Hooves: A Laminitis History Book

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Introduction

The nature of veterinary disease surveillance has changed with the changing nature of disease on dairy farms. Not many years ago, most veterinary attention was directed toward diseases with obvious clinical symptoms. Through advances in production agriculture many farms have minimized clinical syndromes associated with infectious and metabolic disease. The trend toward larger agricultural units and shrinking profit margins has encouraged veterinarians to shift from treatment of clinical disease toward optimizing productivity by reducing the prevalence of subclinical disease. This redirected emphasis has created diagnostic challenges. The beginning of an epidemic of *clinical* disease is usually readily apparent because of an unexpected increase in clinical disease to a level obviously greater than normal. The beginning of an epidemic of *subclinical* disease is usually not clearly defined.

Verification of subclinical disease is often limited by a lack of records and no discernable beginning of the problem. It is complicated by numerous undocumented daily management changes. Determining cause and effect, and identification of the impact of proposed solutions is often based upon perception of the presence or absence of beneficial outcomes. It may be extremely difficult to answer simple but vital questions such as: 1) *Which animals* are affected? 2) *Where* are the affected animals housed? and 3) *When* did they become affected? Rather than depend upon the recognition of acute clinical symptoms, we are often forced to search for indirect indicators of disease such as the level of milk production, body condition score, reproductive success, somatic cell counts, or the presence of disease-specific indicators (such as serum antibodies). We use these indirect indicators to elicit clues regarding the temporal pattern and chronology of subclinical disease outbreaks.

Subclinical acidosis and laminitis are among the most frustrating syndromes to investigate. Subclinical acidosis results in a number of vague clinical signs such as erratic appetite, weight loss, intermittent diarrhea and lameness.[11,12] The multifactorial etiology and lag between the initial metabolic insult and appearance of recognizable clinical signs often make identification of a discrete cause challenging. Milk production records, milk fat and protein relationships, and hoof appearance are often used as indirect indicators of this disease. One indirect indicator is termed the "hardship groove,"[6] which refers to a depression in the hoof wall running parallel to the coronary band of the hoof. Hardship grooves are considered to be evidence of production stress, nutritional mismanagement, or disease and are suggested as a means to pinpoint chronological development of the lesions.[6,7]

The objective of this paper is to review characteristics of hoof growth and to discuss the use of hoof appearance in disease investigation.

Hoof Anatomy and Growth Patterns

There are three surfaces to the bovine hoof.[17] The abaxial surface is normally convex from side to side and marked with slight ridges parallel to the coronary band. The dorsal part of the abaxial surface is normally somewhat concave from edge to edge and reaches about a 30-degree angle with the ground. The interdigital surface is also concave and ridged. The normal basal (ground) surface consists of a slightly concave sole that widens to a prominent rear bulb. The sole thickness is normally about 7 mm.[6] Hoof wall is produced at the base of the coronary band (periople) and moves down the hoof wall. Hoof wall is continuously formed and continuously worn off.[23]

Hoof growth and wear are normally measured by marking a reference point on the claw wall and measuring migration of the mark away from the periople (growth) or bearing (wear) surface. The rate of hoof growth in Ayrshires was initially reported to be 4.0-5.0 mm/month (0.20 in/month).[14] Five to 6.0mm/month (0.25 in) growth is more commonly reported with modern Holstein dairy cattle (Table 1).

Quality of the hoof tissue produced is subject to variation based upon a number of external influences.[8] Nutrition, season, disease, age and genetics have all been reported to influence hoof wall growth, hoof quality and hoof wear. Hoof size and hoof growth are also influenced by hoof location. Front hooves tend to be larger (ratio of hoof volume reported to be 54:46 percent for front versus back) as expected by the distribution of body weight bear-

Table 1. Reported monthly hoof growth of rear, lateral claws for dairy cattle.

