

PATHOGENESIS OF SOLE LESIONS ATTRIBUTED TO LAMINITIS IN CATTLE

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Introduction

In cattle, lesions in the sole usually attributed to laminitis include haemorrhages in the horn, double soles, ulcers in the sole and toe, haemorrhage and separation of the white line, as well as deformation of the whole surface ("dropped sole") (Ossent and others, 1997). Other authors used the term claw horn disruption (CHD) (Clarkson and others, 1996; Hoblet and Weiss, 2001). Usually these lesions occur in the heel, i.e. in zones 3, 4 and 6.

The causes for CHD or laminitis-like lesions are diverse. The incidence and severity of the lesions are influenced by external mechanical factors such as abnormal claw or limb configuration, hard surfaces and soft horn. Systemic factors are associated with rumen acidosis, ketosis and endotoxaemia due to e.g. inadequate feeding. In analogy to the situation in the horse, the pathogenesis has been associated with systemic insult to the microvasculature in the pododerm in conjunction with laminitis. Due to the initial collapse of the suspensory apparatus within the laminar region of the claw the pedal bone sinks within the horn capsule and compresses the underlying corium to produce so called "phase 3 lesions". The theories on pathogenesis and aetiology have been described in detail by Ossent and others, (1997).

The theories on the pathogenesis of sole lesions

The pathogenesis of claw lesions in cattle has long been assumed to be associated with laminitis and, in analogy to the horse, to be due to a disturbance in the microcirculation of the corium of the claw with subsequent degenerative (and inflammatory) changes at the dermal-epidermal junction. Based on this assumption, a more detailed theory was developed in conjunction with the interpretation of post-mortem findings in the claws of animals with clinical laminitis (Ossent and Lischer, 1998). It is convenient to divide the pathogenesis into different phases (Fig. 1).

The primary reaction seems to occur in the vascular system. Thus, phase 1 is initiated by an impairment of the blood supply to the corium due to the action of vasoactive substances e.g. histamine or endotoxin in the blood stream. Vessel wall paralysis and vasodilation cause the blood to stagnate, the claw's arterio-venous shunts open and the main flow of blood normally destined for the corium short-circuits. Hypoxia ensues in the surrounding tissues and in the walls of the blood vessels, which subsequently begin to leak. Transudation leads to oedema. Erythema, oedema, haemorrhages, thrombi and finally necrosis follow. Large dark red patches appear in the normally pink coloured corium, particularly in the laminae. The process may be extremely painful.

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The horn producing and proliferating epidermal basal cells are supplied with nutrients and oxygen from the blood vessels in the underlying dermis (corium). The basal cell layer at the dermal-epidermal junction degenerates first. The deterioration of the dermal-epidermal link leads to a failure of the claw's suspensory apparatus. The link begins to separate and the whole foot sinks within its horn capsule to enter phase 2.

Sinkage of the pedal bone compresses the corium in the sole and heel and further episodes of capillary damage, haemorrhage, thrombosis, cellular inflammatory reaction and finally ischaemic necrosis result. Chronic oedema, combined with compression from the weight of the animal will present a threat to the animal similar to actual sinkage. Obviously, the lesions present a serious threat to the animal's life for they may induce extensive damage with severe pain and lameness. It is important to realize that still nothing is visible to the clinician at this stage although several weeks may have elapsed since the onset of laminitis; the lesions develop on or near the inner surface of the horn capsule.

