Measurements of Trackways as a Method for Assessing Locomotion in Dairy Cows

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Abstract

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The aim of this study was to assess whether locomotion parameters obtained by measurements of cow trackways are reliable and sufficiently sensitive to describe locomotion in non-lame and lame dairy cows on different floors. Thirty-two non-lame cows were used to study the reliability of the trackway measurements. The cows were tested twice over three weeks and measurements from four consecutive strides were used during each test session. To study the effect of different floors on locomotion, 25 non-lame cows and eleven cows with different lameness degrees were tested on five different surfaces: solid and slatted concrete, both with and without 20 mm thick elastic rubber mats, and wet, compacted sand. The reliability of the measurements varied from moderate to low, with measurements relating to inter-limb coordination being most inconsistent. The slippery slatted concrete floor caused restricted locomotion in so far as the strides were significantly shorter here than on all the other floors. Use of yielding rubber mats resulted in a locomotion more similar to that on the sand path. Lameness had an effect on shortening strides and steps, but in most cases the animals' reaction to different floorings was similar in lame and healthy cows. Step asymmetry due to lameness was decreased when cows walked on the soft surfaces. It was concluded that a trackway measurement system is a suitable method to use in field locomotion studies and that the system is useful in identifying differences in kinematics on different floor types. Since there is a relatively high inconsistency in cow walking it is beneficial to use measurements of several strides to obtain a representative gait pattern.

Keywords: locomotion, dairy cows, gait analysis, floor, concrete, rubber, kinematics

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"… No doubt it appeared to you to be a mere trampled line of slush, but to my trained eyes every mark upon its surface had a meaning. There is no branch of detective science which is so important and so much neglected as the art of tracing footsteps. Happily, I have always laid great stress upon it, and much practice has made it second nature to me …"
Arthur Conan Doyle, *A Study in Scarlet*, 1887.

Contents

Appendix

Papers I-II

The present thesis is based on the following papers, which will be referred to in the text by their Roman numerals:

I Telezhenko, E. Measurement of spatial gait parameters from footprints of dairy cows. (Manuscript)

II Telezhenko, E. & Bergsten, C. 2005. Influence of floor type on the locomotion of dairy cows. Applied Animal Behaviour Science, (in press).

Background

The need of cows for free movement and, coupled with freedom of movement, expression of natural behaviour is easier to meet in a loose housing system than in a tie stall system. Cubicle systems are becoming increasingly common in high-performing dairy herds. The floor design is one of the most critical aspects of loose housing systems because of its direct effect on the cattle's locomotor apparatus (Stefanowska et al., 1998). Most walkways in cattle houses are made of concrete because it is fairly durable, cheap and resistant to wear and has acceptable hygienic characteristics. However, the hardness, abrasiveness and slipperiness of concrete floors contribute to foot and leg lesions resulting in lameness (Webb & Nilsson, 1983; Bergsten & Frank, 1996; Manske et al., 2002; Sommers, 2004). For a long time lameness in cattle has been recognised as a large economic problem. It is difficult to appreciate the real extent of the economic loss, however, because lameness involves both direct costs (labour and veterinary treatment) and indirect costs (decreased milk yield, weight loss, impaired fertility, low carcass price, etc). In addition, lameness is a sign of discomfort and pain, and alters the cow's sensation of pain(Whay, Waterman & Webster, 1997). Therefore lameness is an important welfare issue (Logue, McNulty & Nolan, 1998). Moreover, poor floor quality as well as lameness can alter the degree of social and sexual activities in cows and consequently also influences cows' well-being and fertility (Zeeb, 1983; Benz, 2002).

Improved flooring in dairy cow houses is a much discussed topic but few objective assessments have been published of cows' locomotion on different floors (Phillips & Morris, 2000, 2001). For an objective evaluation of locomotion comfort on a particular floor, we need a method that does not interfere with the cows' natural behaviour in the actual environment. It seems essential for future practical applications of quantitative gait analysis to establish whether or not results from the single gait evaluation are representative of a cow's overall gait performance. Repeatability and reproducibility over time of kinematic variables have not previously been studied in cattle.

Introduction

Cattle and locomotion

Need for locomotion

Locomotion is part of the normal behavioural repertoire of cattle (Albright & Arave, 1997). Cattle move to feed and walk to the water trough, to interact with herdmates during social and sexual behaviour and to seek a birth site or shelter. Cattle have an innate motivation for locomotion, which is increased with time of confinement (Loberg et al., 2004). Locomotion maintains adequate blood circulation, stimulates muscular system development and provides increased fitness (Zeeb, 1983; Gustafson, 1993). In their natural environment cattle are able to range over large areas in search of feed. Although extremely long distances covered (up to 40 km per day) reduce feed intake and milk production, cattle need to walk at least 3–4 km per day to keep in good physical shape (Phillips, 1993).

Locomotion and environment

The physical properties of the environment through which an animal moves have a tremendous effect on the evolution of the way and dynamics of its locomotion (Dickinson et al., 2000). Movement on land requires that animals exceed gravity to support and move their bodies and accommodate any changes in the terrain (Biewener, 2003). Like all domestic mammals, cattle rely primarily on their limbs for movement, and the angulation and arrangement of the limb musculature provide strong evidence that their locomotor apparatus has mainly been developed for forward motion (Nickel et al., 1986).

