1. INTRODUCTION

Lameness in dairy cattle causes crippling economic losses to the industry. With up to 52% (average 20-25%) of high-production intensively-managed dairy cows becoming lame each year the loss in milk production is devastating for producers (Clarkson et al. 1996; Green et al. 2002; Warnick et al. 2001). The physiopathological patterns reviewed in this paper also impinge on reproductive performance and accounts for the strong correlation that had been shown, in recent years, to exist between lameness and reproductive inefficiency. Lameness is caused by many diseases being the clinical manifestation of an animal's attempt to relieve pain. Pain causes stress and, therefore, the attendant suffering is a highly important animal welfare issue (Whay et al. 1998; Whay et al. 2003).

During the past few years there has been a burgeoning of research reports resulting in an improved understanding of the physiopathological mechanisms involved in the pathogenesis of foot disorders in cattle. Research has focused in particular on a condition or syndrome called subclinical laminitis (SCL). Laminitis is term that is a scientifically inaccurate description of this disorder as is the recently suggested term “claw horn disruption” (CHD) (Hoblet & Weiss, 2001). SCL weakens the integrity of claw tissues predisposing them to secondary lesions such as white line disease and sole ulcers. It is now accepted that SCL has a multi-factorial etiology and a complex physiopathology resulting from a multitude of ‘risk factors’ inherent to dairy farming (Bosman et al. 1991; Ebeid, 1993; Greenough, 1985; Greenough & Vermount, 1991; Lischer & Ossent, 1994; Mülling & Lischer, 2002). Nocek (1997) postulates that nutritional management and improved cow comfort are major risk factors to be considered in the attempt to reduce lameness in dairy cattle. Inappropriate policies for genetic selection, accelerated breeding protocols, poor periparturient management and even farmer knowledge and skills have been implicated as risk factors.

Well over 90% of lameness causing lesions are found in the claws (Clarkson et al. 1996) and they have been described and are well understood. Research of the past 10 years has become more and more interdisciplinary employing modern methods of epidemiology, cellular biology and molecular biology (Bergsten & Mülling, 2004). New hypotheses have evolved to demonstrate possible links between systemic problems and local damage in the claw. However, understanding the
physiopathology, especially the links between a systemic problem and the local alterations in the claw tissue is still limited.

The bovine foot, or more precisely the claw, serves as an interface between the animal and its environment. The claw is exposed, internally to the influences of the metabolism of the animal while the same time being exposed to the impact of mechanical, chemical and biological agents from the environment. Traditionally, the physiopathology and pathogenesis of SCL has been considered from the perspective of being completely related to nutrition and metabolism (Nocek, 1997). There is a common misunderstanding that subacute rumen acidosis (SARA) directly and inevitably leads to laminitis and the associated claw lesions. In this “classical” approach, a cascade of events starts with a metabolic problem i.e. ruminal acidosis and then the story develops down to the changes and lesions of the foot. Today much greater importance is attached to inadequate housing, foot care and parturition than to nutrition and feeding (Tarlton et al. 2000; Webster, 2001, 2003). In this review a new approach will be adopted focusing on the interaction between the claw tissues and metabolic/systemic problems, that is to say, the physiopathological events that take place inside the claw in response to the internal (metabolic) and external (environmental) challenges. During the review process the link between theoretical knowledge and the on farm situation will be continuously explored.

1.1 New models for studying physiopathology mechanisms in claw tissue

Many attempts have been made to establish a valid animal model for studying bovine laminitis in living cattle. The most recent attempt demonstrated the early acute events and tissue changes occurring in acute laminitis (Thoefer et al. 2004, 2005).