Reference	Animal Studied	Dorsal Growth	Lateral Growth
Prentice, 1973 (14)	Ayrshire yearlings	3.86 mm (0.15")	5.38 mm (0.21")
Clark, 1982 (3)	Holstein cows	6.00 mm (0.24")	6.96 mm (0.27")
Hahn, 1986 (8)	Holstein Lact 1	6.04 mm (0.24")	7.31 mm (0.29")
	Holstein Lact 2 – front	5.79 mm (0.23")	
	Holstein Lact 2 - back	6.14 mm (0.24")	
Manson, 1988 (10)	Holstein – high protein diet	5.00 mm (0.20")	
Tranter, 1992 (20)	Holstein on pasture	5.91 mm (0.23")	

ing.[13] The normal hoof has a toe length of about 7.62 cm (3 in) and a heel height of 3.18 cm (1.25 in).[7]

A number of subtle differences in hoof growth patterns have been reported.[23] In dairy cattle, hooves of first-lactation animals have been reported to grow 0.25 to 0.44 mm/month (0.01-0.02 in/month) faster than hooves of second-lactation animals.[8] Growth of the lateral hoof wall is consistently reported to occur at a slightly faster rate than dorsal growth and is attributed to differences in weight bearing.[21] Differences in hoof growth are also apparent for rear versus fore hooves, with rear dorsal hoof growth occurring about 0.5mm/month (0.02 in/month) faster than hooves of forelimbs.[8] These small differences in growth are well documented but probably too subtle to be detected in most commercial dairy operations.

Seasonal effects

Seasonal effects on hoof growth have also been consistently reported (Figure 1).[3,8,23] In general, hooves grow faster during warmer parts of the year.[8] Similar seasonal patterns have been reported for hair growth.[1] The differences in growth rate have been attributed to both temperature and photoperiod effects.[8,20]

Facility effects

Very subtle claw horn *growth* differences have been attributed to differences in housing systems.[23] However, type of flooring surface has a large influence on the rate of *wear*. In general, horn wear and horn growth are about equal but abrasiveness of the flooring surface can accelerate hoof wear. In some instances, the abaxial wall of cows confined on concrete shortens and more weight is placed on the sole. It has been suggested that animals confined on concrete need a dry period on dirt or pasture to recover hoof horn that has been excessively worn by abrasive surfaces.[8,23]

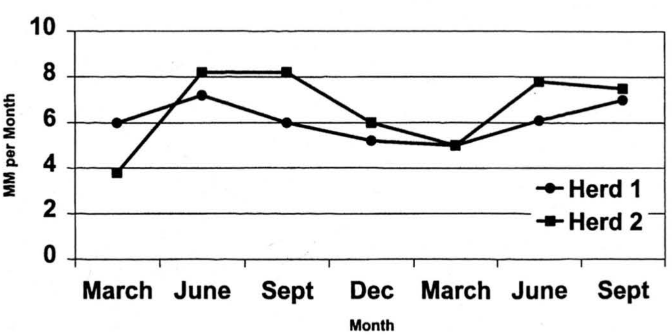

Figure 1. Monthly rates of hoof gorwth for rear hooves of first-lactation cows in two herds (adapted from Hahn, 1986).

Nutritional effects

The relationship between nutritional management and hoof growth and health is well recognized. Supplementation with both zinc and biotin has been demonstrated to influence hoof wear patterns.[15,16] Increased dietary protein and high-energy diets have been related to higher rates of horn growth.[5,10] The most important nutritional impact on hoof health is the relationship between ruminal acidosis and the development of laminitis.[11] The feeding of high-carbohydrate dairy rations is commonly involved in the development of this syndrome.[22]

Effect of Disease on Hooves

Laminitis

Laminitis is considered to have a multifactorial etiology and can present with a variety of clinical hoof disorders.[11,22] Animals with *acute* laminitis are systemically ill and present with a syndrome similar to equine laminitis. Acute laminitis is often related to gross nutritional mistakes and acute ruminal acidosis. Acute laminitis does not immediately produce visible changes in the hoof wall but often recurs and may progress to *chronic* laminitis. *Subclinical* laminitis develops after repeated low grade insults and can progress to chronic laminitis. Subclinical and chronic laminitis do not usually present with obvious acute systemic clinical signs.

