The Vertical Ground Reaction Force and the Pressure Distribution on the Claws of Dairy Cows While Walking on a Flat Substrate

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ABSTRACT

The pressure distribution under the bovine claw while walking was measured to test the hypotheses that the vertical ground reaction force is unevenly distributed and makes some (regions of the) claws more prone to injuries due to overloading than others. Each limb of nine recently trimmed Holstein Friesian cows was measured five times while walking over a Footscan pressure plate firmly embedded on a Kistler force plate. The pressure plate had a spatial resolution of 2.6 sensors/cm² and was sampled simultaneously with the force plate with a temporal resolution of 250 measurements/s. Five moments during the stance phase were selected on basis of the force plate recording for the analysis of the pressure distribution: heel strike, maximum braking, midstance, maximum propulsion, and push off. At the forelimbs, the vertical ground reaction force was equally distributed between medial and lateral claw. At the hind limbs at heel strike, the force was exerted almost completely to the lateral claw. During the rest of the stance phase the load shifted towards the medial claw, until, at push off, it was more or less equally divided between both claws. The average pressures determined were 50 to 80 N/cm². Maximum pressures increased from 90 to 110 N/cm² at heel strike to 180 to 200 N/cm² at push off. It was concluded that at the hind limb these pressures constitute a major threat to overloading particularly for the softer parts of the lateral claw, e.g., the sole and bulb area. (**Key words:** dairy cattle, lameness, horn, biomechanics)

Abbreviation key: GRF = ground reaction force.

INTRODUCTION

Claw disorders and lameness in dairy cattle have increased greatly with the advance of artificial housing

(Clarkson et al., 1996; Esslemont and Spincer, 1993; Russel et al., 1982; Somers et al., 2003). Due to the abnormal load bearing on a hard floor during the housing period it is assumed that normal horn production and horn abrasion are disturbed (Bergsten and Stranberg, 1990; Vermunt and Greenough, 1995; Shearer and van Amstel, 2001). Subclinical lameness affects up to 70% of cattle in the western dairy industry (Hedges et al., 2001). The problem has a strong economic impact (Borsberry et al., 1999; Enting et al., 1997) and constitutes a major reduction of animal welfare (Whay et al., 1997).

During standing or walking ground reaction forces (GRF) are exerted to the claw by the floor. The vertical component of this GRF is distributed over the contact area of the claws of a limb in a way that depends on the shape of the claws and the way the claw is placed on the floor. In turn, the vertical force distribution between lateral and medial claws and over the contact area of each claw determines the degree of local compression of the horn and underlying tissues. If cows with deformed claws walk on a hard floor it is easy to see how contact areas become reduced and pressure concentrations induced. Although the average pressure may stay within acceptable limits, local pressure concentrations may cause tissue overloading. This may on the one hand lead to horn fracturing and the opening up of infection routes and, on the other hand, cause damage to the corium, resulting in haematoma and abnormal horn formation (Toussaint-Raven et al., 1985; Greenough and Weaver, 1997; Blowey et al., 2000).

Previous work showed that during standing pressure concentrations occur at the bulb area of the lateral hind claw; this region of the bovine claw is known to be susceptible to injuries (van der Tol et al., 2002). However, during walking the total load applied on a limb can be more than twice as high (Scott, 1988), and a limited area of the claw may carry this load. There is no information available of how these loads are distributed over the potential weight-bearing area of the claw. Moreover, at certain moments during the stance phase of the step-

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cycle the weight applied on the supporting limb is exerted on a relatively small area, for example at heel strike or at push off.

The aim of this study is to determine the GRF and to measure the magnitude and distribution of the average and maximum pressures exerted to the contact area of the claws of dairy cattle, while walking on a flat, relatively hard surface. The hypotheses are tested that the vertical GRF and the pressures are equal for the fore and hind limbs, the vertical GRF is equally divided over both claws of a foot and that the pressures applied to each foot are equally distributed over its contact area. These dynamic measurements are now possible with a new pressure distribution plate (Footscan) firmly assembled on a (Kistler) force plate simultaneously sampling with a high spatial resolution and at high frequency.

