Pathogenesis of Laminitis

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Introduction

Subclinical laminitis has been considered the most important underlying factor predisposing dairy cows to lameness. Subclinical laminitis is a somewhat loose term in that much of the pathology is now thought to involve hoof horn germinative tissues in addition to those of the laminae. Thus, a better umbrella term that has been proposed is claw horn disruption or hoof horn disorder. At the present time, the subclinical laminitis condition is considered to be of multi-factorial etiology. Feeding management, nutrition, parturition, disease, cow management, environment and behavior all may be involved in causation.

Anatomy and physiology

Hoof horn is modified epidermis, as are fingernails and hair. Hoof horn consists of a protein, keratin, that is formed by the innermost, and only living layer of epidermis, the stratum germinativum. The stratum germinativum has papillae that produce horn tubules and intertubular horn to form the stratum corneum. Hoof horn of the wall is produced in the coronary segment at a rate of approximately 5 millimeters per month. Hoof horn formed by papillae in the stratum germinativum of the sole typically reaches the weight-bearing surface two to three months after it is produced. The papillae also produce the horn of the heel.

The white line (zona alba) forms the junction between the wall and sole and consists of horn formed from three segments of the wall, namely cap horn, terminal horn and horn leaflets. Horn leaflets are the hardest horn of the zona alba and are produced in the coronary-wall transition region. The lower portion of the wall segment produces cap horn. Cap and terminal horn portions of the zona alba are relatively soft and pliable. They constitute a filling horn substance that occupies the space between the horn leaflets.

The dermis layer in the hoof is known as the corium or pododerm. The pododerm contains the blood vessels. There is no subcutaneous space between the sole and PIII. Hoof horn produced in the coronary segment of the wall *slides* down the dermal leaflets as it grows toward the weight-bearing surface. One function of the laminae, which are in reality folds, is to increase contact area between the hoof horn and underlying pododerm. In this way the weight of the cow is transferred from the skeleton to the ground by way of the laminae.

Pathophysiology

Although the pathophysiology of laminitis is not fully understood, it is generally accepted that a vascular disturbance mediated by vasoactive substances such as histamine and endotoxins are involved. At the cellular level there is an interruption of nutrient supply and oxygen delivery. This in turn causes the keratin-producing cells to produce hoof horn of inferior quality. Because vascular disturbances lead to inflammation in the general corium, and not just in the laminae, the term pododermatitis aseptica diffusa may more correctly describe the condition than does the term subclinical laminitis. There is general agreement that episodes of inflammation lead to incomplete keratinization resulting in soft horn or claw horn disruption in the wall, sole and white line. Episodes of laminitis are thought to be repetitive and an initial bout may increase the likelihood of subsequent episodes. The theory of "burdening of the pododerm" or overgrowth of the sole suggests that repeated episodes result in height differences between inner and outer claws of the hind limb. The increased height thus results in the outer claw bearing even a greater proportion of the weight than it does normally and becoming even more susceptible to pathologic changes. Others have indicated that as a result of inflammation of the pododerm there is separation between dermal and epidermal layers. As a result the position of PIII may change, causing more pressure-induced hemorrhage and necrosis of the pododerm or corium of the sole.

Lesions

Hoof horn disorders resulting from subclinical laminitis are not observed until several weeks or months after the vascular disturbance occurs in the corium. Lesions generally include the following:

- *Yellow discoloration of the sole*—Yellow discoloration may indicate intercellular material escaping from an inflamed corium and is associated with soft, poor-quality horn.
- *Hemorrhages of the sole*—Hemorrhages range from those that are barely perceptible (so-called paintbrush hemorrhages) to severe ulceration with exposed corium.
- *Separation of the white line*—Recent work in the United Kingdom has indicated the progressive nature of sole hemorrhages and separation of the white line. Electron microscopic studies found that low-quality horn preceded the appearance of sole hemorrhages and white-line disease by several weeks. High rates of horn production, such as occurs at the posterior end of the zona alba, result in soft, incompletely keratized horn. The striated appearance that may be present in the white line can then be explained as the result of softer cap and terminal horn crumbling and falling away, with harder horn leaflets remaining as remnants.
- *Heel horn erosion*—Controversy exists as to the extent of involvement of subclinical laminitis in heel horn erosion. Some believe that not only is heel erosion part of

the subclinical laminitis syndrome, but that heel erosion also increases the subsequent risk of sole ulcer. It was hypothesized that the heel functions as a shock absorber that when lost, predisposes the hoof to ulcer formation at the so-called typical spot (junction of heel and sole, inner side of lateral rear hind claw). Others have proposed that although heel horn erosion results primarily from bacterial infection, the subclinical laminitis process may be indirectly involved as a consequence of the production of horn of inferior quality. Still others have observed pastured cattle with other lesions of subclinical laminitis, but without heel horn erosion.

