Short communication: Changes in gait symmetry in healthy and lame dairy cows based on 3-dimensional ground reaction force curves following claw trimming

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ABSTRACT

Lameness is a frequent health problem in dairy cows. This preliminary study aimed to detect gait differences between healthy and lame walking cows using 3-dimensional force plates. We examined left–right leg symmetry changes of healthy and lame Holstein dairy cows following claw trimming. Gait scoring (GS) was performed on d –5, 0, 1, and 7 relative to claw trimming. Before the experiment, 5 cows walked normally (initial GS = 1) and 4 cows limped moderately on a hind leg (initial GS = 3). Gait was measured on d –2, –1, 0, 1, and 7 relative to trimming by obtaining ground reaction forces as cows walked repeatedly across 2 parallel 3-dimensional force plates. From the ground reaction forces, stance phase data were derived using computerized procedures. Left–right leg symmetries of entire curves in the 3 force directions were calculated. Effects of lameness and trimming were analyzed in a mixed model, using a low lameness threshold (GS > 1). One week after claw trimming, only one cow was mildly lame. In addition, the symmetries of all 3 dimensions were significantly improved shortly after trimming. Importantly, lameness significantly worsened vertical symmetry. Lame cows walked significantly more slowly than healthy cows. In conclusion, all force symmetries seemed capable of detecting gait responses to claw trimming. Although our results are based on a small number of animals, vertical leg symmetry was affected by lameness.

Key words: gait analysis, lameness

Short Communication

Lameness is a serious health problem in dairy cows, with a reported mean herd prevalence up to 55% in the United States (von Keyserlingk et al., 2012). Lameness causes milk loss, reduced fertility, and treatment costs (Cha et al., 2010) and is associated with pain (Bicalho et al., 2007). Regular claw trimming improves gait score (GS) and decreases prevalence of clinical lameness (Manske et al., 2002), although GS may be aggravated immediately after trimming (Chapinal et al., 2010a). We performed a claw trimming to experimentally alter the cows' gait.

Different automated lameness detection methods using force-derived data have been proposed for cattle. For instance, one system automatically detected hind-leg lameness from vertical forces in cows walking across 2 parallel force plates (Rajkondawar et al., 2006). Another system let heifers walk across a pressure plate and demonstrated better right–left leg symmetry of the vertical force in animals without claw lesions compared with animals with foot lesions (Almeida et al., 2007). Also, mildly lame cows could be distinguished from healthy cows walking on a pressure mat (Van Nuffel et al., 2013). Until now, no studies have used 3-dimensional (3D) curve symmetries to distinguish between healthy and lame cows.

Our study aimed to detect left–right leg curve symmetry differences between healthy and lame cows walking across 3D force plates. We hypothesized that lame cows would exhibit less symmetry than healthy cows, and that 3D forces would detect symmetry changes following a claw trimming.

Nine Danish Holsteins were included in this preliminary study: 4 primiparous cows weighing 580 ± 22 kg and 5 multiparous cows weighing 616 ± 29 kg. Cows were 36 ± 13 d postcalving with an average ECM yield of 39 ± 5 kg/d. Cows were housed on rubber mats in the tiestall facilities of the Department of Animal Science, Aarhus University, without access to pasture.

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They were milked and fed a TMR ad libitum twice a day.

Animal procedures were approved by the Danish Animal Experiments Inspectorate and complied with the Danish Laws concerning animal experimentation and care of experimental animals.

Cows were trimmed on the same day by the same certified and experienced hoof-trimmer. Immediately after trimming, an experienced veterinarian (not the same as the hoof-trimmer) scored all 4 feet for the following claw lesions: white line disease, double sole, foot rot/interdigital necrobacillosis, sole hemorrhage, sole ulcer, heel-horn erosion, interdigital dermatitis, digital dermatitis, and interdigital skin hyperplasia, as defined by Manske et al. (2002). The first 3 types were scored as absent or present and the rest were scored as absent, mild, or severe. The hind feet diagnoses of the 4 lame cows were as follows: cow 1: severe interdigital skin hyperplasia in left foot, severe heel-horn erosion in both feet; cow 2: mild sole hemorrhage and mild sole ulcer and severe heel-horn erosion in left foot, mild sole ulcer and mild heel-horn erosion in right foot; cow 3: severe interdigital dermatitis and mild sole hemorrhage in right foot, severe sole hemorrhage and mild heel-horn erosion in left foot; and cow 4: white line fissure in right foot, mild heel-horn erosion in left foot. Heel-horn erosion was present in all 9 cows. Neither foot root nor double sole was found. All claw lesions are reported in Table 1.

On d -5, 0, 1, and 7 relative to claw trimming, GS was assessed by the same veterinarian who scored claw lesions. The veterinarian had extensive experience in gait scoring with an intraobserver variation calculated as weighted kappa at 0.75 to 0.85 in other studies, indicating good repeatability. On d 0, GS was assessed after claw trimming; a 5-point scale ranging from 1 to 5 was used (Sprecher et al., 1997).