MATERIALS AND METHODS

All procedures of the experiment had been approved by the Animal Experimentation Committee (DEC) of the Faculty of Veterinary Medicine, Utrecht University. Nine dairy cows (Holstein-Friesians, age: 5.1 ± 2.1 yr, weight: 671 ± 101 kg) with no visual signs of claw disorders or lameness were subjected to the experiment, which took place in September at the end of the grazing period. The animals came from a herd, kept at the De Tolakker research farm at the Faculty of Veterinary Medicine, Utrecht University, and are representative for the Dutch population of high-producing dairy cows (average production: 8000 kg/lactation). They were kept in a loose cubicle house with slatted concrete floors; the walking areas were cleaned automatically every 20 min by means of a manure scraper. Their hind claws were examined and trimmed according the Dutch trimming method (Toussaint-Raven et al., 1985) by an experienced claw trimmer 2 wk prior to the experiment.

The pressure/force measuring system consists of a pressure distribution plate and a force plate sampled simultaneously (250 Hz). The pressure distribution plate (Footscan Scientific Version, RSscan International, Olen, Belgium) has a 976 mm $\times$ 325 mm measuring surface, containing 8192 conductive pressure-sensitive polymer sensors. These sensors measure vertical force only. Because the size of the sensors is known (0.39 cm²), the pressures can be determined automatically. This plate was embedded in an aluminium plate, which was solidly assembled on the force plate (Type Z4852/c, 600 mm $\times$ 900 mm, Kistler Corp, Winterthur, Switzerland). The force plate measures the vertical, longitudinal, and transverse components of the GRF. The assembly was placed level in a concrete pathway. The pathway and measuring apparatus were covered with a 5 to 6 mm

thick rubber mat to provide enough frictional force to allow normal locomotion.

Each trial had a standard duration of 4 s. Per measurement 8192 (sensors) $\times$ 1000 (samples) data points were collected. The threshold level was set at 5 N/sensor to discard noise-related data. All above-threshold values were color-coded. The values for one step were linearly distributed over 256 available colors between the threshold (blue) and the maximum value (red). The Footscan Pressure plate uses directly the output (vertical GRF) of the Kistler Force plate for calibration. The sum of the vertical forces applied to all individual sensors of the pressure plate was automatically adjusted to the total vertical force registered by the Kistler force plate. The force plate was calibrated with the aid of a heavy weight as prescribed by the manufacturer.

Measurements and Data Processing

The cows were repeatedly walked down the path, lead by an experienced handler to control the direction of locomotion. A measurement started at initial contact of the fore foot touching the pressure plate. The acquisition time of 4 s provided enough time to measure both the fore and hind limb of one side of an animal in a single trial. The trials continued until eight measurements for each limb had been recorded.

When processing the data, we observed that in some measurements not only the fore and hind limbs at the side of interest, but also an opposite fore or hind limb was standing on the force plate, but not on the pressure plate. These measurements had to be discarded, as the on line calibration procedure between the force and pressure plate (see above) would lead to erroneous results. From the eight consecutive measurements the first five technically correct measurements were analyzed.

The step cycle of a limb during walking can be described as a weight-bearing phase and a non-weight-bearing phase, respectively, the stance and the swing phase. The stance phase starts with the foot landing on the ground and ends after the push off when the foot is lifted from the ground (Leach, 1993; Schamhardt, 1998). During the stance phase the forces due to locomotion are exerted by the foot to the ground (Figure 1a). With the aid of these GRF recordings, several characteristic moments can be described. During the stance phase of each individual limb, five of these moments were automatically selected to perform the analysis upon. These moments were called: heel strike, maximum braking, midstance, maximum propulsion, and push off. They were defined as follows:

- 1) Heel strike: the moment just after impact when the foot is settled on the ground and the weight is being transferred to the limb, whereby the vertical compo-

a) Ground reaction forces of a measurement of the left fore and hind limb.

b) The pressure distribution over;

The left forelimb at moment:

The left hind limb at moment:

Figure 1. An example of the ground reaction forces of the left fore and hind limb at walk (a, the yellow lines and numbers indicate the moments of the force and pressure analyses) and the changes of the pressure distribution at walk from heel strike to push off during the stance phase (b). In each picture the lateral claw is to the left; the medial claw is to the right. The color codes represent the same pressure in each picture within the stance phase. The red dot indicates the center of pressure (COP) in each picture; the white line corresponds with the trajectory of the COP during the stance phase.

ment of the GRF has reached 30% of its maximum value of that step.

- 2) Maximum braking: the moment the limb is subjected to the highest braking force (e.g., deceleration), whereby the longitudinal component of the GRF reaches its minimum value.
- 3) Midstance: the moment the limb makes a transition from braking to propulsion, whereby the longitudinal component of the GRF equals zero.
- 4) Maximum propulsion: the moment the limb exerts the highest accelerative force to propel the body forward, whereby the longitudinal component of the GRF reaches its maximum value.
- 5) Push off: the moment the foot is almost pushed off the ground, when the vertical component of the GRF is reduced to 30% of its maximum value.