European domestic cattle (*Bos taurus*) are descended from the aurochs (*Bos primigenius*), big animals which lived in transitional areas of woodland interspersed with open spaces (Baars et al., 2003). This means that the locomotor system of cattle evolved in an environment with plenty of space and yielding ground surfaces. Although the domestication of cattle started in about 7 000 BC this fact has probably not had a major effect on the basic dynamics of cattle locomotion, since animals were still grazed in conditions similar to their natural habitat.

When housing for cattle was introduced the animals were usually tied or were kept in a very limited space. Hence there was very little need for selection, either natural or artificial, for development of a locomotion system that was to be more suitable for an environment different from the natural one.

With the relatively recent introduction of cubicle housing, which ought to promote free movement of the animals indoors, the problem of arranging walking surfaces emerged. For several economic and practical reasons, the space for locomotion was provided in the passageways between cubicles and the majority of the floors were made of concrete. Although housed cattle do not need to cross large distances to feed, there is still a significant amount of locomotion associated with social and other activities (Albright & Arave, 1997). As a result, the cows, which have a locomotion system adapted for moving through grassland at the edge of forests, were forced to move in a confined environment, sometimes with low light intensity and unclean, hard, slippery and/or too abrasive walking surfaces (Zeeb, 1983; Phillips et al., 2000; Phillips & Morris, 2000, 2001).

Because of the contrast between the terrain in the natural habitat of cattle and the flooring in cubicle systems it is not surprising that lameness, defined as a severe disturbance of locomotion, is more common in the cubicle systems than on a pasture (Faye & Lescourret, 1989; Boelling & Pollott, 1998) or even in tie stalls (Maton, 1987; Faye & Lescourret, 1989; Bergsten & Herlin, 1996; Cook, 2003). Apart from the lameness effect, today the general comfort of locomotion in cattle is in focus. The limited space and slatted concrete floors in cubicle houses seem to reduce cows' locomotion activity (Zeeb, 1987). It has been shown that keeping cows tied or on slatted concrete floors in loose housing without access to pasture distorts their normal locomotion (Herlin & Drevemo, 1997).

Methods of studying locomotion in cattle

Subjective methods

Subjective locomotion assessment in cattle is a method commonly used by veterinary clinicians to estimate the quality of gait, in which most attention is devoted to determination of the degree of lameness. The most well-known scoring system for cattle locomotion has been published by Manson & Leaver (1988). This system uses a nine-point score reflecting small changes in locomotion leading to lameness. More simple scoring systems have been used to categorise the degree of lameness severity (Tranter & Morris, 1991; Whay et al., 1997). Sprecher, Hostetler & Kaneene (1997) have developed a system focusing (along with gait scoring) on the back posture, a system that was later adapted and used by several authors (Uchida et al., 2001; Juarez et al., 2003).

While lameness scoring can help in evaluation of the disorder, it does not provide sufficient objective measures of gait. Although it is possible to compare the locomotion scoring results of different studies, it should be noted that the accuracy of scoring is strongly influenced by the observer's skill and perception (Whay & Main, 1999). It has been demonstrated that use of gait analysis with quantitative (kinematic) methods is more precise than results obtained through subjective locomotion scoring (Keegan et al., 1998).

Objective methods

Kinematic and kinetic analyses have been successfully used to study gait in domestic animals, primarily horses (Clayton & Schamhardt, 2001; Barrey et al., 1999). Kinetics is a science that studies the causes of motion, explaining them by the force applied to the body, its mass distribution and its dimensions. Marey (1873) was the first researcher to use a pressure sensor under the horse's hoof to measure hoof-ground contact duration at various gaits. The modern sensor technology today allows recording of ground reaction forces over a large range of conditions (Roepstorff & Drevemo, 1993). The kinetics of cattle locomotion has been studied by Webb & Clark (1981) and Scott (1987). Van der Tol et al. (2003) used pressure sensors in combination with a force plate to study ground reaction forces and between-/within-claw pressure distribution in cows walking on a flat surface.

Kinematics describes the geometry of animal movement, studying changes in the position of the body parts during a specified time. The first kinematic animal locomotion study using chronophotography was performed by Muybridge (1887). Since then many kinematic studies of animals have been performed and at present the majority of kinematic studies are carried out with videographic or opto-electronic systems consisting of integrated hardware and software components (Clayton & Schamhardt, 2001). However, only a few published studies have applied quantitative measurements of locomotion to cows (Herlin & Drevemo, 1997; Phillips & Morris, 2000, 2001). In recent years a new interest has emerged for studying cow kinematics by quantitative methods including standard motion systems (Chida et al., 2004) and a treadmill (Meyer et al., 2004). The new studies have also used a larger animal material. Flower, Sanderson & Weary (2004), for instance, used 46 cows to study biomechanics related to claw pathologies utilising a two-dimensional (2-D) motion system.

Trackway measurements

While many of the sophisticated motion analysis systems are highly accurate, they may not be the optimal choice for wide implementation of objective locomotion measurements in cattle because of high cost and some procedural difficulties. Such drawbacks precipitate the need for validation and use of an inexpensive, objective gait analysis system which is possible to use in a livestock barn environment.