The pathogenesis of laminitis is thought to be based upon disruptions in hemodynamics of the bovine digit.[2] Ischemia occurs when blood is shunted away from corium capillary circulation through arteriovenous anastomoses (AVAs). The AVAs are thought to be caused by vasoactive substances (such as histamine or endotoxins) responding to ruminal dysfunction, trauma, systemic disease or compressive stress.[22] Reduced digital capillary perfusion through the hoof corium is thought to produce the characteristic hoof changes. The sequence of events that results in the development of hoof lesions related to chronic laminitis has been illustrated (Figure 2).[2,11]

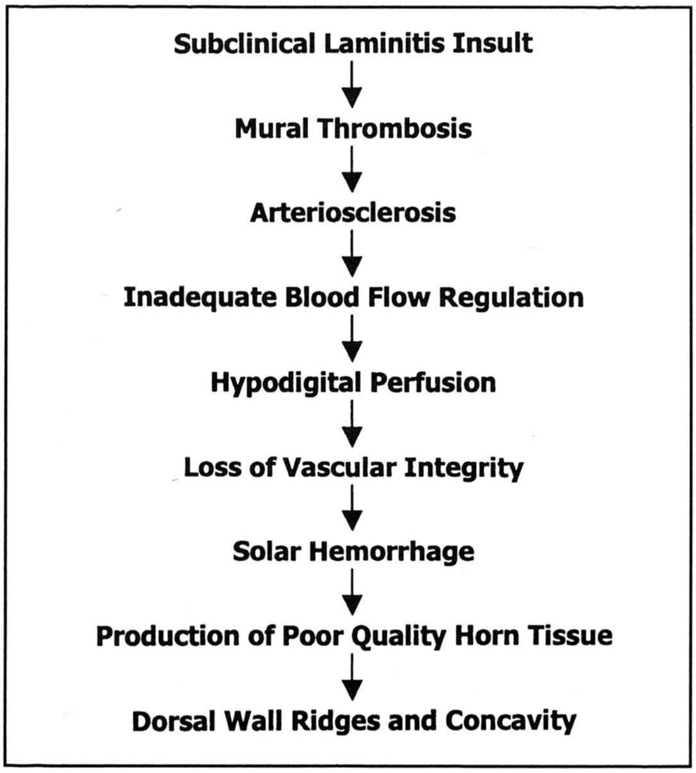

Figure 2. Development of hoof wall changes in cows with chronic laminitis.

A variety of hoof abnormalities have been attributed to subclinical laminitis.[6] Most common gross abnormalities include yellow sole discoloration, sole hemorrhage and ulceration, white line separation and heel erosion. Visible hoof lesions indicative of subclinical laminitis were identified in 15% to 85% of cows and 100% of 13 Ohio herds examined in a recent study.[18] Evaluation and ranking of subclinical laminitis between herds based upon the observed severity of hoof lesions was difficult because of the variety of lesions observed.[19] Sole hemorrhages are a sequel to vascular breakdown and hemorrhage of the capillary beds of the corium. Sole hemorrhage will not become externally visible until the affected sole has reached the external surface. Therefore, observation of sole hemorrhage is indicative of a historical event.

Application of Hoof Lesions to Disease Investigation

Pinpointing time of onset of such subclinical diseases as laminitis or other metabolic disorders can be helpful in targeting preventive health programs. Hoof appearance can be a good source of circumstantial evidence. In some instances, multiple sources of circumstantial evidence can be used to pinpoint the start of a problem. For example, in one herd investigation relating to lameness, hooves were examined during routine foot trimming. A number of animals were measured with "hardship grooves" approximately 3.8 cm (1.5 in) away from the hairline. Extrapolation of expected hoof growth patterns (5-6mm/month) suggested that the initial insult may have occurred 5-6 months earlier. Production records were supportive of this finding (Figure 3). Additional investigation focused on dietary changes during that time. While feed samples from that period were unavailable, examination of ration formulations revealed dietary fiber was inadequate during that period.

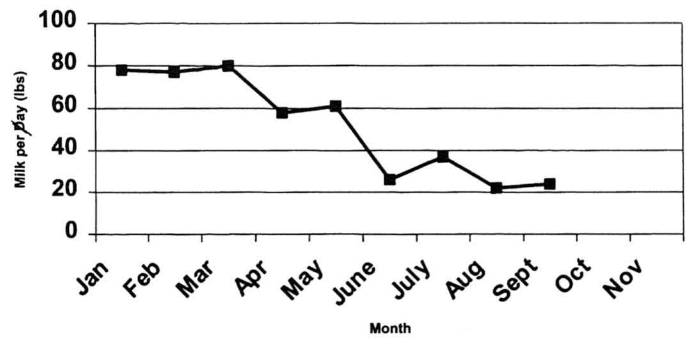

Figure 3. Milk production of a cow examined in November 1995.

