Assessment of bovine hoof conformation and its association with lameness, animal factors and management practices on small-scale dairy farms in Kiambu district, Kenya

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ABSTRACT

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Digital health and conformation were assessed in 216 dairy cattle on 78 randomly selected small-scale farms. For each cow, gait was assessed and the digits examined in detail. Hoof measurements (angle and length of the dorsal hoof wall, heel depth and hoof-base area) were also made.

Hoof measurements varied most between individual cattle. Dorsal angle was correlated with heel depth ($r = 0{,}53$; $P = 0{,}001$) and dorsal length ($r = -0{,}40$; $P = 0{,}001$). The hoof-base area was correlated with the dorsal length ($r = 0{,}41$; $P = 0{,}001$). There were significant breed differences in dorsal angle ($P = 0{,}03$) and dorsal length ($P < 0{,}01$). The dorsal angle was correlated with parity and body condition, while the dorsal length, heel depth and the hoof-base area were correlated with the heart girth ($P < 0{,}01$).

Hoof conformation was associated with both clinical lameness and hoof lesions. A 1-cm increase in the dorsal length increased the odds of lameness by 16,9, heel erosion by 1,8, underrunning by 5,4 and overgrowth by 40 ($P < 0{,}01$).

Keywords: Dairy cattle, hoof conformation, lameness

INTRODUCTION

Abnormal hoof conformation can be considered either a risk factor for foot lameness (Greenough 1991) or an important step in its pathogenesis (Toussaint-Raven 1985; Peterse 1986a). Conformational abnormalities may be congenital or acquired. Acquired abnormalities may result from excessive and/or abnormal wear and tear of digital tissues or from foot diseases such as chronic laminitis (Greenough, MacCallum & Weaver 1972). Conformational abnormalities may cause clinical lameness by themselves (Greenough, MacCallum & Weaver 1972), but what is more important is that they predispose to other digital conditions which, in turn, cause clinical lameness (Rebhun & Pearson 1982) and the attendant loss in animal productivity (Weaver 1986; Vermunt & Greeenough 1995).

On most small-scale farms, cattle are confined to small paddocks or sheds all year round. In addition to the confinement, they are also subjected to altered diets, physical environment and management. Such changes have been associated with an increased incidence of lameness (Gitau 1994) and are also likely to result in abnormal conformation owing to alteration in the nature and amount of stress exerted on the digital tissues. Indeed, abnormal digital conformation may be an underlying process in the causal mechanisms of clinical lameness in small-holder dairy cattle.

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The normal conformation of bovine digits has been well described (Toussaint-Raven 1985). On a flat, hard surface, the digit contacts the ground, mainly at the distal edge (*margo solearis*) of the dorsal and abaxial hoof wall and at the heel (Toussaint-Raven 1985). The two main digits on a limb are usually of the same size and the toes almost touch, except during mass bearing when they diverge slightly (Greenough *et al.* 1972). The digit bears mass most efficiently when the dorsal hoof wall, which is about 7 cm long (Weaver 1986), lies at an angle of 50–55° to the horizontal (Greenough *et al.* 1972).

Hoof conformation can be objectively characterized by measuring the angle and dorsal length of the dorsal hoof wall, the depth of the heel and the area at the base of the hoof (Hahn, McDaniel & Wilk 1984a). Except for heel depth, these measurements can be determined accurately and repeatably (Smit, Verbeek, Peterse, Jansen, McDaniel & Politiek 1986). This study was conducted to assess the conformation of cattle kept on small-scale farms, and these measurements were used to assess how conformation relates to the prevalence of lameness and digital lesions, and various management, farm and animal factors.

MATERIALS AND METHODS

One hundred small-scale dairy farms were selected from the registry lists of three dairy societies in Kikuyu Division of Kiambu District in Kenya, and random numbers were used. Of these, seven had shortly sold all their cattle, five were not considered small-scale (ten or fewer cattle and less than 5 ha of farmland), five could not be located, three had inadequate facilities for hoof examination and two refused to participate. The remaining 78 farms were visited in March 1993. During the farm visits, data on housing, management, nutrition and signalment of cattle were collected. A general physical inspection and detailed clinical examination of the locomotor system (Tranter & Morris 1991; Rebhun & Pearson 1982) was conducted on all cattle. A clinical lameness-scoring system as described by Wells, Trent, Marsh, McGovern & Robinson (1993) was used. Cattle with a lameness score of 2 (moderate and consistent gait abnormality, but able to walk without continuous stimulation) or nore were considered to be clinically lame. In addition, heart girth was measured, body condition scored by use of the five-point score described by Radostits & Blood (1985) and reproductive status of females determined by rectal examination.

