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Lameness is one of the greatest insults to the productivity, health and welfare of dairy cattle. More than 80 potential lameness hazards have been identified (Bell et al., 2008). Hazards to claw health and cow mobility can take many different forms. For instance, many aspects of the cow environment such as flooring quality (Faull et al., 1996) and cubicle design (Bernardi et al., 2009) can put claw health at risk. Management decisions such as claw trimming routine (Espejo and Endres, 2007) or over-crowding (Leonard et al., 1996) also have an impact on claw health.

Advice to help dairy producers reduce lameness risks can be quite a challenge due to the multi-factorial nature of the influences on claw health. Tailored solutions to particular farm situations are required. However, a better understanding of the patho-mechanisms of claw injury/disease will help veterinarians and hoof trimmers identify specific farm risks and develop effective preventive management strategies.

In this talk we will highlight what we believe to be 4 of the most pertinent risk factors in western Canada. We will relate each risk to the internal claw structures affected by exposure to the hazard, highlighting parts of the talk, “Environmental influences on claw function and integrity”. The take-home messages for this talk are designed to assist farm veterinarians to provide advice to dairy clients that will help reduce the occurrence of lameness on their farms.

1. **Problems with claw shape**

Aberrations in claw conformation (both internal and external) impact on lameness and are indeed a result of many claw pathologies. Breeding/genetics as well as environmental insults can contribute to sub-optimal claw shape. For instance, prolonged standing in manure can cause heel erosion through exposure to moisture (softens claw horn, Borderas et al., 2004) and bacteria (*Treponemes*, Read et al., 1992) that degrade the heel horn.

**Patho-mechanisms - How the problems with claw shape impact claw health**

HORN PRODUCING LIVING EPIDERMIS

Mechanical overload and tissue compression interfere with the perfusion of fluids and with supplies to horn producing tissue. Bioactive molecules derived from metabolic activity or systemic disease will impact on vascular walls and perfusion. These factors have the potential to change the diameter of the dermal vessels or to damage the endothelial wall. Of particular relevance is metabolic stress related to parturition, lactation or dietary problems resulting in...
metabolic disorders like ketosis or acidosis. Some factors such as histamine, lactate, endotoxin can directly damage the endothelial lining of the vessels and increase transvascular movement. Vasoactive factors such as serotonin or bradykinine will cause constriction of vascular walls with the result of reduced perfusion or reduced drainage form the capillary bed. The latter will result in increased transvascular movement and increased pressure inside the claw capsule (Christmann et al., 2002). Both reduced perfusion and alterations in the vessel themselves will impair horn production and finally provoke horn of inferior quality. A significant weakening of the horn capsule is a central result of subclinical laminitis. The consequence is an increased susceptibility of the claw to damage and lesions secondary to laminitis.

Pressure is transferred via the cornified and living epidermis to the basal cell layer stimulating proliferation of cells thereby accelerating the production of horn. If the load on a foot is unevenly distributed between the two claws the imbalanced increase in the rate of horn production. The claw with the greatest load will produce more horn and increase in size usually at the heel (overburdening). This causes more pressure more horn and a vicious circle is initiated. Functional claw trimming with the objective of distributing load evenly between both claws, and thereby breaking the vicious circle, is the appropriate measure to interrupt this circle.

DERMIS INCLUDING THE SUSPENDING SYSTEM OF THE PEDAL BONE
Housing and exposure to concrete are major hazards to claw tissue integrity. Mechanical irritation and or overload cause matrix metalloproteinase (MMP) activation and collagen degradation. These enzymes degrade collagen and weaken or destroy the connection between the pedal bone and the horn capsule (the suspensory apparatus).

SUBCUTIS WITH THE SUPPORTING DIGITAL CUSHIONS
Prolonged exposure to concrete surfaces causes the solar surface of the lateral claw to flatten and increase in width. This process changes the dynamics inside the claw. Instead of weight-bearing being confined to the wall part of the load is transferred to the central part of the sole of the sole. This creates abnormal pressure on the dermis of the sole. This process accounts for the ‘traumatic’ component in the etiology of subclinical laminitis.

**What can be done on-farm to improve claw shape?**
Designing cow environments to reduce the impact of environmental insults to claw conformation is ideal; however changes to flooring, housing and other major capital investments can be prohibitively expensive. Recommend changes that can have major benefits to claw health without requiring complete reconstruction of the cow environment and producers are more likely to accept the advice.