However, animal models are expensive use and are invariably associated with concerns about animal welfare. In recent years in vitro models have gained more importance in studying the physiopathology of claw diseases. Tissue explant studies have already provided important insights into regulation of differentiation in healthy and diseased claw tissue (Hendry et al. 1997, 1999, 2001, 2003). Cell lines and simple three-dimensional cell cultures are already available (Nebel et al. 2002, 2003, 2004). The development and experimental application of novel in vitro models was a major task of the EU framework 5 project Lamecow (http://www.abdn.ac.uk/lamecow). Parts of the outcome of this project are different cell culture systems including three dimensional organotypic culture systems and tissue explants systems. In addition a novel ex vivo model, the isolated haemoperfused distal cow limb model (Wüstenberg, 2004), has been developed and used for experiments. These models enable in vitro studies under standardised conditions in cell clines, complex organotypic cultures and finally testing in the isolated limb perfusion model under conditions as close as possible in a model to the in vivo situation.

1.2 Tissue components

The relevant tissue components of the claw are:

- the sub cutis (digital cushion),
- the dermis (including the suspensory apparatus of the digit),
- the dermal vascular system,
- the dermo-epidermal junction,
- the horn producing living epidermis.
2. PHYSIOPATHOLOGY

The performance of the foot is genetically determined and limited. The interaction between the above listed structures and the environment results in a cascade of physiopathological events leading to adaptation changes, alterations or damage in the tissues. In high-performance dairy cows under conditions of intensive-management the foot is continuously challenged by environmental and metabolic factors. Any weakening of the structural integrity of the claw has immediate functional consequences followed by all of its biological, economical and welfare consequences.

2.1 Subcutis with the supporting digital cushions

2.1.1 Anatomy and physiology

The digital cushion extends forward beneath the pedal bone and is made up of three cylindrical parallel oriented bodies each with a capsule of connective tissue filled with soft fat (Räber et al. 2004).

During normal gait the heel bulbs make the first contact with the ground and the weight will be distributed equally between the outer and inner claw. While the resilient bulbs reduce the initial shock on the posterior part of the claws the weight of the animal is smoothly transferred to the wall and adjacent sole by slight splaying of the claws. The dermis of the sole and heel and the underlying fat cushions in the subcutis function as “shock absorbers” bearing a considerable proportion of the impact of the first phase of each step the animal makes when walking. The digital cushion acts in conjunction with the retinaculum of the digit and surrounding soft-elastic horn of the bulb. The elastic tissues of the retinaculum expand laterally when compressed during weight-bearing. The lateral pressures are transferred to the wall which normally has high tensile strength functioning as a spring to absorb some of the energy of locomotion. This tensile strength of the wall diminishes if the quality of the horn of the wall is compromised by disorders such as subclinical laminitis, horizontal or vertical fissures, or heel erosion.

It has been assumed that the weight distribution between the medial and lateral claws is equal. However, the medial claw is frequently smaller than its lateral counterpart. Prolonged exposure to concrete surfaces causes the solear 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 SCL.

2.1.2 Physiopathology - Alterations of the digital cushion

There is a marked change in the composition of the digital cushions as the animal gets older. In heifers the fat cushions are not completely developed and functional. They develop to full shock absorbing capacity during the first 2 lactations. The fat content is significantly higher in cows (38%) than in heifers (27%) (Räber, 2000; Räber et al. 2004). The cushions in the heifers are composed predominantly of loose connective tissue with abundant amorphous ground substance. In cows however, there was a marked increase of adipose tissue with progressing age (Räber et al. 2004). A comparison of the digital cushions between sound claws and claws with sole ulcers revealed that the phalanx of ulcerated claws had sunken and the solear dermis and subcutis were thinner than in the controls. The cushions contained significantly less adipose tissue than the controls but had been replaced by collagenous connective tissue (Lischer et al. 2002). The fatty acid composition and the size of the fat cushions change under the influence of metabolic disorders, in particular in cows with lipid mobilisation syndrome (LMS, ketosis). The fat in the digital cushion has a high content of monounsaturated fatty acids (MUFA). MUFA are mainly produced endogenously and the greater
the quantity of these fatty acids in the fat tissue, the softer it is; the structural fat in the digital cushion possesses its own ‘fat softener’ (Räber et al. 2002). Heifers have significantly less fat in the cushions and slightly more saturated fatty acids (SFA) than the cows. This indicates that the change from SFA to MUFA and the proliferation of fat occurs at first parturition and during the following lactation. It is possible that these changes in the heifer's digital cushions make them less resistant to pressure load. Epidemiological studies have shown that there is a higher tendency for sole lesions to occur at the beginning of the first lactation (Boosman et al. 1991; Enevoldsen et al. 1991; Greenough & Vermunt 1991; Smilie et al. 1999).