Each foot (fetlock and below) was cleaned with a brush and water and placed on a plastic board lined with a rubber mat. The four hoof measurements, dorsal angle, dorsal length, heel depth and hoof-base area, and estimation methods used by Hahn *et al.* (1984a), were adopted. In brief, the dorsal angle was measured with an abney level modified by attaching two prongs, 3 cm apart, at its base. The first prong was always placed at the lower margin of the periople and the second, midway along the dorsal hoof wall as described by Hahn *et al.* (1984b). The level was then placed on the board alongside the abaxial wall of the lateral digit to determine the angle of the board to the vertical. This was used to adjust each dorsal-angle measurement for the slope of the ground on which the digit was placed. To determine the hoof-base area, three measurements (width at the palmar surface, width at the plantar surface and distance from the lateral aspect) were taken with a calliper at the level of the coronet just above the periople, as described by Hahn *et al.* (1984a). The area was calculated as the average width multiplied by breadth.

After all measurements had been taken and recorded, the limb was lifted off the ground to examine the bearing surface and the interdigital cleft for lesions. A thin layer of horn was pared off from the bearing surface to expose any changes in colour, texture or continuity of the horn. Hoof pincers (testers) were used to apply pressure to all hoof surfaces to detect abnormally sensitive areas.

Data were entered and edited on DBASE-IV (1988. Ashton-Tate Corporation, 20101 Hamilton Ave. Torrance, CA, USA) and analyzed with the use of SAS (1988. Statistical Analysis System Institute, Cary, NC 27512-8000, USA) and STATISTIX (1992. Analytical Software, Box 130204, St. Paul, MN 55113 USA) programs. The relative importance of the farm, individual animal, limb or digit (medial or lateral) as a source of variation in hoof measurements, was determined by comparing the variance components estimated under restricted maximum likelihood (PROC VARCOMP; SAS 1988).

Partial Pearson's correlations were used to describe correlations between hoof measurements. Associations between hoof measurements and individual animal characteristics were estimated by means of T-tests and ANOVA for discrete variables, and Pearson's correlation for continuous variables. Associations between hoof measurements and the occurrence of lameness and foot lesions were modelled by means of logistic regression. All main effects and two-way interactions were investigated.

As the deviance is not a reliable measure for binary models, Sommer's D (Collet 1991), which estimates the correlation between the observed and predicted probabilities, was used as a measure of goodness-of-fit. The adequacy of the fitted models was assessed by the use of index plots of standardized Pearson's and deviance residuals and the hat matrix diagonal elements (leverage) as described by Collet (1991). The contribution of individual observations to the parameter estimates were assessed by the use of index plots of the delta-beta statistic (Pregibon 1981).

RESULTS

Hoof measurements

The mean hoof measurements for all cows and for cows subdivided by housing system are presented in Table 1. Cows kept under zero-grazing (total confinement) had smaller dorsal angles, longer dorsal lengths and shallower heels than other cows.

The largest percentage of variation for most hoof measurements was between individual cows (58,3–75,6%), except for the dorsal length of the dorsal wall in which 54,7% of the variation was between herds (Table 2). The only significant between-digit variation was in the hoof-base area, which differed between the fore and the hind digits (fore = 70,21 ± 0,53 cm^2; hind = 65,91 ± 0,50 cm^2; $P < 0,001$).

Dorsal angle was correlated with heel depth (r = 0,53; $P = 0,001$) and dorsal length (r = –0,40; $P = 0,001$) while hoof-base area was correlated with the dorsal length (r = 0,41; $P = 0,001$). The correlation between the dorsal angle and the hoof-base area was not significant when controlled for hoof length (r = –0,09, $P = 0,188$). Likewise, neither was that between heel depth and dorsal length when controlled for the dorsal angle (r = –0,07, $P = 0,32$).