Routine claw trimming has been shown to decrease the occurrence of claw problems (Manske et al., 2002; Espejo and Endres, 2007). At least some of the cows on every farm will have problems with claw shape (and in some cases the shape is a result of poor claw health, not the cause of poor claw health). However, since claw conformation problems are ubiquitous, veterinarians and hoof trimmers can often find an opportunity to discuss the frequency of claw trimming on-farm. It is recommended that hoof trimming (or at least examination of all claws) is performed twice in the lactation cycle for every cow - at peak
lactation when the majority of claw problems will become apparent and at dry-off to rebalance claws and provide a sound basis for healthy claws when entering the subsequent lactation. The quality of the hoof trimming is paramount. Anyone performing hoof trimming should be properly trained.

Claw lesion recording is important for monitoring the types of problems that occur on an individual farm and within a certain animal. This allows patterns to be identified and changes to improve claw health to be scrutinized. In Alberta, the Hoof Trimmer’s Association is working with Alberta Milk to collect claw lesion data on a large scale in order to: 1) help determine on-farm lameness management strategies and 2) produce a database for researchers to use in developing long term strategies to help reduce lameness based on research into risk factors and injuries specific to western Canada.

Breeding for strong internal and external claw conformation should be a priority. Claw conformation and health should be considered when deciding to breed for replacement stock. I.e. consider using beef bulls for cows with consistently poor claw conformation and claw health issues.

2. **Hygiene**

Poor claw health is often the result of poor claw hygiene. Conditions that result in claws being exposed to moisture and manure for prolonged periods, whether it’s standing in pooled manure on concrete or wet bedding can negatively influence the internal claw structures through degradation of the heel horn and softening of the sole horn, altering the weight distribution in the claw.

Infectious sources of claw pathologies (digital dermatitis, heel erosion, foot rot) are readily passed from cow to cow through prolonged standing in slurry. Digital dermatitis causes changes in cow mobility associated with pain and discomfort (Flower and Weary, 2009).

**Patho-mechanisms - How claw hygiene impacts claw health**

**HORN PRODUCING LIVING EPIDERmis**

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**What can be done on-farm to improve claw hygiene?**

Comfortable, clean lying spaces (cubicles or straw bedding) will help ensure that cows do not spend excessive amounts of time standing on concrete (Bergsten and Frank, 1996). This is of particular importance if the farm suffers from poor quality concrete flooring in alleyways or collecting yards where water and manure are likely to pool.
If cows have a large amount of caked or fresh manure on their claws and lower limbs it may be appropriate to question the method and frequency of scraping alleyways.

An appropriate footbathing routine and washing feet with a hose while cows are in the parlour can help control digital dermatitis (Laven and Logue, 2006).

3. **Inadequate awareness/detection of lameness**

We know that producers are not inclined to detect lameness in the majority of cows that would be considered clinically lame by researchers. Leaving lame or unsound cows untreated or waiting until lameness is severe before presenting a cow for treatment can make lameness more difficult to treat and reduce the ability of the claw to heal properly.

**Patho-mechanisms - How inadequate awareness/detection of lameness impacts claw health**

**HORN PRODUCING LIVING EPIDERMIS**

Mechanical overload and tissue compression interfere with the perfusion of fluids and with supplies to horn producing tissue. Bioactive molecules derived from metabolic activity or systemic disease will impact on vascular walls and perfusion. These factors have the potential to change the diameter of the dermal vessels or to damage the endothelial wall. Of particular relevance is metabolic stress related to parturition, lactation or dietary problems resulting in metabolic disorders like ketosis or acidosis. Some factors such as histamine, lactate, endotoxin can directly damage the endothelial lining of the vessels and increase transvascular movement. Vasoactive factors such as serotonin or bradykinine will cause constriction of vascular walls with the result of reduced perfusion or reduced drainage from the capillary bed. The latter will result in increased transvascular movement and increased pressure inside the claw capsule (Christmann et al., 2002). Both reduced perfusion and alterations in the vessel themselves will impair horn production and finally provoke horn of inferior quality. A significant weakening of the horn capsule is a central result of subclinical laminitis. The consequence is an increased susceptibility of the claw to damage and lesions secondary to laminitis.