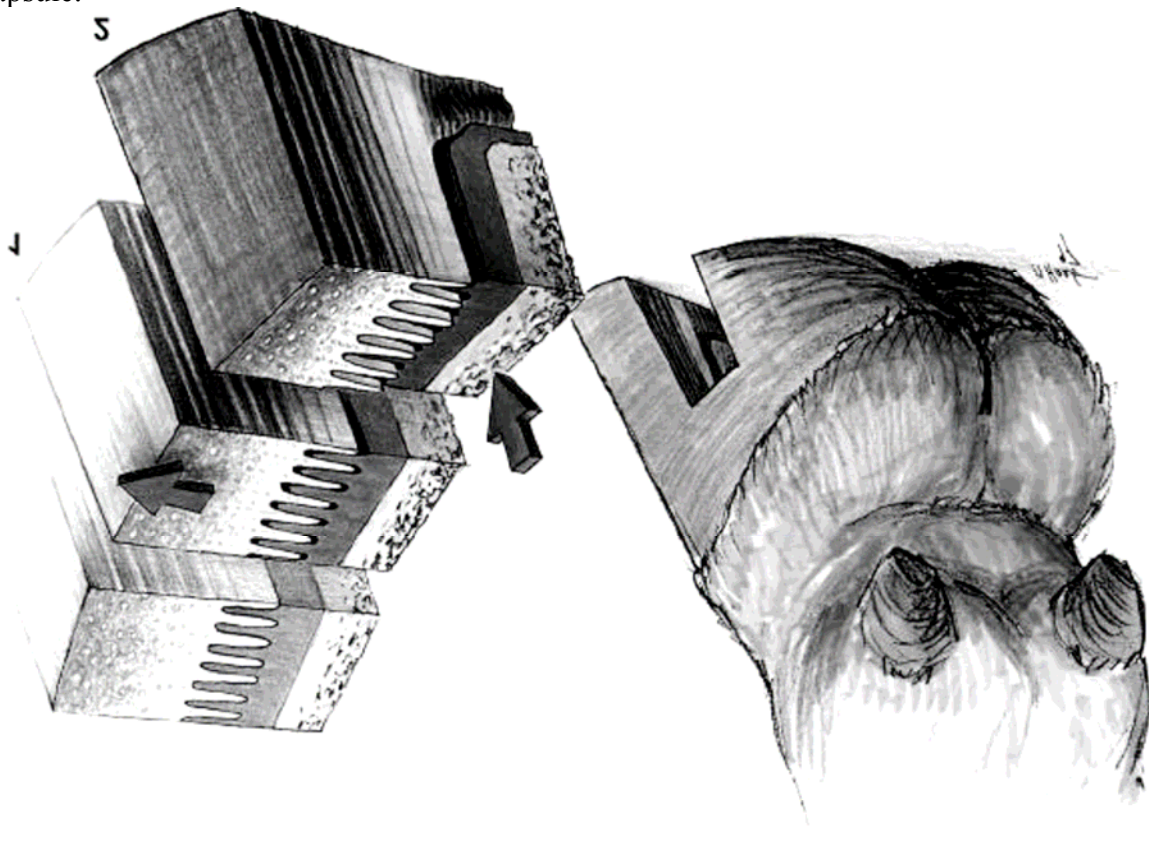


Figure 1:
Different stages in the pathogenesis of laminitis:
Top: Normal claw wall: A substantial part of the animal's weight is suspended from the claw wall. Clearly the forces can only be transmitted to the wall and thence to the ground, if the interdigitating lamellar structures in the lamellar layer are intact.

Phase 1: Degeneration at the dermal-epidermal junction. Circulatory disturbances in the corium lead to structural changes in the carrying layers. Eventually the lamellar junction disrupts and the wall separates from the corium.

Phase 2: Sinkage of the distal phalanx. Once the degree of separation is too severe to suspend the weight of the animal, the distal phalanx sinks within the horn capsule and compresses the corium beneath it.

In phase 3 after about 8 weeks, lesions begin to become apparent in the horn capsule. Until quite recently these lesions in the horn were regarded as separate disease entities. Accumulations of exudate between the lamellae or lamellar hyperplasia or a separation at the epidermal-dermal junction cause the white line to disrupt and to become wider. The friable layers will appear at the bearing edge of the claw and may provide a port of entry for infection (white line disease). Furthermore, necrotic tissue masses and accumulations of blood at the surface of the corium retard or hinder horn production. Once growth continues, the detritus is incorporated into the new horn that gradually grows out to the surface to appear as red patches, or when the haematomas are sufficiently extensive, a double sole or heel. An ulcer will develop when the production of horn is wholly blocked; its exact site depends on where the necrosis is located. The typical sites for ulceration are where the tissues are compressed and damaged most, where the soft tissues are thinnest.