- *Sole ulcer*—The site most commonly involved in sole ulcer is in the rear lateral claw near the inner junction of sole and heel. Several investigators have presented evidence suggesting that sole ulcers are a sign of a systemic generalized disturbance. That is, sole ulcers tend to occur in multiple feet of the same animal with the highest incidence occurring during the first four months after calving.
- *Other lesions*—Other lesions that have been considered to be part of the subclinical form of pododermatitis aseptica diffusa include abscess of the sole and white line, sole overgrowth, inflamed coronary bands, flaky or chalky white powdery sole, deformed claws, horizontal grooves in hoof horn, sunken or rotated distal phalanx, overgrown claws and double sole.

Risk factors

Herd environment, nutrition, feeding management, parturition, other management factors, other foot diseases and individual animal factors and genetics have all been implicated as risk factors for subclinical laminitis. Others have found interactions among the various risk factors. There is general consensus that subclinical laminitis causation is multi-factorial, with herd-to-herd differences in the relative importance of a particular factor.

- *Parturition*—Numerous investigators have reported an increase in lesions during the period before and after calving. Periparturient stress, dietary changes, hormonal changes and increased risk of acute systemic disease have all been implicated in the pathogenesis of subclinical lamintis.
- *Nutrition*—Factors implicated at one time or another have been excess energy, inadequate fiber, excess protein, vitamin deficiency, deficiency of minerals and amino acids (cysteine and methionine).
- *Feeding management*—Factors thought important have included forage to concentrate ratio, particle length, relative time of feeding forage and concentrate, and whether each feed was fed separately or as part of a TMR. Feeding chronically high rations of readily fermented carbohydrates, too rapid introduction of readily fermented carbohydrates without time for rumen acclimation, and bolus feeding of readily fermentable carbohydrates have all been implicated. Others have not observed these relationships. The author (unpublished data) has observed several herd problems of subclinical laminitis in heifers where bunk refusal from the lactating herd was fed to growing heifers. In each case, energy and fiber levels in the heifers' ration appeared to change substantially from day-to-day.
- *Environment*—Type of housing facilities, bedding materials, floor surfaces, and manure management have all been considered important. Excessive standing or inadequate resting have also been implicated.
- *Cleanliness*—In a Swedish study, cleanliness of cows was directly related to hoof health of housed cows. Dry matter of hooves and erosion of the heel were significantly related to cleanliness. There was a significant negative correlation between dry matter content of sole horn and heel horn erosion.
- *Other factors*—Cows that had been treated for metabolic, digestive and reproductive disorders have been shown more likely to develop sole ulcers. Foot and leg conformation, claw conformation and claw size have been mentioned as possible important individual animal or genetic factors related to the occurrence of subclinical laminitis. Improper foot trimming techniques may result in traumatic laminitis. Numerous interactions have been observed relating interdigital dermatitis, digital dermatitis, interdigital fibromas and claw overgrowth to abnormal weight-bearing resulting in overburdening and digital disease.

Corrective strategies

- Environment — Cow comfort and clean, dry facilities should be stressed.
- Reduce disease in periparturient period — Institute accepted practices designed to reduce metabolic and infectious diseases during this high-stress period.
- Feeding management and nutrition — Avoid acidosis. Research is unclear on the severity of acidosis required to trigger an episode of subclinical laminitis or the degree of interaction with environment, cow-comfort, and other causative factors. Further, it must be noted that most of the reports in the literature that link feeding management and nutrition to subclinical laminitis resulted from studies conducted in Europe. How different feeds and feeding strategies should be interpreted in light of conditions in the Western Hemisphere is open to discussion.

Data reported to date suggest that multiple factors are likely what cause subclinical laminitis. The relative importance of a particular factor may be expected to differ from herd to herd. Therefore, although certain basic concepts should be universally adopted by producers, specific intervention strategies such as fine-tuning will be expected to vary from herd to herd.

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Identifying Laminitis Insults

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Examining of the hooves of dairy cattle for sole lesions may be useful when determining the prevalence of subclinical laminitis in a dairy herd. Survey work that we have conducted failed to detect consistent patterns among herds with respect to either categories of lesions present or in their anatomical location. If there are differences among herds in the occurrence of lesions, a workable method of identifying, recording, scoring and analyzing such lesions is necessary. In this presentation, such a method will be presented.