2.2 Dermis including the suspending system of the pedal bone

2.2.1 Anatomy and physiology

The suspensory apparatus of the pedal bone consists of collagen fibres that run upwards from their insertion in the bone to the basement membrane of the dermal lamellae were they are anchored and thus connected to the lamellar epidermal of the claw capsule. The lamellar region of the wall segment is far smaller and the carrying capacity of the suspensory apparatus of the digit is far less in cattle than it is in the horse (Westerfeld et al. 2000, 2004). It is implicit in this finding that the functionality of the foot of the two species is different. In cattle the heel plays a greater role by provide cushioning support.

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. Therefore, the structural complex consists of a dermal component with a deeper reticular layer and a superficial papillary layer (dermal papillary body) and an epidermal component including living epidermal layers and the inner parts of the stratum corneum. The dermal and epidermal components of the suspensory apparatus are arranged in interdigitating dermal and epidermal laminae. It is mainly the suspensory apparatus of the digit that determine the degree of tissue compression in the sole beneath 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 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.

2.2.2 Physiopathology

An elongation, loosening or an increasing elasticity in the collagen system suspending the pedal bone inside the claw capsule are central to hypotheses explaining the pathogenesis of subclinical laminitis (Mülling & Lischer, 2002; Mülling et al. 2004).

During the periparturition 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? Evidence is accumulating that housing and claw trimming are a major hazard (Webster 2001, 2003).

Recent 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).

A group of proteolytic enzymes resident in connective tissue, the Matrix Metalloproteinases (MMPs) play a central role in the degradation of collagen. Basing on recent studies on the effects of MMP-2 and MMP-9 on dermo-epidermal explants (Hendry et al. 2003) and a proteolytic enzyme, “hoofase”, (Tarlton & Webster, 2000) two major hypothesis have been developed. One hypothesis favours the central role of MMPs and their activation by proteases (Tarlton & Webster, 2000) or other known activators of MMPs such as cytokines and inflammatory factors (Mülling et al. 2004). The other hypothesis is based on the direct effects of hormones on the connective tissue leading to instability or a loosening of the collagen fibre system. Relaxin present in the peripartal period (Jönsson & Person, 1969) is discussed as the major candidate.

Activation of MMPs can be caused by factors derived from biological mediators circulating in the blood such as endotoxin, lactate, cytokines like TNFα or Interleukin-1. This activation is mediated by cytokines released from local tissues. Under conditions of physiological homeostasis MMPs are controlled by their tissue inhibitors (TIMPs) which normally prevent excessive MMP activity. In disease, elevated levels of active MMP result from decreased TIMP activity and increased conversion of inactive pro MMP into active MMP. When MMP expression is elevated and TIMP activity decreased bioactive molecules activate MMP’s which start degrading collagen fibres. Pathological activity of MMPs leads to increased collagen degradation and loosening and elongation of collagen fibres. The subsequent increased mobility of the pedal bone within the capsule causes displacement (sinking and/or rotation or tilting or a combination of these movements) of the pedal bone to a degree depending on the localization and severity of the collagen degradation. If housing and exposure to concrete are the major hazards to claw tissue integrity then mechanical irritation and or overload are the cause of MMP activation and collagen degradation.

Changes in the collagen network induced by mechanical stresses are an integral part of tendon pathology (Birch et al. 1998) and partial removal of collagen may predispose to tendon rupture (Riley et al. 2002). For tendons it has been reported that the interaction of overload and MMP effect leads to rupture of the tendon. In many pathological conditions there is an imbalance between the synthesis and degradation of the matrix leading to collagen network degradation. An initial degradation of collagen by damage due to mechanical load (overloading failure) as described for tendons (Birch et al. 1998) is likely for the laminitic claw as well.