Linear kinematic data can be obtained by measuring the space between footprints, trackway measurements (Sukhanov, 1974). Assessment of trackways is a simple way to obtain information about animal locomotion when direct observations are impossible, as in the case of extinct animals. The first intensive study of fossil tracks was carried out by Professor Edward Hitchcock (1836). Hitchcock's works, in which thousands of tracks were systematically evaluated and classified, are still classic references for ichnology, the science of fossil trackways and traces. Trackway analysis offers unique and important insights into the behaviour of dinosaurs (Kuban, 1989) revealing details about the lives of ancient animals that are not obvious from skeletal remains.

In 1897 Bradford published his work in which human gait was examined by observation of footprints on sand, dust, mud and snow. In spite of remarkable progress in gait analysis, data obtained from footprints are likely to continue to be used in human biomechanics as a simple and inexpensive method to quantify important aspects of gait (Wilkinson, Menz & Raspovic, 1995). Data obtained from direct measurements of footprints are often used in human biomechanics for clinical investigations (Stolze et al., 1998) and to validate new and more sophisticated gait analysis systems (Gaudet et al., 1990; McDonough et al., 2001).

Still the measurements of trackways remain a fairly unusual method of analysis of animal locomotion including locomotion of dairy cows. Benz (2002) used foot imprints to measure the step length of cows on different floorings. However, there has been no detailed methodological study on use of the trackway measurements for evaluation of locomotion in dairy cattle.

Aims

The aim of this study was to assess the possibility to describe the locomotion of dairy cows using measurements of their trackways. The focus was on the question of reliability of measured parameters with special emphasis on suggesting indicators for cow locomotion comfort. In addition, the aim was to evaluate, by using the measurements, differences in locomotion in animals with different conditions of the locomotor system on different floors.

Summary of materials and methods

Animals and housing

The study described in Paper I was carried out on the research farm of the Swedish University of Agricultural Science in Alnarp, Sweden. The 32 studied cows were of the Swedish Holstein breed, mainly in first and second lactation, without signs of lameness. The average height at withers was 143 cm (range 133–154 cm) and average body length was 181 cm (range 161–192 cm). The cows were kept in cubicles with slatted concrete passageways. An alley (with a slatted concrete floor) from the cubicles to the milking parlour was used for the gait analysis. The dynamic coefficient of friction (COF) of the slats was 0.55.

The study described in Paper II was carried out on a commercial organic dairy farm in western Sweden. Eighteen Swedish Red and White and 18 Swedish Holstein cows were studied. All cows were kept under similar management conditions in cubicles with slatted concrete walkways.

The presence and severity of lameness (Paper II) was scored on a four-point scale, modified from Sprecher et al. (1997), according to which, animals with normal gait (n = 25) and mildly (n = 6) and moderately (n = 5) lame cows were identified. No severely lame cows were used in the study. A walkway from the milking parlour to the pasture was used. The walkway included both slatted concrete (dynamic COF = 0.31) and solid concrete (dynamic COF = 0.58). Twenty mm thick KEN® rubber mats (Gummiwerk Kraiburg Elastik, Germany) with rubber-studded underside profiles were used on the slatted and solid 10 m of the walkway. The dynamic COF of the rubber mats was 0.46. The rubber mats were introduced 1 month before the measurements started. At the exit to the pasture a sand track was prepared from moist sand compacted by a tractor.

The friction of the floors in both papers was measured with a portable friction tester (PFT). Because of different measurement principles, the friction values obtained with the PFT were higher than those obtained with the more commonly used pendulum swing device (skid resistance tester (SRT) or British pendulum tester). To make the results more comparable to those of other studies, PFT friction values were converted to SRT friction values by a formula developed by the Swedish National Road and Transport Research Institute and the SRT values were then transformed into a COF value (Astrom, 2000).

Gait assessment

In both papers a trackway measurement system was used for the gait analysis. To obtain visible foot imprints (Fig. 1), lime powder ($Ca(OH)_2$) was dispersed over the walkway and mixed with a thin layer of slurry (Fig. 2). The cows walked one by one over the prepared surface at their own chosen speed. In order to make the cows walk continuously, a person followed them slowly at a distance of several metres (Fig. 3). Only trackways from cows that walked evenly were used for the measurements. In the first paper the following elements of trackways were measured (see Fig. 2 in Paper I): stride length (the distance between two consecutive imprints of the same rear foot); step angle (the angle between the lines connecting the three consecutive imprints of the rear feet); step width (the distance between the right and left rear foot imprints, along the line perpendicular to the line of progression); step length (the distance between two consecutive imprints of the left and the right rear foot); step asymmetry (the absolute value of the difference between two consecutive steps); overlap (the lengthwise distance between the front foot imprint and the next imprint of the same side's rear foot); step abduction-adduction (the sideways distance between the front foot imprint and the next placement of the same side's rear foot).

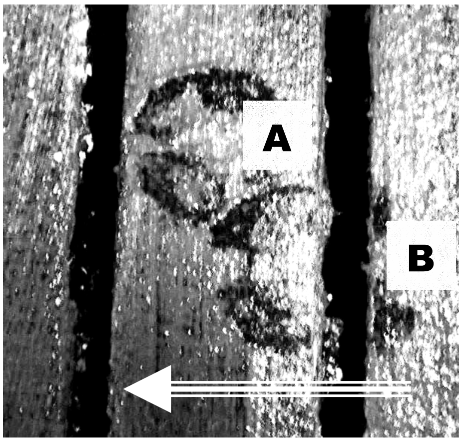

Figure 1. Imprints of the left front (A) and the left rear (B) foot on the slatted concrete floor. The rear imprint is placed behind (negative overlap) and laterally (positive abduction-adduction) of the front imprint. The arrow indicates the direction of movement.