Scoring of lesions

For the purpose of scoring lesions, the weight-bearing surface of each claw on a front and rear limb is divided into six zones according to an international recommendation (6th International Symposium on Diseases of the Ruminant Digit, 1990). In our scoring system, four categories of lesions of the sole are routinely considered: yellow discoloration, hemorrhages, separation of the white line and erosion of the heel.

Yellow discoloration is scored as either present or absent. Hemorrhages are scored as: 0 = no hemorrhages, 1 = barely perceptible hemorrhages, 2 = petechial to small ecchymotic hemorrhages, 3 = large ecchymotic hemorrhages, 4 = exposed corium. Separation of the white line is scored on a five-point scale: 0 = no separation, 1 = striated appearance of white line, 2 = slight separation, 3 = moderate separation, and 4 = complete separation of the white line. Striation of the white line (lesion score = 1) is considered to be present when thin, dark striations are visible along the white line. Separation of the white line is present when a visible crevice between the wall and sole is observed. Erosion of the heel is also scored on a five-point scale: 0 = normal heel, 1 = multiple shallow irregular depressions, 2 = multiple deep irregular depressions, 3 = shallow oblique grooves, and 4 = deep oblique grooves with complete loss of structure of the heel.

Analyzing scores of lesions

After the lesion scores from each particular category of lesion have been recorded, they are further and arbitrarily classified as being either satisfactory or unsatisfactory. Yellow waxy discoloration is initially recognized as present and in the analytical phase is considered unsatisfactory. Scores for hemorrhage of 3 and 4 are classified as unsatisfactory. Thus, although any visible hemorrhage is initially recognized and scored, for the purposes of analysis only hemorrhage scores 3 and 4 are considered unsatisfactory. Similarly, moderate separation of the white line (lesion score 3) and complete separation (lesion score 4) are classified as unsatisfactory. Erosions of the heel with the formation of grooves (lesion scores 3 and 4) are also classified as unsatisfactory.

Ranking of herds

Comparing rankings of lesions among herds in a manner similar to that already done with other measures of herd performance (eg. DHIA records) may be helpful when troubleshooting the cause of subclinical laminitis within a herd or for purposes of monitoring progress in a herd.

Results of our survey

We conducted a survey of high-producing Ohio Holstein herds to determine the prevalence of lesions associated with subclinical laminitis. When herds were ranked according to the category of lesion observed, rankings were not consistent. Not only was there an overall lack of consistency among the herds most and least affected, but individual herds may have been in the most affected quartile in one category and the least affected quartile in another.

Examples of ranking herds in our study were:

TABLE 1: Herds ranked by the mean percentage of hooves that were unsatisfactory for hemorrhage of the sole.

Mean	Rank	Mean%	Mean % adjusted for days in milk*
M	1.5	8.3	7.3
A	1.5	8.3	9.4
K	3	11.7	11.4
L	4	15.0	14.5
J	6	16.7	16.5
H	7	23.2	23.8
I	8	37.5	37.3
B	9	41.7	41.7
E	10	67.5	67.8
G	11	71.7	71.8
C	12	87.5	87.3
D	13	91.7	91.6

*Adjusted for days in milk by analysis of covariance.

TABLE 2: Herds ranked by the mean percentage of hooves that were unsatisfactory with respect to separation of the white line.

Mean	Rank	Mean%	Mean % adjusted for days in milk*
A	2.5	0.0	0.0
D	2.5	0.0	0.0
H	2.5	0.0	0.0
C	2.5	0.0	0.4
L	6	3.3	1.0
B	7	3.8	4.6
E	5	1.3	5.1
G	8	5.0	5.2
I	9	3.3	9.1
J	10	18.2	19.3
F	11	18.3	19.3
K	12	27.1	29.3
M	13	30.3	33.3

*Adjusted for days in milk by analysis of covariance.

Subclinical laminitis is generally thought to be of multi-factorial etiology. The relative importance of environment, management, nutrition and other risk factors that predispose cattle to lesions of the hooves is unknown and may vary among herds. Ranking herds and evaluating each category of lesion independently may be helpful from a diagnostic standpoint. For example, because of the possibilities of multiple factor etiology, it may be necessary to apply specific corrective measures at different times in the production cycle in different herds to reduce the incidence of subclinical laminitis.

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