B. 2006. Housing system, milk production, and zero-grazing effects on lameness and leg injury in dairy cows. Journal of Dairy Science 89, 4259-4266.

Hernandez, J.A., Garbarino, E.J., Shearer, J.K., Risco, C.A., Thatcher, W.W. 2005a. Comparison of milk yield in dairy cows with different degrees of lameness. Journal of American Veterinary Medical Association 227, 1292-1296.

Hernandez, J.A., Garbarino, E.J., Shearer, J.K., Risco, C.A., Thatcher, W.W. 2005b. Comparison of the calving-to-conception interval in dairy cows with different degrees of lameness during the pre-breeding postpartum period. Journal of American Veterinary Medical Association 227, 1284-1291.

Hernandez-Mendo, O., von Keyserlingk, M.A.G., Veira, D.M., Weary, D.M. 2007. Effects of pasture on lameness in dairy cows. Journal of Dairy Science 90, 1209-1214.

Huzzey, J.M., von Keyserlingk, M.A.G., Weary, D.M. 2005. Changes in feeding, drinking and standing behavior of dairy cows during the transition period. Journal of Dairy Science 88, 2454-2461.

Jensen, M.B., Pedersen, L.J., Munksgaard, L. 2005. The effect of reward duration on demand functions for rest in dairy heifers and lying requirements as measured by demand functions. Applied Animal Behavior Science 90, 207-217.

Juarez, S.T., Robinson, P.H., DePeters, E.J., Proce, E.O. 2003. Impact of lameness on behavior and productivity of lactating Holstein cows. Applied Anim. Behav. Science 83, 1-14.

Kempson, S.A. Logue, D.N. 1993. Ultrastructural observations of hoof horn from dairy cows: changes in the white line during the first lactation. Veterinary Record 132, 524-527.

Knott, L., Tarlton, J.F., Craft, H., Webster, A.J.F. 2007. Effects of housing, parturition and diet change on the biochemistry and biomechanics of the support structures of the hoof of dairy heifers. The Veterinary Journal, In Press.

Kremer, P.V., Nueske, S., Scholz, A.M., Foerster, M. 2007. Comparison of claw health and milk yield in dairy cows on elastic or concrete flooring. Journal of Dairy Science 90, 4603-4611.

Leach, K.A., Offer, J.E., Svoboda, I., Logue, D.N. 2005. Effects of type of forage fed to dairy heifers: Associations between claw characteristics, clinical lameness, environment and behaviour. The Veterinary Journal 169, 427-436.

Lee, C.N., Hillman, P.E. 2007. Thermal responses of Holstein dairy cows on pastures with high solar loads and high winds. In: Proceedings of 6th International Dairy Housing Conference, Minneapolis, Minnesota, June 16-18 at http://asae.frymulti.com/conference.asp?confid=dhc2007

Leonard, F.C., O'Connell, J.M., O'Farrell, K.J. 1994. Effect of different housing conditions on behaviour and foot lesions in friesian heifers. Veterinary Record 134, 490-494.

Leonard, F.C., O'Connell, J.M., O'Farrell, K.J. 1996. Effect of overcrowding on claw health in first-calved friesian heifers. British Veterinary Journal 152, 459-472.

Lischer, Ch. J., Ossent, P., Raber, M., Geyer, H. 2002. Suspensory structures and supporting tissues of the third phalanx of cows and their relevance to the development of typical sole ulcers (Rusterholz ulcers). Veterinary Record 151, 694-698.

Marin S., M.J., Schaefer, M.J., Mentink, R.L., Banks, R.J., Calderon, B.D., Cook, N.B. 2007. State of the art free stall designs: Do they allow lame cows to maintain normal patterns of stall use? In: Proceedings of 6th International Dairy Housing Conference, Minneapolis, Minnesota, June 16-18. at http://asae.frymulti.com/conference.asp?confid=dhc2007

Munskgaard, L., Jensen, M.B., Pedersen, L.J., Hansen, S.W., Matthews, L. 2005. Quantifying behavioural priorities-effects of time constraints on behavior of dairy cows. Applied Animal Behavior Science 92, 3-14.

Norring, M., Manninen, E., de Passille, A.M., Rushen, J., Munksgaard, L., Saloniemi, H. 2008. Effects of sand and straw bedding on the lying behavior, cleanliness, and hoof and hock injuries of dairy cows. Journal of Dairy Science 91, 570-576.

Phillips C.J.C., Rind, M.I. 2001. The effects on production and behaviour of mixing uniparous and multiparous cows. Journal of Dairy Science 84, 2424-2429.

Rushen, J., de Passille, A.M. 2006. Effects of roughness and compressibility of flooring on cow locomotion. Journal of Dairy Science 89, 2965-2972.

Russell, A. M., Rowlands, G.R., Shaw, S.R., Weaver, A.D. 1982. Survey of lameness in British dairy cattle. Veterinary Record 111, 155-160.