**DERMO-EPIERMAL JUNCTION**

Epidermal-dermal interactions play an important role in regulating the proliferation and differentiation of keratinocytes, i.e. the process of horn production and the amount and quality of the horn produced. Theses interactions also play an important role in repairing surgical and traumatic injuries of the claw capsule. Early in the pathogenesis of laminitis alterations in the dermo-epidermal region have been reported such as initial molecular and structural changes followed by functional disturbances. In addition, on the dermal side, activation of MMPs (Tarlton et al., 2000) leading to degradation of collagen and subsequent functional loss of the suspensory apparatus plus activation of growth and necrosis factors, molecular and structural alterations in the basement membrane (Hendry et al., 2003) and alterations of capillary walls.

**DERMO-EPIERMAL JUNCTION DERMIS INCLUDING THE SUSPENDING SYSTEM OF THE PEDAL BONE**
The system of fibres suspending the pedal bone is responsible for transferring the load (weight of the animal) from the pedal bone to the claw capsule (Westerfeld et al., 2000, 2004). All of the structures between the surface of the bone and the inner aspect of the cornified claw capsule contribute to suspensory functionality. The dermal and epidermal components of the suspensory apparatus are arranged in interdigitating dermal and epidermal laminae. Collagen fibres of the connective tissue are the crucial structural and functional components of the suspensory apparatus of the digit. The quality of these fibres is of critical importance if the pedal bone is to be held in a stable position inside the claw capsule (Lischer et al., 2002; Maierl et al., 2002; Tarlton and Webster, 2002; Westerfeld & Mülling, 2000). For whatever reason a loosening or increase in length of this connective tissue occurs it will lead to displacement (sinking, rotation, tilting) of the pedal bone within the horn capsule and subsequent increase in pressure onto the soft tissue between bone and horn.

**What can be done on-farm to improve awareness/detection of lameness?**

Mobility scoring as a regular farm practice will enable cows with slight changes in gait to be separated for inspection. Conditions contributing to unsoundness of gait can be identified and rectified before the animal becomes clinically or severely lame.

4. **Nutrition**

For the modern dairy cow, rations tend to be well-balanced and change gradually so that nutrition problems that have the potential to cause acute laminitis are not a large risk factor for lameness. However, it is indisputable that proper nutrition helps maintain claw health through the production of good quality horn.

It has also been shown that nutritional supplements such as biotin and zinc can help reduce lameness through improving claw horn quality (Green and Muelling, 2005).

Biotin (vitamin H) is essential for two major metabolic pathways in keratinisation, keratin protein synthesis and lipogenesis (Sarasin, 1994; Whitehead, 1988). Improved quality of the intercellular cement and resulting from this improved cell to cell adhesion occur under Biotin supplementation (Hochstetter, 1998). Biotin is in particular essential in the synthesis of long chain fatty acids (Moss and Lane, 1971; Wertz and Downing, 1992) which are part of complex lipid molecules in the intercellular cementing substance. In dairy cows it was demonstrated that supplemented animals had a reduced susceptibility to claw diseases such as sole ulcers, dermatitis digitalis and horn erosion. Looking at the claw horn of supplemented animals on the histological level the integrity of the horn has improved (Hochstetter, 1998; Koller et al., 1998; Schmidt, 1995).

Zinc has been identified as a key mineral in the processes of keratinisation. Zinc is a component of over 200 enzyme systems. It has a role in key functions during keratinisation including the formation of the structural proteins.

*Patho-mechanisms - How nutrition impacts claw health*

HORN PRODUCING LIVING EPIDERMIS
The highly active horn producing epidermal cells depend on a sufficient and balanced supply of nutrients and oxygen. Required nutrients for normal keratinisation are (Tomlinson et al., 2004): amino acids, especially sulphur containing amino acids such as cysteine, fatty acids, such as linoleic and arachidonic acid, minerals, in particular calcium, furthermore trace elements like zinc, and vitamins, in particular biotin. The supply with all these substances has entirely to be performed by diffusion from the blood vessels in the underlying dermis, because the epidermis itself is a completely avascular tissue. Mechanical overload and tissue compression interfere with the perfusion of fluids and with supplies to horn producing tissue. Bioactive molecules derived from metabolic activity or systemic disease will impact on vascular walls and perfusion. These factors have the potential to change the diameter of the dermal vessels or to damage the endothelial wall. Of particular relevance is metabolic stress related to parturition, lactation or dietary problems resulting in metabolic disorders like ketosis or acidosis. Some factors such as histamine, lactate, endotoxin can directly damage the endothelial lining of the vessels and increase transvascular movement. Vasoactive factors such as serotonin or bradykinine will cause constriction of vascular walls with the result of reduced perfusion or reduced drainage from the capillary bed. The latter will result in increased transvascular movement and increased pressure inside the claw capsule (Christmann et al., 2002). Both reduced perfusion and alterations in the vessel themselves will impair horn production and finally provoke horn of inferior quality. A significant weakening of the horn capsule is a central result of subclinical laminitis. The consequence is an increased susceptibility of the claw to damage and lesions secondary to laminitis.