Gait measurements took place on d -2, -1, 0, 1, and 7 relative to claw trimming. During measurement, cows walked freely and individually along a narrow aisle (width 1.0 m) across 2 parallel custom-designed 3D strain gauge force plates (Bertec Corp., Columbus, OH). Each force plate measured $0.46 \times 2.07 \text{ m}^2$. The force plates were covered by a 13-mm-thick rubber mat to provide sufficient friction for walking. Force plate dimensions allowed cows to make 2 to 4 stance phases on each plate. Two photocells 7.3 m apart recorded walking speed. Each cow completed 8 to 9 walking trials/day after morning milking. To prevent cows from stopping, a technician followed the cows at a distance of a few meters until reaching the first photocell. The force plates were placed in the aisle connecting the barn and the milking parlor, and on the first gait measurement day, cows were allowed to pass over the force plates twice to allow adaption.

From each force plate, vertical (F_v), longitudinal (F_l), and mediolateral (F_m) ground reaction forces and their corresponding moments were sampled at 2 kHz using a custom-made data acquisition system (Mr. Kick, Knud Larsen, Aalborg University, Denmark, based on National Instruments technology, Austin, TX). Force signals were low-pass-filtered at a cut-off frequency of 5 Hz using a fourth-order, zero-lag Butterworth filter (Matlab 2006, The MathWorks Inc., Natick, MA).

Data processing and statistical analysis was performed in R (R Development Core Team, 2013). The detection of full stance phases valid for data analysis and their classification as originating from either front or hind foot is described elsewhere (Skjoeth et al., 2013). Trials with walking speed $>2.0 \text{ m/s}$ were disregarded, as cows were considered to be hurrying. The total number of full stance phases was 1,123.

Symmetry parameters were calculated for each of the 3 force directions to compare the entire stance phase

Table 1. Number of claw lesions reported in number of affected cows, grouped by gait score, front and hind feet, and lesion severity (scored as absent, mild or severe), n = 9

Claw lesion	Gait score	Cows	Mild lesion		Severe lesion	
			Front	Hind	Front	Hind
Heel-horn erosion	1	5	0	8	0	1
	>1	4	2	3	0	3
Sole hemorrhage	1	3	2	2	0	0
	>1	4	3	2	0	1
Sole ulcer	1	0	0	0	0	0
	>1	2	2	2	0	0
Interdigital dermatitis	1	1	0	0	0	1
	>1	1	0	0	0	1
Digital dermatitis	1	2	0	2	0	0
	>1	0	0	0	0	0
Interdigital skin hyperplasia	1	0	0	0	0	0
	>1	1	0	0	0	1

Figure 1. Symmetry calculated from average hind-leg force curves of one cow sampled on the same day. Vertical (top), longitudinal (middle), and mediolateral (bottom) forces. The left column shows right (solid) and left (dashed) leg forces (N/kg) relative to stance time (%); the middle column presents phase plots of right versus left legs; here, a trace more parallel to the unity line gives a lower (better) symmetry; the right column illustrates the across-cows densities of symmetries (solid curve: front part, dotted curve: hind part) with a solid vertical line representing the symmetry of the selected cow.

Figure 2. The vertical force (N/kg) relative to stance time (%) from the hind legs (right leg: solid line, left leg: dashed line) of a lame cow (top row) and a healthy cow (bottom row) 2 d before trimming (left column) and 7 d after trimming (right column).

curves of the left and right legs (Crenshaw and Richards, 2006). The scale was 0 to 100, with lower values signifying better symmetry; that is, more parallel left and right leg curves. Thus, left and right leg curves were not required to be at the same level to be parallel. In Figure 1, symmetry is illustrated for the average hind-leg force curves of one cow sampled on the same day. The right side plots depict the symmetry of the example cow in relation to other cows.

The walking speeds of healthy and lame cows were analyzed using a *t*-test. Lame versus healthy classification was based entirely on GS. Data were compiled by cow, body part, and day, yielding 90 observations. Using the median, symmetry was tested in a mixed model using the lme4 R-package (Bates et al., 2011):

$$Y_{ijkl} = \text{GS}_i + \text{Trimming}_j + \text{Body Part}_k + (\text{Body Part} \times \text{GS})_{ik} + \text{cow}_l + e_{ijkl}$$

where Y_{ijkl} was the symmetry parameter of the $ijkl$ th observation; GS [i = healthy (GS 1), lame (GS 2 and 3)], Trimming [j = before (d -2 and -1), early after (d 0 and 1), 1 wk after trimming (d 7)], Body Part (k = front, hind), and the interaction between body part and GS were fixed effects. Cow ($l = 1, \dots, 9$) was a random effect, and e_{ijkl} was the residual term associated with the $ijkl$ th observation.