Chronic diffuse disturbances in the corium will lead to generally inferior horn. In older animals a chronically laminitic claw commonly results from a series of laminitic bouts. With time, the claw becomes broad, flattens and the dorsal wall is furrowed and concave to form a so-called slipper foot.

There is experimental evidence that supports parts of the theory above. The development of claw haemorrhages was recorded according to whether they occurred in the sole or in the white line in a herd of 31 dairy heifers from 4 weeks before calving to 32 weeks after calving (Leach and others, 1997). It is of interest to note that the haemorrhages in the white line appeared at 9 weeks and in the sole at 14 weeks i.e. the blood pigments that had been deposited in the laminar layer had reached the ground surface 5 weeks earlier than those that had developed in the sole or heel i.e. that were far closer to the ground surface. Since one may presume that the horn in these two distinct regions involved grows at the same rate it would imply that there was an interval of several weeks between the first haemorrhages in the wall (phase 1) and the subsequent displacement of the third phalanx (phase 2).

In equine laminitis it is common knowledge that separation of the suspensory apparatus within the hoof occurs at the dermal-epidermal layer and rotation and sinkage of the phalanx may occur within hours or days.

It is important to bear in mind that a large part of the explanations above are theoretical. The weakest link of the attachment of the pedal bone at the inside of the claw capsule, the locus minoris resistentiae, has yet to be demonstrated. Disturbances in the microcirculation by vasoactive agents and the insult to the laminar region of the corium have never been

demonstrated in cattle. Although it seems undisputable that inflammatory mechanisms are responsible for phase 1 lesions there are possible alternative pathways for phase 2. A mechanical separation of the suspensory apparatus through excessive load is highly unlikely since a force 20 times greater than that exerted by normal load is required before the connective tissue between the phalanx and the wall horn tears (Webster A., Personal communication). A more likely explanation would be a softening and increase in the elasticity of the collagen fibres in the suspensory apparatus due to hormones during pregnancy and the perinatal period. Relaxin, a hormone produced by the corpus luteum in both pregnant and non-pregnant females, has a broad range of biologic activities e.g. the induction of collagen remodeling and consequent softening of the tissues of the birth canal (Bani, 1997). Fibrous tissue in general may be affected (Holah and others, 2000). Possibly, the fibres of the suspensory apparatus are affected allowing the third phalanx to sink and cause lesions. The results would be the same as when there is separation at the dermal-epidermal junction (Ossent, 1999).

The lamellar wall segment is far smaller and the carrying capacity of the suspensory apparatus is far less in cattle than in the horse (Westerfeld and others, 2000). This implies that the bovine heel must provide proportionally far more cushioning support from underneath. It is thus logical that this second structure's consistency and functionality also determines the degree of tissue compression in the sole or heel under the pedal bone.

Supporting structure

a) Digital cushion in sound claws

In contrast to the horse where the pedal bone is largely suspended from the dorsal hoof wall, the corium of the sole and heel in cattle and especially the underlying fat cushions in the subcutis are essential shock absorbers that bear a considerable proportion of the animal's weight.

The digital cushion not only serves as a shock absorber for the pedal bone but represents a layer that allows considerable mobility between the pedal bone and the horn capsule. The structure consists of three parallel fat cylinders; axial, abaxial and central (Fig. 2). A similar triple cushion principle is used in running shoes. Multiple transverse finger shaped cushions connect the axial and abaxial cushions in front of the tuberculum flexorium. The tuberculum flexorium itself is covered by the central cushion. There were no differences in the tissue composition of the cushions of the outer and inner claws.

b) Influence of age and load to the digital cushion

The cushions in the heifers were predominantly of loose connective tissue with abundant amorphous ground substance. There was a marked increase of adipose tissue with progressing age.