DERMO-EPIDERMAL JUNCTION
The dermo-epidermal interface is a highly developed and specialized region at the border between dermis (connective tissue) and epidermis (epithelium) (Mülling & Budras, 2002). The living epidermal cells located on the interface proliferate and show high metabolic activity. All nutrients, substances and factors required for the epidermal activities have to pass from the dermis into the epidermis and vice versa. With its functions the dermo-epidermal junction is a structure of crucial importance for the integrity and normal function of the claw. It establishes the attachment of the living epidermis to the underlying dermis. Signals between dermal and epidermal cells also run through this interface.

DERMIS INCLUDING THE SUSPENDING SYSTEM OF THE PEDAL BONE
Collagen fibres of the connective tissue are the crucial structural and functional components of the suspensory apparatus of the digit. The quality of these fibres is of critical importance if the pedal bone is to be held in a stable position inside the claw capsule (Lischer et al., 2002; Maierl et al., 2002; Tarlton and Webster, 2002; Westerfeld & Mülling, 2000). For whatever reason a loosening or increase in length of this connective tissue occurs it will lead to displacement (sinking, rotation, tilting) of the pedal bone within the horn capsule and subsequent increase in pressure onto the soft tissue between bone and horn.

During the peri-parturition period and throughout the onset of lactation the properties of the connective tissue of the suspensory apparatus (more precisely the extracellular matrix in the connective tissue, the collagen fibres) undergo changes leading to decreased stability of the dermis (Holah et al., 2002; Mülling et al., 2004). As a result, there is increased mobility of the pedal bone inside the claw capsule (Lischer et al., 2002; Mülling & Lischer, 2002). The critical questions however are: What are the hazards/risk factors causing degradation of the
collagen? And what are the local mechanisms in the claw mediating alterations of tissue? Experiments designed to explore the importance of housing, feeding and parturition/lactation indicate that the structural integrity of connective tissue was most severely compromised by housing in cubicles. Parturition and lactation amplified this effect whereas feeding had no significant influence (Webster, 2001, 2003; Webster et al., 2005). Within this context it must be re-emphasized that the dermis is exposed to high local mechanical pressure (Hinterhofer et al., 2006; van der Tol, 2002), particularly when cows stand for excessively long period throughout the day. Cubicle housing in comparison to straw yards leads to elevated level of pro MMP2 and active MMP 2 in the connective tissue of the claw (Tarlton et al., 2000; Webster et al., 2005).

SUBCUTIS WITH THE SUPPORTING DIGITAL CUSHIONS
Baird et al. (paper currently under peer review, JAS) have shown that the fatty acid composition of the digital cushion can be somewhat altered through diet.

What can be done on-farm to improve awareness/detection of lameness?
Manage facilities so that there is no/low risk of animals gorging on high energy diet components that could cause acute laminitis.

Ensure the diet is properly formulated.

Consider feeding biotin supplements. Biotin must be fed consistently for at least 4-6 months in order to see full benefits in claw health. Green and Muelling (2005) explained that results from epidemiological studies of supplementation indicate that a supplement of 20mg per day active biotin given continuously each day at all stages of production is effective at reducing lameness/claw lesions in cattle 6 months from the start of supplementation. Reduction in lameness will vary by herd but may be as high as 50%.

TAKE-HOME MESSAGES
Critical lameness control points can sometimes be easily identified (e.g. broken/slippery concrete, overcrowding leading to aggression), but often critical control points require management improvements, not major capital investment to better control lameness risks.

These critical control points are:

- Optimal claw conformation – proper hoof trimming routine
  - Recommend at least 1x/year all cows have all 4 feet lifted and pared if needed
    - Preferably 2x/yr – at peak lactation and at dry-off
    - By a trained hoof trimmer/farmer/herdsperson!
  - Continuous lesion recording (not simply keeping records of those animals treated with drugs)
- Claw hygiene
- Lameness awareness
- Ensure proper diet formulation; Consider supplements
Literature Cited


Westerfeld, I., Ch. K. W. Mülling and K.-D. Budras. 2000. Suspensory apparatus of the distal phalanx (Ph III) in the bovine hoof. XI International symposium on disorders of the