Measurements in Paper II included all parameters mentioned above with the exception of step width and step abduction-adduction. The measurements were taken from four consecutive strides using a ruler and an angle meter (Fig. 4). The measurements and their reference points are described in detail in Paper I. The walking speed of each cow was measured with a stopwatch.

Figure 2. Preparing the walkway with lime powder and slurry

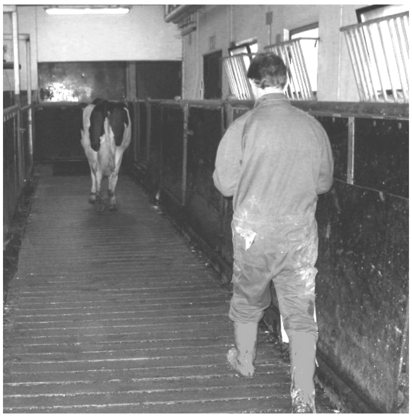

Figure 3. Obtaining the trackway and measuring the speed

Locomotion measurements in Paper I were repeated after three weeks in all cows.

Cow locomotion in Paper II was tested on five different surfaces in the same test run, viz. solid concrete without rubber mats, slatted concrete with rubber mats, slatted concrete without rubber mats, solid concrete with rubber mats and wet, compacted sand.

All measurements were made by the author of the thesis (E.T.).

Figure 4. Measuring the trackway

Statistical analysis

Paper I

The analysis was performed using the PROC MIXED procedure in SAS (SAS v. 8 for Windows; SAS Institute, Inc., 2002). The statistical model for trackway measurements included effect of cow, test day and interaction between cow and day of the test. All the terms in the model were considered random and independent.

The parameters for the variance components were estimated with the residual (restricted) maximum likelihood (REML) method. To assess the impact of each factor on the total variance, the percentage of each variance component was calculated. The proportion of the total variance that is due to variance among cows was used as a measure of reliability. We interpreted proportion of between-subject variance <20% to mean "very low reliability"; one of 20–45% to represent "low reliability"; one of 46–70% to show "moderate reliability"; and one of >70% to mean "high reliability".

To measure the strength of the linear association between gait parameters, Pearson product-moment correlation coefficients were calculated for individual means. The same procedure was applied to assess correlations of locomotion parameters with body size. To estimate the linear association between gait parameters within individuals, analysis of covariance was used and partial correlation coefficients within subjects were calculated according to the method described by Bland & Altman (1995).

Paper II

The speed and individual trackway means, obtained from measurements of four consecutive strides on each floor, were calculated with analysis of variance (ANOVA) with the between- and the within-subject design. Two different statistical models were used to describe the data. The first model included floor as within-subject effect and lameness degree as between-subject effect. In the second model only cows without signs of lameness were included in the analysis. In this model breed and parity were included as between-subject effects, and floor as the within-subject effect. The cow effect was considered random and other effects were considered fixed in both models. Multiple comparisons were performed using Tukey's Honestly Significantly Different (HSD) test. We used JMP v. 5 for Windows (SAS Institute, Inc., 2002) for the statistical analyses.

A 5 % significance level was used throughout both papers.

Summary of results

Paper I

The reliability was moderate for walking speed (66.67%), stride length (62.35%), step angle (57.23%), step width (51.8%) and overlap (65.38%). Step length and step abduction-adduction showed a fairly low reliability (37.76% and 25.44%, respectively).

Step asymmetry had almost negligible between-subject (18.09%) and between-test variation (5.30%) but within-test variation was large (76.57%).

Increased stride was associated with an increased step angle, as well as with increased step length and increased overlap. Increased abduction was associated with a decreased step angle, increased step width and slightly increased step asymmetry.

Height at the withers was positively associated with stride length and step angle and negatively with step width and abduction-adduction. Body length correlated positively with stride and step length and tended to have negative correlation with overlap.

Paper II

Strides and steps were considerably shortened and the rear foot imprints were placed at a greater distance behind the front ones (larger negative overlap) on a slippery slatted concrete floor in comparison with all the other floors. On the solid, crude concrete floor the cows took shorter strides and steps than on the sand surface, but the speed did not differ significantly. Length of strides and steps increased on the elastic rubber mats compared with the corresponding concrete floors. In moderately lame animals speed was lower and the stride and step lengths were shorter compared with those in non-lame and mildly lame cows. Analyses within each lameness degree revealed that the moderately lame cows walked with a significantly wider posture on solid and slatted concrete than on the yielding surfaces. Comparisons of cows with different lameness scores within a floor type showed that the moderately lame cows compared with the non-lame ones had a smaller step angle on the concrete flooring while there were no significant differences between lame and non-lame animals when walking on yielding surfaces. Step asymmetry increased progressively from the non-lame to the moderately lame cows on all floor types. In cows with moderate lameness the step asymmetry was less pronounced on the sand and on the floor with continuous rubber covering.