Use of screening tests for the detection of subclinical disease is common in veterinary medicine. Both pathognomonic tests (such as culturing *Staphylococcus aureus* from milk samples) and surrogate tests (such as measuring non-esterified fatty acids (NEFA) in dry cows) are useful in subclinical disease investigations.[9] The appearance of horizontal grooves is recommended as a surrogate test for identification of subclinical problems but test characteristics have not been reported.[2,6] Both false positive and false negative test results can occur with surrogate tests (Figure 4).

An understanding of the sensitivity (ability of a test to correctly identify diseased animals) and specificity (ability of a test to correctly identify non-diseased animals) is necessary to properly interpret test results. Additionally, knowledge of the predictive values of a test is needed to estimate the likelihood of disease in test-positive or test-negative animals. To determine test characteristics of the use of horizontal grooves as a surrogate test, we examined 172 hooves from 86 lactating dairy cows from the University of Wisconsin – Madison dairy herd. The lateral claw of the right rear and right fore hooves were cleaned, photographed and evaluated for horizontal grooves. A divider was used to measure

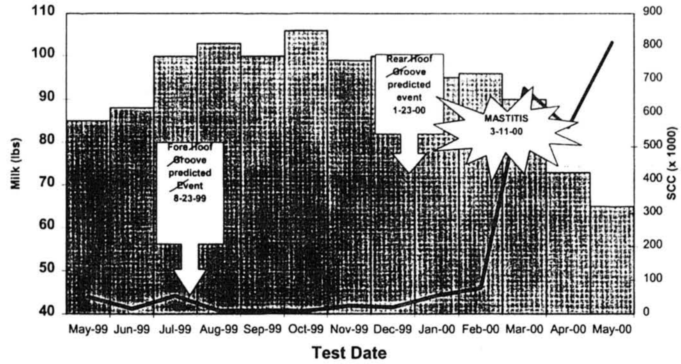

Figure 4. Milk production, somatic cell count (cells/ml) and predicted events for cow 4039.

the distance from the periople to the horizontal groove on the dorsal surface of the hoof wall. Individual cow records were searched and production, health and nutritional information was obtained for each animal. Test characteristics were calculated using Epi-Info.[4]

Descriptive Statistics and Test Characteristics of Horizontal Grooves

Animals in this study were high-producing cows in late lactation. Average parity was 2.5 lactations; average days in milk were 232; and aveerage milk production per-cow was 31.6 kg (69.5 lb). The 86 dairy cows experienced 397 events. Events included in the study were: 1) begin feed trial; 2) end feed trial; 3) clinical mastitis; 4) facility change that included major nutritional change; 5) calving; 6) displaced abomasums; 7) diarrhea; 8) ketosis; 9) general illness; 10) early embryonic death or abortion. Horizontal grooves were present on the hooves of most animals, indicating that most animals had been exposed to some type of metabolic stress. Since most animals in this herd are used in multiple feed trials, this finding should not be considered as representative of commercial dairy operations.

The *sensitivity* of a test is its ability to correctly detect events or diseases and is calculated as the proportion of animals with the event or disease that test positive. Test *specificity* is the ability to correctly detect animals without the disease or event. Specificity is calculated as the proportion of animals without the event of interest that test negative. Additional information about the usefulness of screening tests is learned from *predictive values*. The positive predictive value of a test estimates the proportion of test-positive animals that truly have the event of interest. The negative predictive value estimates the proportion of test-negative animals that truly do not have the disease or event of interest.

In this study, test characteristics were calculated by comparing the ability of the test (measurement of a horizontal groove) to correctly detect selected events that occurred within a defined time period (Figure 5). Test characteristics were calculated for the ability of the groove to detect any 1 of 4 events in Jan, Feb or March 2000: 1) put on a nutritional trial, 2) treatment of clinical mastitis, 3) changed facility or 4) diagnosed with displaced abomasum. Test characteristics were calculated using measurements from the right rear hoof only, the right fore hoof only, grooves on either hoof, or grooves on both hooves. Test characteristics were also calculated for detection of events in January through March, within 31 days of which they were predicted, based upon hoof groove measurements.