Shearer, J.K., van Amstel, S.R., Benzaquen, M., Shearer, L.C. 2006. Effect of season on claw disorders (including thin soles) in a large dairy in the southeastern region of the USA. In:

Proceedings of the 14th International Symposium on Lameness in Ruminants, Uruguay, November 8-11, pp 110-111.

Singh, S.S., Ward, W.R., Lautenbach, K., Murray, R.D. 1993a. Behaviour of lame and normal dairy cows in cubicles and in a straw yard. Veterinary Record 133, 204-208.

Singh, S. S., Ward, W.R., Lautenbach, K., Hughes, J.W., Murray, R.D. 1993b. Behaviour of first lactation and adult dairy cows while housed and at pasture and its relationship with sole lesions Veterinary Record 133, 469-474.

Sogstad, A.M., Fjeldaas, T., Osteras, O., Plym Forshell, K. 2005. Prevalence of claw lesions in Norwegian dairy cattle housed in tie stalls and free stalls. Preventive Veterinary Medicine 70, 191-209.

Somers, J.G.C.J., Frankena, K., Noordhuizen-Stassen, E.N., Metz, J.H.M. 2003. Prevalence of claw disorders in Dutch dairy cows exposed to several floor systems. Journal of Dairy Science 86, 2082-2093.

Tarlton, J.F., Holah, D.E., Evans, K.M., Jones, S., Pearson, G.R., Webster, A.J.F. 2002. Biomechanical and histopathological changes in the support structures of bovine hooves around the time of calving. The Veterinary Journal 163, 196-204.

Telezhenko, E., Bergsten, C. 2005. Influence of floor type on the locomotion of dairy cows. Applied Animal Behavior Science 93, 183-197.

Thoefner, M.B., Pollitt, C.C., van Eps, A.W., Milinovich, G.J., Trott, D.J., Wattle, O., Anderson, P.H. 2004. Acute bovine laminitis: A new induction model using alimentary oligofructose overload. Journal of Dairy Science 87, 2932-2940.

Tomlinson, D.J., Mulling, C.H., Fakler, T.M. 2004. Invited Review: Formation of keratin in the bovine claw: Roles of hormones, minerals, and vitamins in functional claw integrity. Journal of Dairy Science 87, 797-809.

Tranter, W.P., Morris, R.S. 1991. A case study of lameness in three dairy herds. New Zealand Veterinary Journal 39, 88-96.

Tucker, C. B., Weary, D.M., Fraser, D. 2003. Effects of three types of free stall surfaces on preferences and stall usage by dairy cows. Journal of Dairy Science 86, 521-529.

Tucker, C.B., Weary, D.M., de Passille, A.M., Campbell, B., Rushen, J. 2006. Flooring in front of the feed bunk affects feeding behavior and use of freestalls by dairy cows. Journal of Dairy Science 89, 2065-2071.

Tucker, C.B., Dalley, D.E., Burke, J.-L.K, Clark, D.A. 2007. Milking cows once daily influences behavior and udder firmness at peak and mid lactation. Journal of Dairy Science 90, 1692-1703.

Van Amstel, S.R., Shearer, J.K., Palin, F.L. 2004. Moisture content, thickness, and lesions of sole horn associated with thin soles in dairy cattle. Journal of Dairy Science 87, 757-763.

Vanegas, J., Overton, M., Berry, S.L., Sischo, W.M. 2006. Effect of rubber flooring on claw health in lactating dairy cows housed in free stall barns. Journal of Dairy Science 89, 4251-4258.

Vokey, F.J., Guard, C.L., Erb, H.N., Galton, D.M. 2001. Effects of alley and stall surfaces on indices of claw and leg health in dairy cattle housed in a freestall barn. Journal of Dairy Science 84, 2686-2699.

Wagner-Storch, A. M., Palmer, R. W., Kammel, D.W. 2003. Factors affecting stall use for different free stall bases. Journal of Dairy Science 86, 2253-2266.

Warnick, L.D., Janssen, D., Guard, C.L., Grohn, Y.T. 2001. The effect of lameness on milk production in dairy cows. Journal of Dairy Science 84, 1988-1997.

Webster, A.J.F. 2001. Effects of housing and two forage diets on the development of claw horn lesions in dairy cows at first calving and in first lactation. Veterinary Journal 162, 56-65.

Wells S.J., Trent, A.M., Marsh, W.E., Robinson, R.A. 1993. Prevalence and severity of lameness in lactating dairy cows in a sample of Minnesota and Wisconsin dairy herds. Journal of American Veterinary Medical Association 202, 78-82.

Whay, H. R., Waterman, A.E., Webster, A.J.F., O'Brien, J.K. 1998. The influence of lesion type on the duration of hyperalgesia associated with hindlimb lameness in dairy cattle. The Veterinary Journal 156, 23-29.

Whay, H.R., Main, D.C.J., Green, L.E., Webster, A.J.F. 2002. Farmer perception of lameness prevalence. In: Proceedings. 12th International Symposium Lameness in Ruminants, Orlando, Florida, pp 355-358.