General discussion

Trackway measurements and error due to measurements

Measurement of trackways is a method for obtaining several spatial kinematic variables in cows in their actual environment. The cow trackway measurements system was developed to analyse cows' gait on different floorings (Telezhenko, Bergsten & Manske, 2002). Clearly the information obtained from trackways is not as precise and complete as that obtained with three-dimensional (3-D) motion analysis. However, the method of trackway measurements is inexpensive, easy to apply and interferes minimally with the movement of cows in their natural environment. Because it uses direct measurements, trackway analysis could result in more reliable records than achieved with e.g. 2-D video analysis because of deviation in animal movement from line perpendicular to the camera. However, the measurements of trackways lack some important kinematic parameters such as different angulations and trajectories of joints as well as important temporal stride characteristics. The only temporal parameter used in the present studies was speed, calculated from the time used for passing the tested walkways. By measuring the time with a stopwatch, certain measurement errors are inherited. To improve the precision of speed measurements, it would be possible to complete measurements of the trackways with a video recording of the cow passing the walkway.

Because all measurements were performed by one operator we did not assess between-operator variation. Nevertheless it should be noted that the source of such variation could lie in different determination of reference points for the measurements. Detailed recommendations for finding points of reference were made in Paper I. The main argument was that each place of the imprint could be a reference point; however, the reference point should consistently be the same place in each footprint within a trackway. It has been shown in humans that with very well-defined reference points for measurements of gait parameters from footprints, between-observer variability is very low (Wilkinson & Menz, 1997).

The abduction-adduction of the limb implies that the limb moves from or towards the mid-sagittal plane. In measuring the lateral deviation from the front imprints we did not take into account the abduction-adduction of the front limbs. We made the assumption that the front limbs move more parallel to the mid-sagittal plane than the rear limbs (Ndikuwera & Zishiri, 1990). Because of low reliability of the trait abduction-adduction was not used in Paper II and its meaning was substituted with the parameter characterising base of support, viz. step angle.

Although it is possible to identify differences in locomotion on floors of very different quality, trackway measurements are probably a fairly rough method for determining smaller differences in locomotion on more similar surfaces.

Reproducibility of gait

The reliability of gait parameters obtained from trackways and defined as portion of between-subject variation was lower than that of published values in trotting horses (Drevemo et al., 1980a; b, c) and humans (Kadaba et al., 1989). However, even variable gait patterns, measured under natural conditions, could be worth studying, since "steady locomotion is more the exception than the rule for animals travelling through natural environments" (Dickinson et al., 2000).

The self-chosen speed of the cow walking on different floors is an important indicator of her reaction to a specific floor. It should be noted that locomotion parameters obtained at different speeds are much more complicated to interpret (Paper II). Still it seems that a particular cow uses more or less the same speed when she walks on the same floor type and in the same direction (Paper I). The speed of locomotion may also have a close relationship with the motivation for movement. Usually cows are more motivated to move from the milking parlour to the cubicles than in the opposite direction, which can result in differences in speed and other speed-related parameters (Telezhenko, unpublished). Analysis of repeatability and reproducibility of trackway elements revealed significant within-test variation. Although cows walked apparently smoothly, some speed variation did occur and contributed to variation of speed-related gait parameters (i.e. stride length). The walk itself may be a less consistent gait than e.g. trot. In one study horses walked less consistently on the treadmill and needed more habituation time than at a trot (Buchner et al., 1994).

The low reliability of step asymmetry suggested non-systematic changes in inter-limb coordination in non-lame cows. The within-test variation was very high and can be explained both by within-test speed inconsistency and by tactics adopted to avoid falling and slipping.

Quality of gait

Definition of good locomotion

Gait quality in cows has usually been evaluated in terms of presence or absence of lameness (Manson & Leaver, 1988; Whay & Main, 1999). In sport horses, however, associations between stride kinematics and subjective assessment of movement quality have been found (Clayton, 2001). Horses with good movements showed more retraction in the forelimbs and more protraction in the hind limbs, a prolonged swing phase and ability to achieve a particular speed using a long stride length and a low stride frequency. Impaired locomotion in cows has been described as stride shortening and a "stiff gait" and has also been described in terms of the degree of abduction or adduction in the hind limbs (Whay, 2002). Still, no detailed description of "good locomotion" in cows measured using quantitative methods has been published.

Indicators of cow locomotion comfort

Stride length

When assessing gait quality, we used the trackways on sand as a standard surface with properties for the best locomotion comfort (Paper II). The most informative parameter for locomotion comfort assessment was stride length. The stride length was significantly decreased in moderately lame cows, and non-lame as well as lame cows increased their strides on the yielding surfaces. The stride shortening during lameness is characterised by shortened swing durations and longer stance durations, which is an important method of reducing the peak loads on the lame limbs (Buchner, 2001). In Paper II it was suggested that stride lengthening is a more efficient way to increase speed during walking than is increasing stride frequency. However, effectiveness of stride lengthening during walking is limited by the effectiveness of the pendulum-like energy exchange between kinetic energy and gravitational potential energy. The effectiveness of the exchange depends on the angle the legs make from vertical (Alexander, 2003). Too long a stride would imply a too large angle for the legs and therefore not enough potential energy to be transformed to kinetic energy, which would raise the metabolic energy cost of transport. Under normal conditions animals choose the walking speed and stride length which corresponds to the most optimal exchange between potential and kinetic energy (Biewener, 2003). Therefore it was concluded that maximal stride lengthening on the sand surface at cows' own chosen speed constitutes natural movement with minimal energy expenditure. It has also been shown that cows increase their stride length when the COF of the floor is satisfied for unconstrained walking (Phillips & Morris, 2000, 2001). Walking with shorter strides on a slippery floor is an adaptive mechanism for preventing slipping, in which the COF required for walking is kept below the available COF (Van der Tol et al., 2005). However, maintaining the speed by increasing frequency with shortened strides is an attribute of inefficient walking (Paper II). Slippery floors force animals to modify their posture and develop a "stiff" gait, which can remain even when a cow walks on a floor with acceptable friction (Herlin & Drevemo, 1997).