The fat in the digital cushion has a high content of monounsaturated fatty acids (MUFA). MUFA are mainly produced endogenously and the more there are in the fat tissue, the softer it is; the structural fat in the digital cushion possesses its own "fat softener" (Räber et al., 2001).

Epidemiological studies have shown that there is a higher tendency for sole lesions at the beginning of the first lactation (Boosman and others, 1991; Enevoldsen and others, 1991; Greenough and Vermunt, 1991; Smilie and others, 1999). Heifers had 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. Possibly it is these changes in the heifer's digital cushions that makes them less resistant.

Another interesting aspect concerning load and age seems to be the significant difference in concentration of arachidonic acid between heifers and cows. Arachidonic acid, the precursor of prostaglandin, is a mediator of inflammation. Higher concentrations of arachidonic acid were generally found in zones where more load is expected although the concentration in cows was markedly lower than for heifers. One may speculate that the digital cushions act as a local reservoir for arachidonic acid that is released upon compression and tissue damage. Chronic subclinical inflammation and a consumption of arachidonic acid for the production of prostaglandins may occur in these zones, particularly in cows with progressing age.

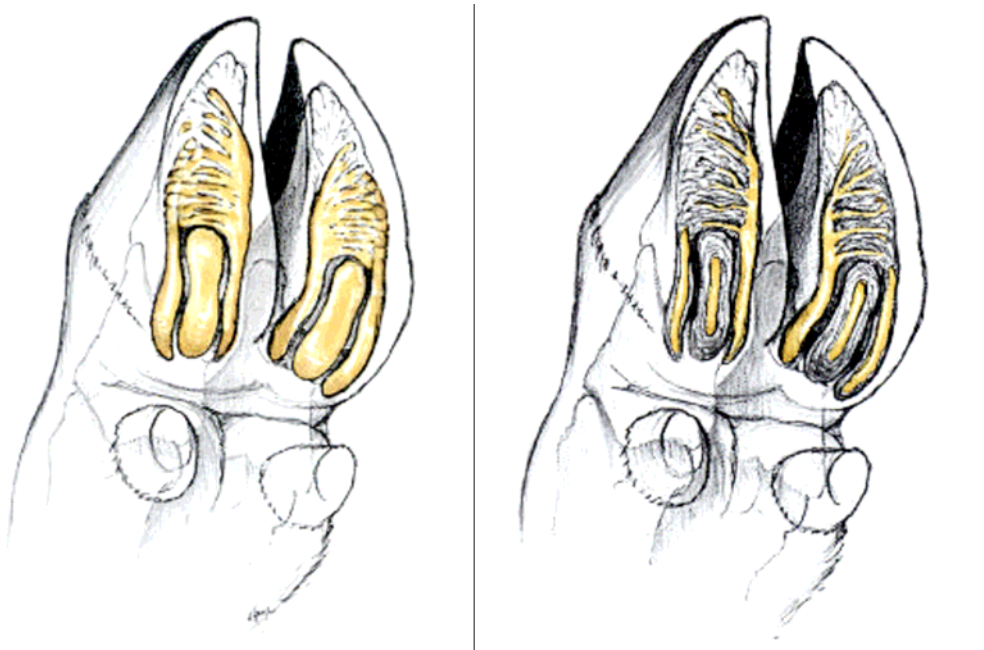


Figure 2: The bovine heel cushion consists of three parallel fat cylinders: axial, abaxial and central (left). In cases of sinkage the amount of fat in the digital cushions is substantially reduced and replaced by connective tissue (right).

c) Digital cushion in ulcerated claws

It is these tissues that are damaged when the suspensory apparatus, regardless whether at the epidermal-dermal junction or the collagen layer, gives way sufficiently to allow the pedal bone to sink and compress the underlying structures.