Hoof grooves were able to correctly detect the occurrence of an event 28% to 56% of the time (Table 2). As expected, sensitivity was lowest when the most rigor was applied to the test. For example, when grooves on both feet were required for a positive test, and the prediction window (time period allowed for event to occur to be considered accurate) was +/- 31 days, the sensitivity of hoof grooves was only 28%. In contrast, when a single groove on either foot was considered evidence of

		Experienced Event in Jan-March[2]				
		Yes		No		
Groove in either foot indicating events in Jan-March[1]	Yes	27	A	6	B	33
	No	21	C	32	D	53
		48		38		86

Sensitivity	56.3%	A/(A+C)
Specificity	84.2%	D/(B+D)
Predictive Value of Positive Test	81.8%	A/(A+B)
Predictive Value of Negative Test	60.4%	D/(C+D)

[1]grooves measuring 10-24 mm from periople at the date of sampling in May 2000; [2]events included initiation of nutritional research trial; clinical mastitis regardless of severity; or displaced abomasum

Figure 5. Calculation of test characteristics of measuring hoof grooves to detect selected events, January – March, 2000.

a historical event and the event was allowed to occur any time within the 3-month time period, hoof grooves correctly identified 56% of the selected events. When the prediction window was wide (event could occur any time within the 3-month period of interest), animals with grooves were 5-6 times as likely to have experienced one of the selected events as compared to animals that did not have a groove. When the window was narrow (within 30 days of prediction), there was no significant relationship between the hoof groove and the events unless matching grooves appeared on both feet (Table 2). The inaccuracy of hoof measurement and variable hoof growth rates probably contributed to this discrepancy. It is likely that sensitivity was limited by the lack of discrimination within this data regarding severity of illness. For example, clinical mastitis that required only intramammary antibiotic infusions was not differentiated from severe clinical mastitis requiring systemic therapy. Disruptions of hoof growth occur more commonly with more serious conditions.

In some instances the specificity of using hoof grooves for disease detection was quite acceptable. When grooves on both feet had to agree about a prediction, >90% of animals without the selected events did not have grooves.

Conclusions

Dairy cow hooves grow at a rate of about 5-6 mm/month (0.25 in) and growth rates are subtly affected by a number of influences. Subclinical laminitis and other metabolic insults to horn hoof growth can result in visible horizontal grooves that can be measured to provide an approximate time when events may have occurred. In this data, the sensitivity of hoof measurement as a test to detect historical events was generally low, but this finding may have been due to limitations in the data regarding disease severity.

Specificity of horizontal grooves used as a diagnostic test was relatively high for selected events. If the test characteristics reported in this study are applicable to the broader population of dairy herds, the lack of observable hoof grooves in low-prevalence herds or groups would be acceptable circumstantial evidence that major events had not occurred. Likewise, in a herd or group of animals in which it was suspected that there was a high prevalence of events (such as acidosis/laminitis), the identification of hoof grooves may be acceptable confirmatory evidence of metabolic insults.

This data was obtained from a university research herd that experienced a high prevalence of feed-related events. Data from commercial dairy operations would more clearly reflect the true epidemiology of hoof horn health on dairy farms.

References

1. Berman A, Volcani R: Seasonal and regional variation in coat characteristics of dairy cattle. Aust J Agric Res 12:528, 1961.
2. Boosman R, Nemeth F, Gruys E, Klarenbeek A: Arteriographical and pathological changes in chronic laminitis in dairy cows. Veterinary Quarterly 11:144-155, 1989.
3. Clark AK, Rakes AH: Effect of methionine hydroxy analog supplementation on dairy cattle hoof growth and composition. J Dairy Science 65: 1493-1502, 1982.
4. Epi Info vers. 6.04. 1997. Center for Disease Control. Available

Table 2. Test characteristics of hoof grooves in a university research herd for events[1] occurring in January through March 2000