Recent findings from in vitro studies (Mülling et al. 2004) provide initial insights into the collagen alterations causing increased instability of the suspensory apparatus of the pedal bone. The structural alterations demonstrated are comparable to the collagen removal process described in human and equine tendons (Birch et al. 1998; Riley et al. 2002). Exposure of dermal collagen to activated MMP-2 and MMP-9 leads to a removal of collagen from the dermal network and subsequent disintegration of the system as revealed by electron microscopy. Degradation of a certain number of collagen microfibrils within the collagen fibres can prepare the pathway for mechanical induced microruptures which has been described for stressed tendons. Damage of a
limited number of collagen fibres leads to a microrupture and a slight increase in length of a small fibre bundle. The overall elongation and instability will depend on the number of fibres affected. If the damaged matrix is loaded, elongation is the consequence leading to displacement of the pedal bone in the claw capsule without actual separation of the connective tissue.

2.3 Dermal vascular system

2.3.1 Anatomy and physiology

The dermal vascular system of the claw is unique in its three-dimensional arrangement, complexity and density, which is the reason for its high susceptibility to structural damage and disturbances to the perfusion of blood (Hirschberg et al. 1998, 2001). Structural peculiarities in the vascular system and arterio-venous anastomoses (AVA’s) in particular have been described as having a central role in development of laminitis. AVA’s are shunts between the arterioles bringing the blood into the capillary bed and the venule draining the blood from the capillary bed. They are supplied with nerves which innervate smooth muscle in vessel walls which can close blocking perfusion of the capillary bed of the dermis. More recent micro-corrosion cast studies by Hirschberg et al. (1999, 2001) have demonstrated that there are almost no AVAs in the vascular system of the digits of healthy claws. Arteriovenous anastomoses are present in the skin where they play an important role in thermoregulation.

It has frequently been hypothesised that AVAs play an important role in initial stages of bovine laminitis (Vermunt & Leach 1992). However, there is no evidence to support the theory that AVA’s play any role in the pathogenesis of laminitis. The number of AVAs in the dermis of the claw at any given time depends on functional challenge. That is to say there is an increase in the number of AVA’s if a disease is present, e.g. during laminitis or around the periphery of sole ulcers. Consequently the hypotheses favouring closure of AVAs as a major initial event in the pathogenesis of laminitis do not apply.

The overall microvascular in the dermal papillae and lamellae is quite extensive, but not all branches of this microvascular bed are perfused at all times. A primary pathway supplies the dermal and the adjacent epidermal cells with their basic needs. This is different from the functional pathway which responds to the functional demands required from the dermis and epidermis, e.g. region-specific rate of proliferation and horn production. The actual perfusion pattern is adapted permanently to the tissue needs by precapillary sphincters. The primary pathways (“thoroughfare channels”) are the main routes within the capillary bed where the central arteriole and venule are connected inside a papilla. The functional pathway required for proper supply of the adjacent epidermal layers is provided by the extensive capillary network of the papilla. Arteriovenous anastomoses are located outside the microvascular bed and regulate extreme demands for perfusion. Therefore, they occur at the base of the lamellae and papillae and in the deeper layers of the connective tissue of the claw, not within the lamellae and papillae. These arteriovenous anastomoses are also subject to function related remodelling and are formed on demand that is, mostly in response to changes in the environmental temperature (Hirschberg, 2001; Hirschberg & Plendl, 2005).

2.3.2 Physiopathology

The dermal microvascularisation and the perfusion patterns are highly adaptable to metabolic and functional requirements. Mechanical forces during weight-bearing deform the papillae and open or close pathways within the vascular system of the papillae. Thus, the perfusion pattern of the microvascular bed is regulated by demand and by mechanical forces. Structural adaptation of the
Angioarchitecture is facilitated by active remodelling processes of the capillaries by sprouting and intussusception (Hirschberg & Plendl, 2005).