Parameters. Consider F_i an above-threshold vertical force, applied to the i th sensor of the pressure plate. A_s is the surface of each sensor. The following parameters were determined during the five moments of the stance phase:

- 1) The vertical GRF exerted to the lateral (F_{v_l}) and medial claw (F_{v_m}) in Newton (N):
 $F_{v_l} = \sum F_i$ ($F_i > 5$ N) of the lateral claw,
 $F_{v_m} = \sum F_i$ ($F_i > 5$ N) of the medial claw.
- 2) Contact area of the foot with the floor (A_f in cm^2):
 $A_f = \sum n(F_i > 15 \text{ N}) \times A_s$
 $n(F_i > 15 \text{ N})$ = the number of sensors with an above threshold-level of 15 N/sensor. To account for the partial contribution of sensors located at the contour of the contact area, the threshold level was increased to 15 N/sensor.
- 3) The average pressure per foot (P_{av}) in N/cm^2
 $P_{av} = (F_{v_l} + F_{v_m})/A_f$
- 4) The maximum pressure per foot (P_{max}) in N/cm^2 .
 $P_{max} = F_{i(max)}/A_s$
 $F_{i(max)}$ = the highest F_i occurring at the contact area of the entire foot.

Statistical Analysis

The data consisted of measurements on four variables (F_v , A , P_{av} , and P_{max}) at five moments during the stance phase (factor Time), for the left and the right limbs (factor Asym) and for the fore and the hind limbs (factor Fore-hind). In addition, for variable F_v , a distinction could be made between the vertical force exerted to the lateral and to the medial claws (factor Claw). The data matrix was complete; each cell contained data of nine cows. The value for each individual cow was the average value of its five steps. An analysis of variance (general linear model, repeated measures; performed with the statistical package SPSS, SPSS Inc.) with the factors time, asym, and fore-hind was performed separately for the

variables A , P_{av} and P_{max} . For the variable F_v , the factor claw was also included. Although the average values for (paired) left and right limbs were almost equal, a certain amount of variance might be explained by asymmetry. Therefore, the highest and the lowest value of the limb pair were assigned to the categories "high" and "low" of a factor called Asym.

For A , P_{av} , and P_{max} , the hypotheses were tested separately that the variables had equal values for all limbs at each moment. For F_v , in addition, the hypothesis was tested that the vertical GRF were equally distributed between the medial and lateral claw. Both the effects of factors and the interactions between factors were considered to be significant at $P < 0.05$. For factors that interacted significantly, post-hoc-tests were performed either to analyze differences in Time, Asym, or Fore-hind.

RESULTS

General

Force plate measurements are shown in Figure 1a; the yellow vertical lines indicate the five moments at which the force and pressure distributions were analyzed. The longitudinal GRF (red line) shows a negative peak in the first half of the stance phase (a braking, decelerating force, directed backward), becomes zero at midstance and shows a positive peak at the second half of the stance phase (a propulsive force, directed forward). In Figure 1b an example is shown of the change of the pressure distribution in time for the fore and hind limbs. The force and pressure distribution and their change over time are somewhat different for the fore and hind limbs. The interindividual variation in the forelimbs appeared to be higher than in the hind limbs.

In general, at heel strike the forelimb (Figure 1b) lands on the bulb area of the lateral claw and to a lesser extent on the bulb area of the medial claw. After heel strike, both claws remain more or less subjected to the same vertical force (as can be observed by the center of pressure between both claws), mainly at the bulb area and at the walls. The sole is loaded lightly, as can be seen from the characteristic sickle-shaped claw print (Figure 1b). From midstance to maximum propulsion, the load shifts somewhat toward the medial claw. At push off the forces are equally distributed, loading the anterior parts of the wall and sole.

At the hind limbs (Figure 1b) the forces during heel strike are exerted mostly (> 95%) to the outer side of the lateral claw. From maximum braking to maximum propulsion the vertical load shifts towards the medial claw. However, the greater part of the force remains exerted to the lateral claw, in particular to its sole and bulb. At push off, the forces are exerted more or less

Table 1. The results of the analysis of variance, repeated measures.