Overlap

Overlap distance describes the lengthwise position of the rear foot imprint in relation to the imprint of the same side's front foot. It was repeatedly stated that cows normally put their rear feet on the same spot that the front feet has just been lifted from (Tranter & Morris, 1991; Whay, 2002). Usually positive or cloze to zero overlap characterises the good, progressive movements; and lameness and slippery floor cause an under-reaching of the rear foot in relation to the front foot, or a negative overlap (Paper II). However, we found that some degree of lameness could be associated with an over-reaching (large positive overlap) as well (Paper II).

The overlap characterises the extent of hind limb protraction and in Paper I was associated with the stride increasing. However, the negative correlation between overlap and body length (Paper I) implies that when evaluating the overlap attention should be paid on proportions of the animals, i.e. a long body with short legs will result in placement of the rear foot imprints further behind the front ones (negative overlap) and a short body with long legs will result in placing the rear imprints in front of the front ones (positive overlap). The between-breed differences in overlap found in Paper II were most probably due to such differences in animal proportions.

Step length and step asymmetry

The contribution of step length alone to the assessment of locomotion comfort is no greater than that of stride length. The two measurements are highly correlated but step length can be less reliable as a measure of progression because it is influenced by the width of the support base (step width, step angle) and step abduction-adduction. The important derivative we can obtain from the step length measurements is step asymmetry. Step asymmetry arises primarily from shortening of one step, but varied step abduction can contribute to bigger step asymmetry as well. Step asymmetry showed good agreement with the subjective assessment of lameness and, besides, was proof of increased walking comfort for lame cows on the yielding floors (Paper II). A similar decrease in foot lameness expression on soft surfaces has been shown in horses (Ross, 2002). Nevertheless it may be complicated to use step asymmetry as an exact tool for determination of the site of the pain. Even in cases of only supporting lameness (caused by the pain associated with weight bearing), where a cow will shorten her step shifting from, e.g., the right limb to the left, it may mean a problem with weight acceptance of the left limb, or a problem with propulsion of the right limb. Increased asymmetry in non-lame cows on the slippery floor showed the possible implementation of the measurement as a parameter of altered stability. Consequently asymmetric steps may be a parameter for presence of gait abnormality, without being a diagnosis.

Width of walking posture

The width of the posture during walking can be described either by measuring step width or by measuring step angle, the latter method having an advantage in determination of landmarks for measurements (Paper I). Step angle correlated positively with stride length and big angle (narrow walking posture), usually a characteristic of a more efficient gait due to minimal lateral displacement of the centre of gravity (Alexander, 1985). On the other hand, with a small step angle the centre of mass is placed centrally within a cow's base of support and a more balanced position is provided. Step angle was not a very informative parameter of locomotion comfort on different floors in non-lame cows (Paper II). Only on the slippery slatted concrete floor was it considerably diminished. On the hard concrete surfaces lame cows walked with a significantly smaller step angle compared with non-lame cows, while on the soft surfaces the step angles of lame cows were no different from those of non-lame cows (Paper II). The difference in step angle between lame and non-lame animals could be explained by more hind limb abduction in the lame cows.

All the described parameters mostly reflect one single element of cow locomotion – steady-state, straight level walking, which is only one part of the repertoire of cow movements. Other types of movement, such as accelerating, stopping and turning, put higher demands for locomotion comfort on the environment (Van der Tol et al., 2005). Also, we need to develop methods for objectively and more comprehensively analysing gait quality in cows.

Conclusions

It was concluded that a trackway measurement system is suitable for evaluating locomotion comfort in field studies. The system is able to measure differences in kinematics on different floors if the quality of floors is very different. Because of the relatively high inconsistency of cow walking it is beneficial to use several strides to obtain a representative gait pattern. Future studies in cow biomechanics should focus on the development of simple yet sensitive methods to comprehensively assess locomotion comfort of cattle in different flooring systems.

Svensk sammanfattning

Med ökad medvetenhet om djurens välbefinnande har husdjurens hälsa och möjlighet till naturligt beteende satts i fokus i djurskyddslagen och inom mjölkproduktionen. Kornas rörelsekomfort är en viktig del av djurens naturliga beteende och välfärd, och klöv- och benhälsan är ofta en indikator på den miljö de exponeras för. Behovet av rörelse tillfredställs bättre i lösdriftsystem än i uppbundna system och intentionen inom mjölkkohållningen är att uppbundna system successivt ska ersättas med lösdriftsystem. Men, trots att kor i lösdriftstall har större rörelsefrihet och större möjlighet till sociala kontakter än uppbundna kor, innebär lösdrift större risk för och högre förekomst av skador på framförallt ben och klövar, med rörelsestörningar och hälta som följd. Större exponering för en undermålig miljö i form av snävt tilltagna rörelseytor, dålig hygien och hårda, halkiga, onaturliga golv bidrar till dessa problem.