Obviously, damage to the horn producing layers will be offset best in those claws where the fat cushions under the third phalanx are well developed. 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 palmar corium and subcutis were thinner than in the controls. The heel cushions

contained significantly less adipose tissue than the controls (Fig. 2); the fat had been replaced by collagenous connective tissue (Lischer and Ossent, 2000). There are some indications that fat metabolism in the high performance cow could have some relationship to the development of sole lesions in respect to alterations in the shock absorbing function of the digital cushion. However, the metabolic processes involved and their effects on the health of the claws are not sufficiently clear yet.

a) Suspensory apparatus in sound claws

In the equine hoof the suspensory apparatus connects the surface of the pedal bone to the inner aspect of the dorsal wall (Pellmann and others, 1996). A similar structure consisting of a connective tissue layer and a laminar layer has the same function in the bovine claw. They are connected by the basement membrane located along the dermal-epidermal border. A detailed description is given by (Westerfeld and others, 2000).

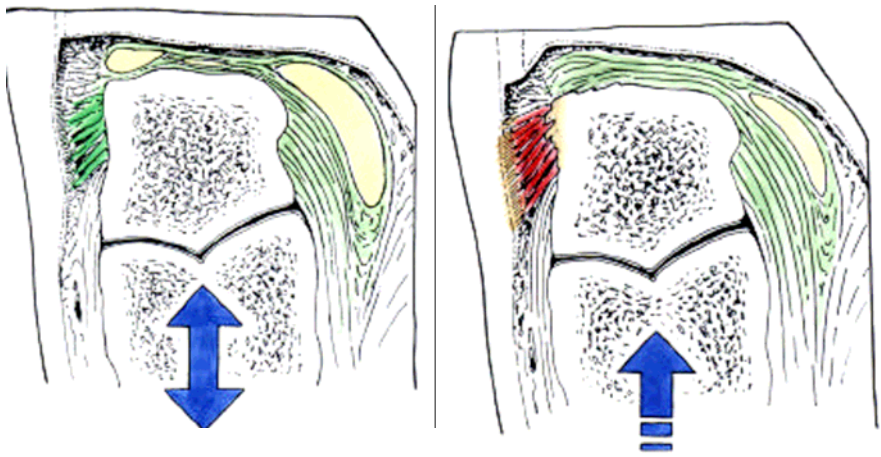


Figure 3: At the level of the tuberculum flexorium the distal phalanx is kept in position by the underlying cushion and the suspensory connective tissue bundles to the abaxial claw wall (left). In cases of sinkage the connective tissue segment of the suspensory apparatus is overextended, the distal phalanx sinks and compresses the corium and deforms the horn sole (right).

d) Failure of the suspensory apparatus

Lesions like sole hemorrhages and ulcers develop as a direct result of focal ischaemia and necrosis due to compression of the corium and of the horn producing epidermal layer, but it is not wholly clear how the compression actually comes about. Some authors suggest that lesions are not only the result of laminitis with consequent loss of integrity of the epidermal-dermal junction, as it is known to occur in the horse, but that other mechanisms may be involved such as changes in another segment of the suspensory structure of the foot, namely the collagen fibres connecting the third phalanx and the horn capsule (Ossent, 1999; Tarlton and Webster, 2000).

Further evidence for this theory were given by (Lischer and Ossent, 2000; Ossent and Lischer, 2000). In a comparative study on cows with and without sole ulcers it was demonstrated that the outer hind claw of cows with sole ulcers showed a significant increase in the displacement of the pedal bone.