Factor ¹ (n = 9)	Vertical GRF		Contact-surface		P-average		P-max	
	F ²	P	F ²	P	F ²	P	F ²	P
Fore-hind	93.6	*	2.5	0.156	15.9	*	35.2	*
Time	42.0	*	122.5	*	21.0	*	11.1	*
Asym	39.0	*	58.1	*	105.2	*	109.1	*
Fore-hind*Time	35.3	*	14.7	*	2.0	0.234	1.8	0.271
Fore-hind*Asym	13.4	*	1.7	0.234	0.1	0.798	0.3	0.619
Time*Asym	7.6	*	2.3	0.189	2.7	0.152	3.8	0.088
Fore-hind*Time*Asym	2.4	0.185	5.3	*	0.9	0.512	0.8	0.577
Claw	38.5	*						
Claw*Fore-hind	26.2	*						
Claw*Time	35.7	*						
Claw*Asym	3.5	0.099						
Claw*Fore-hind*Time	6.7	*						
Claw*Fore-hind*Asym	0.1	0.760						
Claw*Time*Asym	4.2	0.074						
Claw*Fore-hind*Time*Asym	0.5	0.742						

¹The abbreviations of the factors included in the analysis are: Fore-hind = fore- and hindlimb, Time = the 5 moments during the stance phase, Asym = the asymmetry between left and right limbs, and Claw = medial and lateral claws.

²F ratios are exact statistics for Wilks' Lambda.

*Indicates significance at $P < 0.05$.

equally to the anterior part of the wall and sole of both claws.

Vertical Ground Reaction Forces (F_v)

For all limbs the vertical component of the GRF increases until midstance and decreases until push off. The maximum vertical GRF (averaged over left and right limbs) at the hind limb was less (2444 N) than at the forelimb (3324 N). These forces amounted to, respectively, 37 and 51% of the BW. The magnitude of F_v was significantly different for the four investigated factors, e.g. Asym, Fore-hind, Time, and Claw (Table 1). All first-order interactions between these four factors were also statistically significant, except for the interaction between Claw $\times$ Asym. The higher order interaction between Claw $\times$ Forehind $\times$ Time was significant, which is probably due to the asymmetrical loading of the claws being different in time for the fore and hind limb (Figure 2).

Table 2 shows for each moment the absolute forces exerted to the lateral and medial claws of the fore and hind limbs, averaged over the left and right limbs. In Figure 2, the vertical GRF applied to the lateral and medial claws is shown as a percentage of the total vertical GRF exerted to the entire foot. The force is more or less equally distributed between both claws at the forelimbs during the stance phase. The distribution of the force at the hind limbs was remarkably different. At heel strike the load (± 1000 N $\approx$ 1/6th of the BW) was almost completely exerted to the lateral claw. Subsequently, the force distribution equalizes gradually, so

that at push off the applied load to lateral and medial claws was about the same.

Claw Floor Contact Area

At all limbs the claw floor contact area increased from heel strike (± 23 cm²) to midstance (± 50 cm²) and then decreased from midstance to push off (± 15 cm²; Figure 3). The contact area was significantly influenced by the factors Side and Time. The changes in contact area over time were different for the fore and hind limbs. At heel strike and at midstance the contact area was significantly larger at the fore limb, whereas at maximum deceleration, at maximum propulsion and at push off the contact area was not significantly different between fore and hind limb. The first-order interaction between Fore-hind and Time was statistically significant (Table 1). The asymmetry changed also over time, so there was a significant interaction between the factor Asym and Time.

Average Pressures

At the first four time points in the stance phase the average pressure did not change much and amounted about 50 N/cm² at the hind limbs and 60 N/cm² at the fore limbs (Figure 4). However, at push off the average pressure increased to 80 to 85 N/cm² at both limbs. This effect was statistically significant (Table 1, factor Time). Also, the factors Asym and Fore-hind showed significant effects. The average pressure was significantly higher

a) % vertical GRF at the forelimbs

b) % vertical GRF at the hind limbs.

Figure 2. For moments 1 to 5 during the stance phase (from heel strike to push off) the distribution of the vertical ground reaction force over the medial and lateral claws is expressed as a percentage of the total vertical load on the limbs. Left% lat = the percentage vertical force on the left lateral claw, Left% med = the percentage vertical force on the left medial claw, Right% lat = the percentage vertical force on the right lateral claw, Right% med = the percentage vertical force on the right medial claw. Note that the sum of the lateral and medial claw for each limb must be equal to 100% of the vertical ground reaction force.

at the fore limbs at moment 2, 3, and 4. Furthermore, there were no significant interactions.