Five days before claw trimming, 5 cows walked normally (GS 1), whereas 1 primiparous cow and 3 multiparous cows were moderately lame (GS 3) on a

Table 2. Effects and *P*-values of claw trimming, gait score, and body part on 3-dimensional left–right leg symmetries (unitless; small values denote better symmetry) of vertical, mediolateral, and longitudinal force (F) directions, reported as least squares means (SE in parentheses)

Symmetry	Claw trimming		Gait score ¹		Body part	
F _{vertical}	Before	5.21 ^b (0.35)	Healthy	3.97 ^a (0.35)	Front	4.75 ^a (0.35)
	Early after	4.73 ^a (0.35)	Lame	5.61 ^b (0.37)	Hind	4.83 ^a (0.35)
	1 wk after	4.44 ^a (0.37)	—	—	—	—
<i>P</i> -value		<0.001		<0.001		0.29
F _{mediolateral}	Before	11.09 ^b (0.87)		Front		Hind
	Early after	10.58 ^a (0.87)	Healthy	8.42 ^a (0.88)		12.44 ^a (0.88)
	1 wk after	10.73 ^{ab} (0.89)	Lame	8.80 ^a (0.91)		13.55 ^b (0.91)
<i>P</i> -value		0.009		0.019		
F _{longitudinal}	Before	13.97 ^b (1.39)		Front		Hind
	Early after	13.07 ^a (1.39)	Healthy	15.37 ^a (1.40)		15.60 ^b (1.40)
	1 wk after	14.31 ^b (1.42)	Lame	12.79 ^a (1.45)		11.37 ^a (1.45)
<i>P</i> -value		<0.001		<0.001		

^{a,b}Means within a column and symmetry parameter with different superscripts differ.

¹Gait score: healthy = 1; lame >1. The gait score × body part interaction is reported when significant, in which case main effects are not reported.

hind leg. Trimming decreased the lame cows' GS but did not change the healthy cows' GS. Hence, 7 d after trimming, 1 cow out of 4 moderately lame cows was mildly lame (GS 2), and the remaining cows walked normally. Consequently, the improvement in GS of the lame cows was likely due to the health-restoring effect of claw trimming. This supports previous findings of decreased pain thresholds immediately after trimming claws with lesions (Dyer et al., 2007). Our study revealed 2 severe lesions and several mild lesions in the hind feet of healthy cows, supporting Manske et al. (2002), who showed that not all claw lesions are associated with lameness. We trimmed the cows to induce a gait change and to examine how 3D symmetries would change accordingly. We did not aim to assess claw trimming effects per se, nor did we aim to diagnose the causes of lameness.

Walking speed was significantly higher (*t*-value = 3.55; *P* < 0.001) in healthy cows (1.35 ± 0.15 m/s) than in lame cows (1.23 ± 0.15 m/s), confirming results of other studies (Telezhenko and Bergsten, 2005; Chapinal et al., 2010b). Healthy and lame cows' speeds were comparable with another study in which a person also followed the cows (Chapinal et al., 2010b). In an automated and unsupervised setting, however, cows will walk more slowly.

To illustrate the differences between healthy and lame cows and between untrimmed and trimmed states, the vertical forces (normalized to BW) from the hind legs of a healthy cow and a lame cow before and after trimming are shown in Figure 2. By visual inspection, the healthy cow exhibited more symmetric (i.e., parallel) left and right leg curves than the lame cow. Likewise, left and right leg curves were more symmetric after trimming compared with before trimming.

The effects of claw trimming, lameness, and body part on 3D symmetries are reported in Table 2, with

small values denoting better symmetry. Early after trimming (d 0 and 1), all 3D symmetries were significantly improved compared with before trimming. However, 1 wk after trimming, this effect had disappeared in the mediolateral and longitudinal directions. As expected, lameness significantly worsened the vertical symmetry. Significant interactions showed that although front legs were unaffected by lameness, the hind-leg mediolateral symmetry of lame cows was worsened compared with healthy cows, and conversely that the hind-leg longitudinal symmetry of lame cows was improved compared with healthy cows. We do not know of similar studies in quadrupeds, but for comparison, human knee flexion curve symmetries of 0.25 and 4.99 have been measured in normal subjects and in below-knee leg amputees, respectively (Crenshaw and Richards, 2006).

We used 3D force plates, which enable a wider range of gait variables to be analyzed, and potentially create a better basis for lameness detection compared with a 1-dimensional system (Rajkondawar et al., 2006). The use of 3D force plates may help to identify cows that need claw trimming earlier than visual gait scoring. Our results indicate that 3D leg curve symmetries seem worthy of more detailed studies of automated lameness detection and of scheduling claw trimming events.

In conclusion, our hypothesis that lame cows would exhibit less left–right leg symmetry than healthy cows was confirmed, because lameness significantly worsened vertical symmetry. Our second hypothesis was confirmed, because left–right curve symmetry in all 3 force directions was improved early after trimming. Studies including more animals should confirm these findings.

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