Diskussion om förbättrade golvsystem i lösdrift har pågått länge. Dock saknas studier med objektiva uppskattningar av kors rörelsekomfort i olika golvsystem. Det är vanligt med subjektiva betygskalor för att gradera hälta, men sådana metoder är inte anpassade för att värdera skillnader i rörelsemönster hos icke halta kor. Dessutom är de vanligaste förekommande metoderna för biomekaniska undersökningar kostsamma och kan vara svåra att tillämpa i de stallmiljöer som korna befinner sig i.

Vid tillämpning av olika metoder för att beräkna hur kor rör sig på olika underlag är det viktigt att beräkna i vilken grad en ko behåller sitt rörelsemönster från ett undersökningstillfälle till ett annat. Likadeles är det viktigt att beräkna rörelsemönstrets variation mellan och inom individ för uppskattning av mätningarnas tillförlitlighet.

I denna avhandling beskrivs en ny metod för att studera mjölkkors rörelsemönster genom att mäta djurens fotspår på olika golvunderlag. Syftet med studien var att testa tillförlitligheten hos de gångparametrar som erhölls från mätningar av kors klövavtryck, att studera samspelet mellan hälta och golvmaterial samt att studera möjligheten att använda mätningarna för att beskriva rörelsemönster hos kor med och utan rörelsestörningar på olika golv.

För att göra klövspåren synliga beströks gångarna med ett tunt lager släckt kalk ($Ca(OH)_2$) som blandades med befintlig gödsel. För att beräkna tillförlitligheten i metoden studerades 32 icke halta kor. Korna testades två gånger med tre veckors intervall och fyra rörelsecykler mättes vid varje testtillfälle. Följande mätningar av fotspår användes vid tillförlitlighetsstudien: dubbelsteglängd (avstånd mellan två följande fotavtryck av samma fot), stegvinkel (vinkeln mellan linjerna som förbinder tre följande fotavtryck), stegbredd (tvärgående avstånd mellan höger och vänster sidas fotavtryck), steglängd (avstånd mellan två följande fotavtryck), stegasymmetri (skillnaden mellan två steglängder i rad), övertramp (avstånd mellan fram- och bakavtryck på samma sida), abduktion-adduktion (tvärgående avstånd mellan fram- och bakavtryck på samma sida). Mätningarnas tillförlitlighet skattades som en procent av inter-individvariationen av den totala variationen, vilken inkluderade mellan-test- och inom-testvariation samt variationen för test-individsamspel.

I golveffektstudien användes både måttligt halta (n=6), lätt halta (n=5) och icke halta kor (n=25). Rörelsemönstret hos varje ko undersöktes på fem olika underlag: betongspalt och helt golv med och utan mjuka, 20 mm tjocka gummimattor (Kraiburg Gummiverk GmBH) samt på ett naturligt, eftergivande underlag i form av fuktig, packad sand. Graden av hälta uppskattades enligt ett system med fyra klasser, anpassat efter Sprecher m. fl. (1997). Samma mått användes såväl i golveffektstudien som i tillförlitlighetsstudien med undantag för abduktion-adduktion och stegbredd.

Dubbelsteglängd, stegvinkel, stegvidd och övertramp hade måttlig tillförlitlighet (52-65 %), medan abduktion-adduktion och steglängd hade ganska låg tillförlitlighet (25,4 respektive 37,8 %). Tillförlitligheten hos stegasymmetri var mycket låg (18,1 %), vilket kan förklaras med icke-systematiska förändringar i inter-benkoordinationen hos icke halta kor.

Ökad dubbelsteglängd hade samband med ökad stegvinkel, ökad steglängd och större övertramp. Ökad abduktion hade samband med minskad stegvinkel, ökad stegbredd och något ökad stegasymmetri. Mankhöjd visade positivt samband med dubbelsteglängd och stegvinkel, och negativt samband med stegbredd och abduktion-adduktion. Kroppslängd var positivt korrelerad med dubbelsteg- och steglängd, och tenderade att korrelera negativt med övertramp.

Golveffektstudien visade på tydliga skillnader mellan olika underlag i lösdrift på halta och ohalta mjölkkors rörelsemönster. Dubbelsteg- och steglängd var avsevärt kortare på halkigt betongspaltgolv jämfört med alla de andra golven. Dubbelsteg- och steglängd ökade på elastiska gummimattor och sand jämfört med motsvarande betonggolv (spalt eller helt golv). Måttligt halta kor gick långsammare och hade kortare dubbelsteg- och steglängd jämfört med ohalta eller lätt halta kor. Måttligt halta kor gick med signifikant bredare benställning på helt betonggolv och på betongspalt jämfört med på de elastiska gummigolven och sand.

Stegasymmetri ökade progressivt från ohalta till måttligt halta kor på alla golvtyper. Hos måttligt halta kor var stegasymmetrin mindre uttalad på helt gummigolv och på sand än på de andra ytorna.

Slutsatsen av studien är att fotspårsanalyssystemet är lämpligt att använda i fältstudier av kors rörelsemönster i stallmiljö och att man med detta system kan identifiera skillnader i kinematik på olika golv när golvens kvalitet skiljer sig påtagligt. Med hjälp av metoden demonstrerades en förbättring av kons rörelser på golv med gummimattor. Bland annat påvisades ökad rörelsekomfort hos halta kor på gummiunderlag och sand jämfört med på hårda betonggolv. På grund av den stora variationen i kors gång blir det mer representativt om man använder flera steg vid analys av gångmönstret.