TABLE 1 Descriptive statistics of 1728 digit measurements from 216 cows on the 78 small-scale dairy farms, classified by type of housing

Hoof measurements	Pasture	Paddock	Tether	Zero-grazed	Overall
Dorsal angle	49,31[a] (0,99)*	50,14[a] (0,72)	49,87[a] (0,91)	48,16[b] (1,15)	49,21 (0,52)
Dorsal length	6,92[a] (0,18)	6,70[b] (0,07)	6,90[a] (0,18)	7,04[a] (0,25)	7,25 (0,11)
Hoof depth	2,49[a] (0,08)	2,52[a] (0,08)	2,52[a] (0,08)	2,37[b] (0,08)	2,59 (0,04)
Hoof-base area	63,31[a] (2,73)	65,31[a] (1,84)	71,50[b] (1,82)	63,75[a] (1,82)	68,08 (0,95)

Means with different superscripts (a,b) are significantly different ($P < 0,05$)

* Standard error of the mean adjusted for clustering

TABLE 2 Estimated percentage of variance of digit measurements attributed to herd, cow, limb, and digit levels for 1728 digit measurements from 216 cows on the 78 small-scale dairy farms

Measurement	Variance component (%)*				
	Herd	Cow	Limb	Digit	Error
Dorsal angle	23,3	75,6	0,0	0,0	1,1
Dorsal length	54,7	25,3	0,0	0,0	20,0
Heel depth	30,0	58,3	0,0	0,0	11,7
Hoof-base are	5,8	61,3	5,4	0,0	27,5

* Calculated as the percentage of the total variance that is attributable to that level

Association with individual animal factors

The dorsal angles differed between breeds ($P = 0,033$), with the cross-bred animals having the steepest dorsal wall (50,61 ± 0,46°) followed by the Ayrshire, Friesian, Guernsey and then the Jersey (46,94 ± 1,19°). The dorsal angle was also associated with the body-condition score ($P < 0,001$). Cattle with a

TABLE 3 Linear regression models for average hoof measurements of 216 dairy cattle on the 78 small-scale farms

Variable[a]	Coefficient	S.E.	P-value[b]	Model R^{2}[bc]
A. Model for average dorsal angle				
Intercept	45,94	2,05	0,000	
Dorsal length[d]	1,04	0,20	0,000	
Heel depth[d]	10,28	0,58	0,000	
Hoof-base area[d]	–0,00	0,02	0,824	0,41
Parity	–1,31	0,07	0,000	0,66
Body score	–2,40	0,21	0,000	0,82
Heart girth	–0,13	0,02	0,000	0,85
B. Model for average dorsal length				
Intercept	–3,16	1,28	0,014	
Dorsal angle[d]	0,11	0,02	0,000	
Heel depth[d]	–2,51	0,25	0,000	0,31
Hoof-base area[d]	0,01	0,01	0,096	0,48
Heart girth	0,06	0,01	0,000	0,53
Breed[e]				
Friesian	–0,00	0,12	0,978	
-Ayreshyre	–0,08	0,17	0,635	
-Jersey	0,50	0,15	0,001	
-Guernsey	–0,11	0,20	0,580	
Parity	0,13	0,04	0,001	0,55
Body score	0,19	0,09	0,026	0,56
C. Model for average heel depth				
Intercept	–2,67	0,23	0,000	
Dorsal angle[d]	0,06	0,00	0,000	
Dorsal length[d]	–0,14	0,01	0,000	
Hoof-base area[d]	–0,00	0,00	0,843	0,50
Heart girth	0,02	0,00	0,000	0,76
Parity	0,07	0,01	0,000	0,79
Body score	0,12	0,02	0,000	0,83
D. Model for hoof-base area				
Intercept	–11,08	10,16	0,277	
Dorsal angle[d]	–0,26	0,14	0,069	
Dorsal length[d]	1,05	0,66	0,110	
Heel depth[d]	1,21	2,58	0,639	0,43
Heart girth	0,54	0,07	0,000	0,56
Body score	–2,22	0,66	0,001	0,58

a Covariates in the order of entry into the model

b P for Ho: $\beta = 0$ in the final model

c Model R^2 after addition of covariate

d Variables forced into the model prior to the entry of other variables

e Crosses are the reference level

TABLE 4 Digit-level factors in 216 dairy cattle on the 78 small-scale dairy farms