Prediction Window	Hoof	Sensitivity	Specificity	Predictive Value (+)	Predictive Value (-)	Odds Ratio	P
Any time in period[2]							
	Rear	45.7%	87.5%	80.8%	58.3%	5.88	0.001
	Fore	41.3%	89.7%	82.6%	56.5%	6.16	0.001
	Either	56.3%	84.2%	81.8%	60.4%	6.86	0.000
	Both	29.8%	92.3%	82.4%	52.2%	5.09	0.010
Within 31 days of prediction[3]	Rear	36.1%	74.0%	50.0%	61.7%	NS	0.31
	Fore	34.2%	79.2%	56.5%	60.3%	NS	0.164
	Either	47.2%	68.0%	51.5%	64.2%	NS	0.152
	Both	27.9%	90.7%	75.0%	55.7%	3.77	0.027

[1]events included initiation of feeding trials; facility change that included major dietary change; clinical mastitis, regardless of severity; or diagnosis of displaced abomasum. [2]a groove was considered to accurately detect an event if both occurred during January-March. [3]a groove was considered to accurately detect an event if the event occurred within 30 days of a prediction in Jan-March

online: www.cdc.gov/epo/epi/epiinfo.htm.
5. Greenough PR, Vermunt JJ, McKinnon JJ, *et al*: Laminitis-like changes in the claws of feedlot cattle. Can Vet J 31:202-208, 1990.
6. Greenough PR, Weaver AD: Lameness in Cattle, 3rd ed Philadelphia, PA, WB Saunders Co, 1997.
7. Greenough PR, Schugel LL, Johnson AB: Horizontal grooves and fissures in Zinpro Corp. Illustrated Handbook on Cattle Lameness. Zinpro Corp. USA, 1995, pp 16-17.
8. Hahn MV, McDaniel BT, Wilk JC: Rates of hoof growth and wear in Holstein cattle. J Dairy Sci 69:2148-2156, 1986.
9. Martin SW, Meek AH, Willeberg P: Veterinary Epidemiology. Iowa State Press, Ames IA, 1987.
10. Manson FJ, Leaver JD: The influence of dietary protein intake and of hoof trimming on lameness in dairy cattle. Anim Prod 47:191-199, 1988.
11. Nocek JE: Bovine acidosis: implications on laminitis. J Dairy Sci 80:1005-1028, 1997.
12. Nordlund KV: Herd based rumenocentesis: a clinical approach to the diagnosis of subacute rumen acidosis, in R Saltman. (ed.) Northeast Prod Med Symp. Syracuse, NY, 1995, p 1.
13. Phillips CJC, Patterson SJ, Dewi IA: Volume assessment of the bovine hoof. Res Vet Sci 61:125-128, 1996.
14. Prentice DE: Growth and wear rates of hoof-horn in Ayrshire cattle. Research in Vet Sci 14:285-290, 1973.
15. Randy HA, Sniffen CJ, Nocek JE, Wildman WW *et al*: Effect of zinc methionine supplementation on milk yield, lameness and hoof growth in lactating dairy cows. J Dairy Sci 68 (supp 1):277, 1985.
16. Reilly JD, Brooks PH: The effect of supplementary dietary biotin on hoof hardness and hoof growth and wear rates of dairy cows. Proc 8th International Symp on Diseases Rum. Digit, Liverpool, 254 (abs), 1990.
17. Sisson S: Common Integument, in Getty R. The anatomy of the domestic animals. 5th ed. 1975. WB Saunders. Co, 1910, pp 1208-1211.
18. Smilie RH, Hoblet KH, Weiss WP, Eastridge ML *et al*: Prevalence of lesions associated with subclinical laminitis in first-lactation cows from herds with high milk production. J Am Vet Med Assoc 208:1445-1451, 1996.
19. Smilie RH, Hoblet KH, Eastridge ML, Weiss WP *et al*: Subclinical laminitis in dairy cows: use of severity of hoof lesions to rank and evaluate herds. Vet Rec 144:17-21, 1999.
20. Tranter WT, Morris RS: Hoof growth and wear in pasture-fed dairy cattle. New Zealand Vet J 40:89-96, 1992.
21. Toussaint RE: Determination of weight bearing by the bovine foot. Neth J Vet Sci. 5:99-103, 1973.
22. Vermunt JJ, Greenough PR: Predisposing factors of laminitis in cattle. Brit Vet J 150:151-164, 1994.
23. Vermunt JJ, Greenough PR: Structural characteristics of the bovine claw: horn growth and wear, horn hardness and claw conformation. Brit Vet J 151:157-180, 1995.