Pressure in the vessels and tissues increases during laminitis which could be explained by compromised function of AVA’s but a much more likely explanation would be coagulopathy. The pressure increases in the capillaries together with transvascular movement of fluid in tissues may be caused by an increased post-capillary resistance. This resistance is believed to be the result of a reduction in the diameter of the venules in the periphery draining blood from the capillary bed (Christmann et al. 2002).

The linkage between metabolic problems and local changes in the claw tissue and the causes of vascular failure still awaits clear explanations. A number of candidate factors and mediators are listed and discussed in the literature. Ranking high on the list are endotoxins, histamine and lactate.

The initial local reaction to laminitis that takes place in claw tissues are alterations in the vascular endothelial lining (roughening) and in the microcirculation (changes in the rate of perfusion). These events are followed by the activation of a variety of interacting and cross linked inflammatory and regulatory cascades. MMP activation is only one part of the jigsaw. It also may be that there is direct initial damage to the epidermis by mechanical overload. The damage will cause the release of interleukin-1 (IL-1) which is a potent pro-inflammatory cytokine produced and stored by the epidermal cells. IL-1 will then diffuse into the dermis, binding to fibroblasts and triggering the release of keratinocyte growth factor (KGF). KGF is a potent mitogen activating basal proliferation in the epidermis. Parallel to this, IL-1 also activates MMPs. In addition there is positive and negative feed-back between these auto and paracrine regulators (Mülling et al. 2004). These observations strongly support the idea of complex rather than a simple physiopathology. Any hypothesis which reduces everything to the one and only magic factor or molecule is highly suspicious.

The results of Christmann et al. (2002) provide initial evidence that alterations in microcirculation related to early laminitic-like events are different in the bovine claw compared to the equine hoof. They demonstrated in grain overloaded steers an increase in capillary pressure and post-capillary resistance. This facilitates transvascular movement and an increase in tissue pressure. Digital venous constriction is thought to be the initial step in these events. However, horses showed no significant changes in pre-capillary resistance and digital blood flow was found to be normal. The differences in the haemodynamic changes observed between the species may contribute to the differences in clinical presentation of laminitis (Christmann et al. 2002).

Nilsson described, in 1963, the formation of “Neocapillaries” in the dermis of claws of animals suffering from subacute laminitis. Recently Hirschberg and Plendl (2005) investigated the formation of new blood vessels in diseased claws. Based on their studies of the morphology of microvascularisation and angioadaptation of the claw they postulate a central role of pododermal angiogenesis in the pathogenesis of laminitis. It well may be that studies on the angiogenesis, i.e. the de novo formation of blood vessels will significantly contribute to the understanding of laminitis and open new doors for the prevention of laminitis.

2.4 Dermo-epidermal junction - Dermo-epidermal cross talk

2.4.1 Anatomy and physiology

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. During proliferation and synthesis the mitotic cells have to withstand a high mechanical load while transferring all the mechanical forces between the underlying bone and the outer horn capsule and the environment. With its complex functions the dermo-epidermal interface 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.

2.4.2 Physiopathology

Epidermal-dermal interactions (also referred to as dermo-epidermal cross-talk) play an important role in regulating the proliferation and differentiation of keratinocytes which 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 as well as activation of growth and necrosis factors, molecular and structural alterations in the basement membrane (Hendry et al. 2003) and alterations of capillary walls.