Maximum Pressures

The pressures over the foot were unevenly distributed, as evidenced by the fact that the maximum pressures were 2 to 3 times higher than the average pressures. In Figure 4 it can be seen that at heel strike the maximum pressure was about 88 N/cm² at the hind limbs and 107 N/cm² at the fore limbs; the maximum pressures were higher (± 105 and ± 130 N/cm², respectively) the next three moments for both the fore and hind limbs. At push

Figure 3. The claw floor contact area at the five moments during the stance phase. The error-bars indicate the standard deviations over the group of nine cows.

off, the maximum pressure increased up to 180 and 200 N/cm². The maximum pressure was significantly influenced by all factors (Table 1). No interactions were present. At the first four moments the maximum pressures were significantly higher at the fore limbs, whereas at push off both limbs were subjected to the same maximum pressure.

DISCUSSION

The simultaneous use of a force and pressure plate is a relatively new technique that has been applied so far mainly in human movement sciences. It offers an opportunity to analyze the force and pressure distribution under the bovine claws in static and dynamic situations (De Belie et al., 2002; Nilsson et al., 2002; van der Tol et al., 2002).

Figure 4. The average pressure (P_{av} : $\square$ $\blacksquare$) and maximum pressure (P_{max} : $\circ$ $\bullet$) exerted to the fore and hind limbs at moments 1 to 5 during the stance phase. Each value represents an average of the left and right limbs.

Table 2. The absolute vertical ground reactions forces (in newtons) at each moment averaged over the left and right limbs.

Limb	Moment	Heel strike	Maximum braking	Midstance	Maximum propulsion	Push off
Hind	Fz-total	1001.3	2333.3	2444.3	2433.9	1013.3
	Fz-lat	962.8	1828.7	1720.7	1534.9	564.0
	Fz-med	38.5	504.7	723.6	899.1	449.3
Fore	Fz-total	1206.0	2622.5	3324.0	2754.0	1209.5
	Fz-lat	659.5	1370.3	1664.0	1204.1	559.7
	Fz-med	546.2	1251.5	1659.6	1549.5	649.4

The forces applied to the force/pressure measuring system are measured simultaneously. The Footscan Pressure plate uses the output (vertical GRF) of the Kistler Force plate to equalize the summation of the forces applied to all individual sensors of the pressure plate to the total vertical force determined by the Kistler force plate. The pressures exerted to this force- and pressure-measuring system are determined more accurately than in stand-alone pressure plates/mats. Due to the relatively long surface of the measuring system (± 1 m) and the long acquisition time, the number of trials necessary to obtain five good measurements for all feet was rather low (about 40 walks per cow).

Distl et al. (1990) and Mair et al. (1988) quantified the pressures underneath the fore limbs of standing cows at a sampling frequency of 1 Hz. However, their low sampling frequency did not allow investigation of walking cows. Their results were partly in line with the results of van der Tol et al. (2002). Scott (1988) determined once the instantaneous weight bearing area at midstance during walking with the aid of a pressure-sensitive optical system. This method does not enable quantification of the pressures at the weight-bearing area. The present experiment shows that the pressure distribution at walk strongly depends on time. Therefore, only a method employing a high sampling frequency as well as a high spatial resolution will be suitable to analyze the pressures during locomotion.

A representative sample of Dutch high-producing dairy cows was conducted to the experiment, which took place at the end of the grazing period, and 2 wk after trimming their hind feet. Therefore, their claws were considered to be in good condition. In general the five measurements taken per limb were consistent and consequently the average of these five measurements was considered representative for the animal. No strict selection for age, weight, state of lactation, and/or clinical conditions had been applied. However, judging the level of the standard deviations, the results obtained from this heterogeneous sample can be considered as uniform and, as far as could be determined, consistent with previous studies (Toussaint-Raven, 1973; Ossent et al., 1987; Mair et al., 1988; Distl et al., 1990). A rubber floor was

provided in this experiment to allow normal locomotion. The results obtained, therefore, provide a standard for loading conditions at normal locomotion of dairy cows with healthy claws.