Furthermore, the soft tissues under the plantar surface of the bone were compressed. It is of interest to note that the white line always appeared unaltered to the naked eye. Bone proliferation was more marked on the dorsal and lateral surfaces opposite the lamellar region. There was no significant difference in the conformation of the tuberculum flexorium (TF) between controls and the ulcer group. Histological investigation of the suspensory apparatus revealed no difference between controls and ulcerated claws; even at the site where displacement in the ulcerated claws was most pronounced. These gross and histological findings are strong indications that the locus minoris resistentiae in the suspensory apparatus, in contrast to the horse, is not the laminar zone as it has long been assumed but that it must lie in the deeper connective tissue layers of the corium. The only logical conclusion is that the fibrous layer must have possessed increased elasticity, since the hitherto incriminated lamellar zone was intact (Fig. 3).

The gross and microscopic results throw new light on the theories on the pathogenesis of bovine claw lesions but further investigations are needed to determine the exact aetiology of connective tissue weakness. Hormonal fluctuations associated with the periparturient period may be significant in the development of such aberrations and lead to increased mechanical instability of the pedal bone within the claw capsule (Fig. 4).

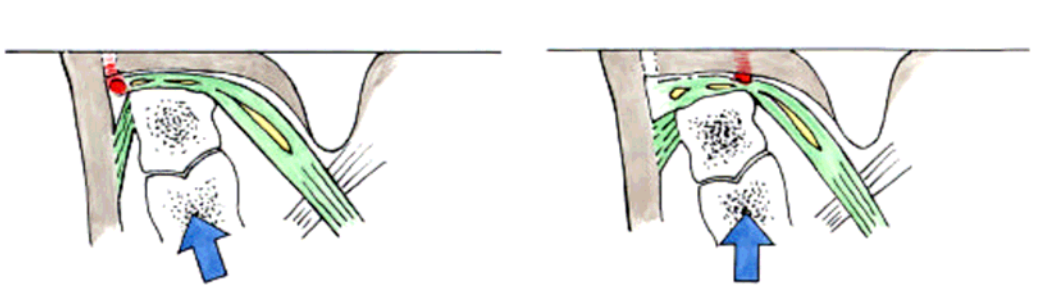


Figure 4: A schematic drawing of the transverse section of the claw at the level of the *tuberculum*

flexorium shows how the abaxial side of the third phalanx is suspended by connective tissue between the bone and the inside of the claw capsule. A cuff of connective tissue that encloses the longitudinal fat cushions and extends into the distal interdigital ligaments supports the axial side of the third phalanx. Increased mobility of the third phalanx within the claw capsule due to alterations in the elastic properties of the collagen tissue lead to contusions of the corium, mainly under the abaxial and plantar edges of the third phalanx.

Left side: A walking cow (loose housing system) with base-wide stance moves her feet unnaturally (wider than her rump) to make room for the udder. This movement results in a lateral impact which may cause haemorrhage in the corium adjacent to the abaxial edge of the pedal bone; especially when the suspensory apparatus is too elastic and unstable. Weeks later, this haemorrhage become visible in the white line.

Right side: Cows in tied stalls however shift their weight from one claw to the other. This exerts more vertical forces on the suspensory apparatus. In these cows, contusion of the corium occurs more at the plantar aspect of the pedal bone, which may predispose to sole ulceration at the "typical site".

Summary

Events usually associated with calving compromise the suspensory apparatus of the foot and predispose the animal to laminitis-like lesions. There is no evidence that the cause lies in the hitherto incriminated lamellar zone. A dysfunction of the fibrous corium, namely increased elasticity, is responsible for the displacement of the bovine pedal bone. Metabolic influences around parturition increase the elasticity of fibrous tissue in many parts of the organism, e.g. the birth canal and may do so in the suspensory apparatus as well. In this context, future investigations should closely examine the role of substances such as relaxin or metalloproteinases and attempt to determine whether inflammatory processes in the fibrous layers of the suspensory apparatus are involved or not. The latter would finally put an end to the speculations that laminitis is at the bottom of this syndrome and would in the case that inflammation is present, let us revert to the term pododermatitis.

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