Changes on epidermal side have to be considered as secondary changes due to disturbed nutrient and oxygen supply. A double paracrine regulation of keratinocyte growth and differentiation has been postulated and recently described in vitro (Mülling et al. 2004). Interleukin-1 (IL-1) and keratinocyte growth factor (KGF/FGF-7) and their receptors are major mediators in this epidermal-dermal signalling. IL-1 is synthesised and stored in the Keratinocytes of claw epidermis. It is released upon physical or chemical injury of the cells but also by the effects of cytokines arriving in the dermis via the vascular system. IL-1 migrates into the dermis were it binds to receptors on dermal fibrocytes. There it causes release of Keratinocyte Growth factor (KGF). KGF is an important stimulator of keratinocyte proliferation as demonstrated in co-culture systems of claw fibroblasts and keratinocytes. There is preliminary evidence for a reciprocal regulatory mechanism present in the bovine claw involving IL-1 produced in the epidermis and KGF originating from fibroblasts. It is reasonable to assume that mechanical load triggers IL-1 release and thus activates the paracrine regulation. Increased rate of proliferation and horn formation would be the consequence. In addition MMPs would become activated by the released Interleukin 1. The collagen of the innermost layer of the basement membrane (lamina fibroreticularis) is a substrate for activated MMP’s which degrade this collagen disrupting the integrity and regulatory/communicative functions of the basement membrane (Hendry et al. 2003).

2.5 Horn producing living epidermis

2.5.1 Anatomy and physiology

The claw epidermis consists of living epidermal cells in the basal and spiny layers and of dead epidermal cells in the horny layer. Formation of claw horn is the result of a dynamic process of proliferation, cellular differentiation (i.e. keratinisation) and programmed cell death called cornification (Mülling & Budras, 1998; Tomlinson et al. 2004). This process is controlled by a variety of bioactive molecules including growth factors and neuropeptides provided by the dermal cells and/or the vascular system. The hallmarks of keratinisation are the synthesis of keratin proteins and of intercellular cementing substance by the living epidermal cells (Mülling & Budras, 1998).

The keratinising epidermal cells are specialised for a high rate of protein synthesis. Already in the basal layer they start to produce keratin proteins with increasing intensity in the superimposed layers. At the end of the differentiation during cornification, the keratins are cross-linked by
formation of disulphide-bonds which consist of a stable protein-complex which provides mechanical and chemical stability to the horn. The second product of keratinising epidermal cells is the intercellular cementing substance consisting of glycoprotein and complex lipids such as phospholipids glycolipids and acylglycosylceramides. Its major function is to establish cell to cell adhesion providing mechanical stability to the horn. The lipids of the cementing substance establish a permeability barrier in the intercellular space. This barrier prevents the passage of aqueous solutions through the horn and thus protects horn cells from excessive loss of water as well as from extreme hydration (Mülling & Budras, 1998).

2.5.2 Physiopathology

The highly active horn producing epidermal cells depend on a sufficient and balanced supply of nutrients and oxygen, minerals vitamins and trace elements. The supply is entirely performed by diffusion from the blood vessels in the underlying dermis because the epidermis itself is a completely avascular tissue. The transport of nutrients by diffusion is dependent on the gradient of concentration as well as the distance between the dermal blood vessels and the epidermal cells.

Mechanical overload and tissue compression interferes 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. On the other hand, thinning the sole during routine claw trimming also increases pressure on the keratogenic cells thereby stimulating the production of healthy horn.

Earlier in this paper slight asymmetry of the claws was briefly discussed. Recent examination by Nacambo et al. (2004) demonstrated a difference in length of the metatarsal bones. According to their results the lateral metatarsal bone (Mt 4) is slightly longer than the medial one (Mt3). This leads to an increased pressure on the outer claw if its height is adjusted equally to the level of the medial claw. The asymmetry of the two metatarsal bones is demonstrated and confirmed by CT examination of the skeleton (Mülling et al. 2004, 2005).
2.5.3 Differentiating epidermal cells

There is growing evidence from morphological and in vitro studies that disruption of the differentiation of keratinocytes in the differentiating hoof epidermis is the major reactive event during pathogenesis of laminitis. This disruption occurs following dermal alterations resulting in disruption of appropriate supplies to the epidermis (Hendry et al. 1999, 2001). This was the theory that has been explored also by Ekfalck (1991) and Wattle (2001). Most of the findings observed in the claw capsule in subacute or chronic laminitis is related to or a result of the reactive changes in the epidermis.