Резюме

Передвижение в пространстве или локомоция является неотъемлемой частью нормального поведенческого репертуара крупного рогатого скота. Кроме того, движение необходимо для общего здоровья продуктивных животных, их нормального роста и развития, плодовитости и увеличения продуктивности. Становящееся все более распространенной, беспривязная система содержания молочного скота призвана обеспечивать свободное круглосуточное передвижение животных. Однако конструкции полов, предназначенных для передвижения животных, зачастую не отвечают требованиям для нормальной локомоции и являются одной из важнейших причин заболеваний конечностей крупного рогатого скота.

Оценка локомоции животных объективными методами (анализ кинетики и кинематики движения) позволяют представить достаточно полную картину характера функции опорно-двигательного аппарата. Однако существующие методы объективного анализа локомоции подразумевают использование дорогостоящего оборудования и, зачастую специальных условий для измерений, что затрудняет широкое использование этих методов в производственных условиях. В данной работе предложен метод оценки локомоции крупного рогатого скота посредством измерения следовых дорожек.

Целью исследования была оценка надежности параметров локомоции, полученных в результате измерений следовых дорожек крупного рогатого скота, а также исследование возможности применения этих параметров для оценки влияния полового покрытия на локомоцию коров с нормально функционирующим двигательным аппаратом, а также с его патологией.

Для изучения надежности параметров локомоции были использованы следовые дорожки 32 коров голштинской породы без признаков патологии органов движения. Измерение следовых дорожек осуществлялось на щелевом бетонном полу, дважды, с трехнедельным интервалом; при этом в каждый тест входили измерения параметров четырех локомоторных циклов. Для анализа влияния полового покрытия на локомоцию были изучены следовые дорожки 36 коров голштинской и шведской красно-пестрой пород, с различным статусом опорно-двигательного аппарата. Состояние опорно-двигательного аппарата оценивалось субъективно по 4-х балльной шкале. В соответствие с этой оценкой животные были выделены в следующие три группы: коровы без видимых нарушений движения, с легкими нарушениями передвижения и нарушениями средней тяжести. Животные с тяжелыми повреждениями органов движения в исследовании не использовались. Локомоция каждого животного изучалась на всех пяти следующих покрытиях: сплошной и щелевой бетонный пол с применением и без применения мягкого резинового покрытия толщиной 20 мм, а также прессованный влажный песок (как образец натурального, природного покрытия). Для лучшей дискриминации отпечатков конечностей на все

поверхности (за исключением песка) наносился водный раствор гидроксида кальция ($Ca(OH)_2$).

При оценке надежности промеров следовой дорожки использовались измерения следующих семи ее элементов: длина двойного шага (расстояние между отпечатками одной задней конечности в течение одного локомоторного цикла), угол шага (угол, образованный линиями, соединяющими три последовательных отпечатка задних конечностей), ширина следовой дорожки, длина диагонального шага (расстояние между двумя последовательными отпечатками задних конечностей), асимметрия шага (разница между значениями двух последовательных диагональных шагов), расстояние недокрытия-перекрытия (расстояние между отпечатками задней и передней конечностей одной стороны по ходу движения), абдукция-аддукция шага (латеральное расстояние между отпечатками задней и передней конечностей одной стороны). При оценке влияния качества пола на локомоцию не использовались показатели ширины следовой дорожки и аддукции-абдукции.

Надежность оценки параметров локомоции измерялась как процент компонентов дисперсии между животными от суммы компонентов дисперсии, включающей дисперсию между тестами, внутри-индивидуальную дисперсию внутри теста, а также дисперсию эффекта взаимодействия между тестом и индивидом. Анализ выявил средний уровень оценки надежности для показателей двойного шага, угла шага, ширины следовой дорожки и величины недокрытия-перекрытия следа (52–65%). Надежность абдукции-аддукции и диагонального шага была довольно низкой (25,4 и 37,8% соответственно). Показатель надежности для асимметрии шага был на очень низком уровне (18,1%), что объяснялось несистематическими изменениями координации конечностей животных с нормальной функцией опорно-двигательного аппарата.

Двойной и диагональный шаг были значительно укорочены при передвижении по скользкому бетонному, щелевому полу в сравнении со всеми остальными покрытиями. В то же время длина шагов увеличивалась при передвижении по мягкому резиновому покрытию. Коровы со средней тяжестью нарушений двигательной системы значительно укорачивали длину шагов по сравнению с животными без нарушений и с легкими нарушениями локомоции. Животные со средней тяжестью нарушения локомоции передвигались со значительно меньшим углом шага по бетонным полам, чем по мягким поверхностям. Асимметрия шага прогрессивно увеличивалась от животных без видимых нарушений движений до животных с нарушениями локомоции средней тяжести. При этом асимметрия шага была выражена в меньшей степени при передвижении по песку и мягким резиновым покрытиям.

Было заключено, что измерение следовых дорожек крупного рогатого скота может служить достаточно хорошим методом для объективной характеристики локомоции крупного рогатого скота в производственных условиях. Метод позволил обнаружить улучшение качества локомоции на полах, усовершенствованных резиновым покрытием. В том числе, было показано повышение комфорта передвижения у животных с заболеваниями конечностей по мягким покрытиям по сравнению с традиционными бетонными полами. Учитывая относительно высокую нестабильность локомоции коров, для получения репрезентативного результата, необходимо использовать измерения элементов нескольких локомоторных циклов.

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