Spatial Data

This study is the first to describe the in vivo force distribution between the claws of walking cows. At the five moments of interest the force was distributed more or less equally over the lateral and medial claw at the forelimbs. However, the force distribution at the hind limbs was remarkably unbalanced; at the first four moments a significantly greater part of the vertical GRF was exerted to the lateral claw. The data obtained by Toussaint-Raven (1973) and Ossent et al. (1987) have shown that the claws take uneven loads while standing. This effect appears to be even greater in walking. As the forces exerted to the limbs during walking are higher than during standing, the claws would be more prone to injuries, due to the uneven loading, particularly in the hind limbs. Uneven wear of the two claws is promoted by this loading pattern (Murphy and Hannan, 1987).

The maximum contact areas during walking were about 54 cm² at the forelimbs and 47 cm² at the hind limbs. A pilot study of Nilsson et al. (2002) showed contact areas in a range from 52.5 to 67.5 cm² of cadaver claws mounted in a press and in vivo measurements on one walking (Holstein-Friesian) cow. Although no explanation was given for the discrepancy, the limited tendon support and the direction of force used in the in vitro study, the trimming method used (or not used), and the amount of time after trimming when the in vivo measurements were performed (1 mo) are probably reasons for the discrepancy in contact areas between these studies.

Horn: Mechanical Loading and Strength

The cyclic compression of claw horn during standing and walking constitutes a risk for fracture, which, in turn, may play a role in the development of claw disorders and lameness. To assess the risk, the in vivo pres-

tures must be related to the compressive strength of horn. Baggot et al. (1988) determined the shore D hardness (SD) of horn samples of the wall, central sole, and bulb area of the hind claws for normal and lame cows. At all sample sites the lame cows had significantly softer horn. In normal cows, the bulb area consists of the softest horn (SD = 31.0), the sole area was harder (SD = 43.7), and the wall samples (SD = 65.5) were hardest. The hardness of the horn at several sample sites in the wall at 2-yr-old was even higher 70 to 75 SD (Russke, 2001). The modulus of elasticity (E), a measure of stiffness, of horn samples taken at the dorsal wall, abaxial wall and sole of the claws of all limbs were significantly higher at the forelimbs. Horn at the sole was four to five times more elastic than wall horn (Zöscher, 2000). Horn at the sole of hind limbs ($E = 106.4 \text{ N/mm}^2$) was significantly softer than at the forelimbs ($E = 162.3 \text{ N/mm}^2$).

Horn hardness and elasticity correlate roughly with strength, wear resistance, and brittleness. However, these hardness data should be used prudently, as they depend on the chemical composition and humidity of the keratin (Baggot et al., 1988), which is influenced by the condition of the animal, environmental humidity (housing) and the use of formaldehyde footbaths. For risk assessment it would be interesting to express the in vivo pressures as a percentage of the ultimate compressive strength. Webb et al. (1984) determined the ultimate compressive strength of the wall of the claws of pigs at 800 N/cm^2 . In cows, the compressibility of bulb horn is four times higher than of wall horn (Zöscher, 2000). If the difference between the compressibility of wall and sole horn is indicative for the compressive strength, the compressive strength of bulb horn would be four times less than the wall horn, i.e., 200 N/cm^2 . Consequently, the maximum pressures measured on the bulb of the lateral hind claw while walking (100 to 125 N/cm^2) constitutes a significant repetitive load. Faster locomotion and sudden movements may result in an increase of the GRF per limb; uneven or partial support of the claw (e.g., grooved and slatted floors) may decrease the bearing area and increase pressure. In both cases pressures may increase to or beyond ultimate values and produce fractures of the horn or haematoma at the corium. It should also be taken into account that compressive strength of horn may be reduced by environmental humidity (wet floor) and adverse health conditions.

CONCLUSIONS

The mechanical induction of claw disorders has been indicated before (Toussaint-Raven, 1973, 1985; Greenough et al., 1997; Blowey et al., 2000), but its supposed relevance for the pathogenesis was hardly analyzed due to the lack of suitable measuring systems in the past

decades. With the aid of force and pressure distribution analyses it is possible to gain insight of the (mechanical) pathogenesis of claw disorders.

The present study revealed that in normal cows the force and pressure distribution at walk on a hard surface form a potential risk for claw integrity, for the following reasons. First, in the hind limb the lateral and medial claws are loaded unevenly during most of the stance phase, which may lead to uneven wear and/or growth of horn. Second, during normal locomotion with healthy claws on a flat surface covered with rubber, the pressures exerted to the contact area reach up to 50% of the probable ultimate strength of horn. This threatens particularly the weakest positions of the claw (the bulb) with mechanical failure. Consequently, a combination of faster, unsteady locomotion or partial claw support may easily lead to overloading and horn fracturing.

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