3. CONCLUSIONS

In this paper the structure function and physiopathology of five tissue elements in the bovine claw have been reviewed. In each instance changes in these structures are explored within the context of the strong biomechanical component related to cow comfort that is now believed to be an important factor in the pathogenesis of claw diseases. The biomechanical component referred to is the pressure exerted on the living epidermis through abnormal loading of the wall and sole of the claw. In the first instance the distribution of load between the claws is determined by the anatomy of the upper limb and the relative shapes of the two claws. The ravages of intensive management disturb the balance between the two claws still further with strong tendencies for the sole of the lateral claw to flatten and widen when exposed to hard surfaces. The loading factor alone induces a chain of physiopathological events within the capsule. These events are exacerbated by two distinct physiopathological processes that are triggered by biological agents that arrive in the foot via the bloodstream from elsewhere in the body. The first process is degradation of collagen fibre systems essential for supporting and suspending the pedal bone. The second process compromises the microvascular system of the dermis which in turn embarrasses the horn production capability of the living epidermis. These two processes result in structural and functional failure of the claw capsule. Christensen et al. (1998) point out that: high production cows in an environment of intensive management are on the verge of failing to attain their genetic potential for production. Furthermore Dillon & Veerkamp (2002) express concern that the practice of giving the highest priority of selecting dairy cows for production traits at the expense of functional traits is degrading the longevity of the herds. These observations throw a very different light on the life of the dairy cow. In this paper very little emphasis has been placed on the role played by nutrition or SARA as a risk factor. High levels of nutrition fuel the metabolism of the cow and push it to the limit and beyond. It should be noted that there has been frequent references to the metabolism of the animal triggering the physiopathology described. The concept of a multifactorial etiology of claw diseases is as valid as it ever was. Preventive measures still must be geared to managing the stress level that precipitates the complex physiopathology that intrinsic to the foot. Routine claw trimming helps to balance the load born by the claw. Eliminating overcrowding improves freedom of movement and the perfusion of blood through the foot. Cow Comfort is not just a sentimental myth but must be interpreted as part of the interaction between the foot of a dairy cow and its internal and external challenges. This is the background for the claw diseases occurring under modern intensive housing conditions.

No longer is it acceptable to believe that SARA = Subclinical laminitis. The disorder can not be managed simply from a nutritional perspective. Multifactorial means that practically every aspect of dairy cow management has to be scrutinized for its potential impact on the claw. The claw is a much more delicate and sensitive organ that it appears to be. Understanding how it functions is an excellent beginning to understanding the overall problem.

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In addition to the measures applied to the animals and their environment it is imperative to develop the herd managers/farmers awareness of the problem, to improve education, dissemination of knowledge and to promote sustainable management strategies for reduction of foot problems.

4. SUMMARY

This paper reviews the physiopathological events in the interaction of the different tissue components of the bovine claw with external and internal challenges, i.e. the interactions between the claw, the organism and the environment.

The anatomy and physiology of the digital cushion, the suspensory system of the pedal bone, the dermal vascular system, the dermo-epidermal junction and the horn producing living epidermis are explored. The importance of the claw as an interface between the animal and the environment is discussed. The performance of the claw is genetically determined and limited. It has been stressed that in high-production intensively managed dairy cows the foot is permanent challenged by metabolic and environmental factors. Any weakening of its structural integrity directly leads to functional failure and disease. The bovine foot is not constructed for permanent use on hard flooring. Continually walking and in particular excessive standing on concrete or asphalt causes reactions and adaptation changes to the point of damage of the tissue.

Physiopathology of foot problems is complex and not completely understood. However, the acquisition of new information is accelerating at a prodigious pace and it can only be hoped that there is the flexibility of mind and dedication to apply the new ideas on the farm.

5. KEY WORDS

Bovine foot, claw diseases, laminitis, physiopathology, cow comfort.