Risk factor	Total number	Number of lameness cases[a]	Number of digits with lesion			
			Heel erosion	Underrunning	Flat sole	Overgrowth
Limb						
right fore	432	15[b]	30	37	28	20
left fore	432	14[b]	30	36	28	18
right hind	432	27	34	34	33	22
left hind	432	27	34	34	30	20
Digit						
medial	864	40	64	71	58	39
lateral	864	43	64	70	61	41
Dorsal angle						
≤ median (51°)	1 177	70[c]	110[c]	85[c]	79	65[c]
> median	551	13	18	56	40	15
Dorsal length						
≤ median (7 cm)	1 031	20[c]	58[c]	41[c]	89[c]	16[c]
> median	697	63	70	100	30	64
Heel depth						
≤ median (2,5 cm)	1 000	64[c]	89[c]	66	73	72[c]
> median	728	19	39	75	46	8
Hoof-base area						
≤ median (65,6 cm^2)	886	44[c]	52[c]	34[c]	52	46
> median	842	39	76	107	67	34

[a] Coronet and interdigital lesions considered to involve both digits
[b] Number of lameness cases significantly different ($P < 0,05$) between fore and hind limbs
[c] $P < 0,05$ for Student's *T*-test of equality of means

higher score (3 and 4) had smaller dorsal angles (47,96 ± 0,53° and 43,27 ± 2,94°, respectively) than those with lower scores (52,30 ± 0,94° and 50,17 ± 0,50° for scores 1 and 2, respectively).

On average, the Jersey breed had longer dorsal walls (7,83 ± 0,33 cm) than the other breeds (Friesian = 7,03 ± 0,07 cm; Ayrshire = 7,20 ± 0,13; Guernsey = 6,93 ± 0,11; Crosses/others = 7,05 ± 0,08; $P < 0,001$). Non-pregnant animals also had longer dorsal walls (7,25 ± 0,09 cm) than the pregnant ones (6,98 ± 0,08 cm; $P = 0,022$).

Heart-girth and body-condition score were associated with the dorsal length and angle of the dorsal wall, heel depth and hoof-base area (Table 3). Parity was associated with the dorsal angle, dorsal length and heel depth. A 10-cm increase in heart girth decreased the dorsal angle by 1,3°, increased the dorsal length by 0,6 cm, heel depth by 0,2 cm and hoof-base area by 5,4 cm^2. A unit increase in the five-point body-condition score reduced the dorsal angle by 2,4° and hoof-base area by 2,22 cm^2. Dorsal length and heel depth, however, increased with increasing body condition (0,19 and 0,12 cm, respectively, for a unit increase).

Association with lameness

The distribution of clinical lameness and foot lesions by potential digit-level risk factors is shown in Table 4. Most (16/25 = 63,6 %) of the clinically lame cattle had hind-limb lesions. Subclinical lesions were also more prevalent in the hind limbs than in the fore, but the difference was not statistically significant (26,6 % vs 31,5 %; $P = 0,1156$). In the logistic models lameness, heel erosion, underrunning and overgrowth were associated with the dorsal length (Table 5). The dorsal angle was positively associated with flat soles, but negatively associated with overgrowth and heel erosion. Hoof-base area was positively associated with flat soles and underrunning, but negatively associated with overgrowth. The depth of the heel was associated only with underrunning.

A digit was 16,9 times more likely to be lame ($P < 0,01$), 1,8 times more likely to have heel erosion ($P < 0,01$), 5,4 times more likely to be underrun ($P < 0,01$) and 40 times more likely to be overgrown ($P < 0,01$) than one which had a dorsal wall shorter by 1 cm. A degree increase in the dorsal angle reduced the odds of heel erosion ($P < 0,01$) and of overgrowth ($P < 0,01$) by a factor of 0,8, but increased the odds of flat soles 1,1 times ($P < 0,01$).

DISCUSSION

In contrast to the study by Hahn *et al.* (1984b), variation in hoof measurements was greater between individuals than between herds/farms. This may have been owing to the small herd sizes, which reduced the power of herd-to-herd comparisons. It may also be that management, environmental and housing

TABLE 5 Digit-level logistic regression models for lameness and lesions in 216 dairy cattle on the 78 small-scale farms