6. RESUME

Cette contribution examine les événements physiopathologiques dans l'interaction des différentes composantes des tissus de l’onglon bovin avec des défis externes et internes, c'est-à-dire les interactions entre l'onglon, l'organisme et l'environnement. L'anatomie et la physiologie des rembourrages digitaux, le système de soutien de l'os du pied, le système vasculaire cutané, la jonction dermo-épidermique et l'épiderme vivant produisant la corne sont explorés. L'importance de l’onglon comme interface entre l'animal et l'environnement est discutée. La qualité de fonctionnement de l’onglon est génétiquement déterminée et limitée. On a noté que chez les vaches laitières intensivement contrôlées de haute production le pied est en permanence défié par des facteurs métaboliques et environnementaux. Chaque affaiblissement de son intégrité structurelle conduit directement à des pertes de fonction et à des maladies. Le pied du bovin n'est pas conçu pour utilisation continue sur des sols durs. Le fonctionnement durable et en particulier la position excessive sur des sols de bitume ou de béton causer des réactions et des modifications adaptatives dans le tissu jusqu'à la destruction locale du tissu.

Le physiopathologie des maladies du pied est complexe et pas encore complètement comprise. Toutefois l'acquisition de nouvelles constatations augmente rapidement et nous pouvons espérer en la flexibilité intellectuelle et en l'engagement de transposer en pratique les nouvelles idées sur les fermes.

7. MOTS CLES

Onglon bovin, maladie des onglons, fourbure, physiopathologie, confort de l’animal.

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8. ZUSAMMENFASSUNG

Dieser Beitrag bespricht die physiopathologischen Ereignisse bei der Interaktion der verschiedenen Gewebekomponenten der Rinderklaue mit äußeren und inneren Faktoren, das heißt die Wechselwirkungen zwischen der Klaue, dem Organismus und der Umwelt.


Die Physiopathologie von Fußkrankheiten ist komplex und nach wie vor nicht vollständig erforscht. Der Erwerb neuer Erkenntnisse nimmt jedoch mit rasch wachsender Geschwindigkeit zu und wir können nur hoffen, dass die intellektuelle Flexibilität und der Einsatz die vorhanden sind, die neuen Ideen in der Praxis auf den Farmen umzusetzen.

9. SCHLÜSSELWÖRTER

Rinderklaue, Klauenerkrankungen, Klauenrehe, Physiopathologie, Kuhkomfort.

10. RESÚMEN

Este artículo se refiere a los sucesos fisiopatológicos de la interacción de los diferentes componentes del tejido de la pezuña de vacas con desafíos internos y externos; es decir, la interacción entre la pezuña, el organismo y el medio ambiente.

Se presenta la anatomía y fisiología de los amortiguadores digitales el sistema de suspensión del hueso del pedal, el sistema vascular dermatológico, la conexión dermo-epidermal y la epidermis viva productora de cuerno. Se discute la importancia de la pezuña como interacción entre animal y medio ambiente. La capacidad de la vaca está genéticamente determinada y limitada. Se destaca que la pezuña de vacas de producción intensiva está exigida permanentemente por factores metabólicos e impactos ambientales. Cada debilitación de su integridad estructural conduce directamente a una pérdida funcional así como a enfermedades. La pata de la vaca no está diseñada para permanecer prolongadamente en superficies duras. El movimiento permanente y especialmente el permanecer de pie en pisos de cemento y asfalto, produce reacciones y transformaciones adaptativas en el tejido hasta la destrucción local del mismo. La patología fisiológica de las enfermedades de la pata es muy compleja y aún no ha sido completamente investigada. Pero el conocimiento está incrementándose día a día y se espera que la flexibilidad intelectual y el esfuerzo existente ayuden a implementar los nuevos conocimientos en la práctica en los campos.

11. PALABRAS CLAVES

Pezuña de vacas, enfermedades de la pezuña, laminitis, physiopathology, comodidad de vacas.
12. ACKNOWLEDGEMENT

Investigations contributing to this work were supported by the European Communities under the Lamecow project QLK5-CT-2002-00969. The authors are solely responsible and the work does not necessarily represent the opinion of the European Communities.

The help of Elke and Christoph Scabell and Elke Langer by preparing the “Resumen” is gratefully appreciated.

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