Variable	Coefficient	S.E.[a]	*P*-value	95% CI (OR)[b]
A. Model for lameness				
Intercept	–11,79	1,15	0,000	
Dorsal length	2,83	0,36	0,000	8,37– 34,32
B. Model for heel erosion				
Intercept	3,06	0,96	0,002	
Dorsal angle	–0,15	0,02	0,000	0,83–0,90
Dorsal length	0,57	0,17	0,001	1,27–2,47
C. Model for underrunning				
Intercept	–12,45	1,49	0,000	
Dorsal length	1,69	0,25	0,000	3,32–8,85
Heel depth	2,97	0,99	0,003	2,80–135,69
Hoof-base area	0,18	0,07	0,006	1,04–1,37
D. Model for flat sole				
Intercept	–1,95	2,10	0,322	
Dorsal angle	0,07	0,03	0,013	1,01–1,14
Dorsal length	–2,52	0,50	0,000	0,03–0,21
Hoof-base area	0,26	0,07	0,000	1,13–1,49
E. Model for heel erosion				
Intercept	–8,25	2,66	0,000	
Dorsal angle	–0,05	0,03	0,042	0,90–1,01
Dorsal length	3,7	0,52	0,000	14,60–112,08
Hoof-base area	–0,34	0,14	0,004	0,54–0,94

[a] Standard error of parameter estimates
[b] 95% confidence interval for odds ratio

factors that influence hoof conformation did not vary significantly between the farms/herds. One of the management factors that would contribute to inter-herd variation is hoof trimming. In this study, none of the farms practised routine hoof trimming.

It has been suggested (Eddy & Scott 1980; Russell, Rowlands, Shaw & Weaver 1982; McLennan 1988) that the fore and hind digits, and the lateral and medial hind digits differ in shape and size, and that large differences in these can predispose to lamenesss. As noted in a recent review (Vermunt & Greenough 1995), no consistent pattern of size or shape variations between different digits has been recognized. In this study, digital measurements of an individual animal tended to be similar, except for the hoof-base area, in which the fore limbs had a larger area than the hind ($P < 0,01$). The hind limbs were more often lame than the fore, but there was no difference in the involvement of the medial and lateral hind digits. Although occurrence of clinical lameness was significantly ($P < 0,01$) associated with a smaller hoof-base area, it is difficult to determine whether hoof-base area or other hind-limb factors were responsible.

The logistic models indicate that a digit with a more acute dorsal angle, which meant a longer dorsal wall and a shallower heel, was strongly associated with clinical lameness, heel erosion, underrunning and overgrowth. Cattle of the Jersey breed, whose digits had this unique conformation, were more susceptible to lameness and foot lesions than other breeds (Gitau, McDermott & Mbiuki 1996). Peterse (1986b) found the length and angle of the dorsal wall to be correlated with the severity of digital disorders, while Anderson & Lundstrum (1981) reported that cows affected by digital disease have longer toes and deeper heels. In another report, steep claws were found to have less numerous and less serious sole lesions (Smit *et al.* 1986). The findings in the current study are in agreement with these reports, but they also indicate a relationship between the dorsal length, dorsal angle and heel depth. These measurements were highly correlated, even in clinically normal hooves.

Normal locomotion requires short dorsal hoof walls and steep dorsal angles (Manson & Leaver 1989). In such digits, the distal edges of the dorsal and abaxial wall contact the ground, reducing the mass borne by the heel and sole (Toussaint-Raven 1985). The correlations between hoof measurements in this study indicate that when the dorsal wall is too long, the hoof is tilted backward, so that the dorsal angle is more acute and the heel is shallow. In such a digit, mass would be borne mainly by the heels. Shallow, overloaded heels are more liable to injury (Amstutz 1965), while the interdigital skin in such feet is more exposed to filth, moisture and infection. This may explain why digits with this conformation were often lame or had lesions.

A digit with a short dorsal wall often had a less acute dorsal angle and a deeper heel. In these digits, most of the mass would be borne by the dorsal and abaxial hoof walls. The consequent wear of the hoof wall makes the dorsal angle even less acute and exposes more of the sole and the rest of the bearing surface to wear. This possibly explains the association between flat soles and less acute dorsal angles.

In this study, hoof measurements were made when the animals became lame, and it cannot be determined whether abnormal hoof measurements preceded or followed lameness. The associations presented are indicative of what would be seen on a single clinical visit. Further data acquired over a period of time are required to determine the nature of the associations observed. The associations between hoof measurements and various individual-animal factors such as breed, age, parity, body-condition score and heart girth tend to support the suggestion (Toussaint-Raven 1985; Peterse 1986a) that change in digital conformation may be part of a mechanism through which these factors predispose to lameness.

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