The mechanical properties and lesion score of the sole and white line horn of front and hind claws of heifers prior to and during first lactation

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ABSTRACT

The aim of this experiment was to study the incidence of lameness and the pattern of lesion formation in the sole horn during the pre- and post-partum period of first lactation Holstein Friesian heifers and to compare these to mechanical testing of the hoof horn strength and with the breed society (Holstein Friesian) index of classification for conformation (HUKI) to compare heifers susceptibility to lameness. Samples of sole hoof horn were taken from all claws of 20 heifers at 144 and 40 days pre-partum and 50, 100 and 150 days post-partum. Simultaneously, all claws were assessed for the lesion score in the sole horn. Locomotion score was assessed weekly and heifers were conformation scored for the Holstein UK Index (HUKI). Hoof samples were analysed for elastic modulus and punch resistance. Punch resistance of the sole horn was significantly greater in front claws when compared to hind claws. The punch resistance, elastic modulus, lesion score and locomotion score increased significantly during the post-partum compared with the pre-partum period. post-partum elastic modulus and punch resistance were significantly negatively correlated to increase in lesion score and locomotion score between measurement periods and positively correlated to the breed society conformation index (HUKI) score for legs and feet. Mechanical tests reflected the changes in housing and in haemorrhage levels that occurred between 144, 40 pre- and 100 days post-partum and there may be a potential to select animals for increased hoof horn quality and reduce wear rates during lactation.

Keywords: Dairy cattle; claw horn; elasticity; punch resistance; locomotion.

INTRODUCTION

The beginning of the lactation period has been related to an increase in the number and severity of claw horn lesions of dairy cows and heifers (Offer *et al.*, 2000). The rearing of heifers, their growth rate, feeding and the occurrence of foot lesions have been found to affect the occurrence of lameness in later life (Thomas *et al*., 1999). The mechanical properties of the hoof horn should reflect the horn structure that is determined by the composition and chemical bonding of keratin proteins, keratin filaments and

filament-associated proteins. The structure, composition and amount of the intercellular cementing substance and the architecture of the horn, *i.e.* the arrangement of horn tubules and intertubular space (Mulling *et al.*, 1994), and morphological differences between front and hind claws have been reported, where the dry matter of claws was significantly higher in areas that had higher values of elastic modulus (Schmid, 1995). The quality of keratinisation has been found to be dependent on the appropriate supply of nutrients and oxygen and the living epidermal cells are very susceptible to disturbance of circulation within the vessels of the corium (Mulling & Budras, 2002). Mechanical factors play an important role in the pathogenesis of claw horn lesions and maximum stresses are found in the axial wall and heel areas (Hinterhofer *et al*., 2005) and, in other studies, in the sole area (Van der Tol *et al*., 2002), those areas being more susceptible to suffer damage to the corium. The distal part of the hoof horn, which encompasses the sole, white line and heel areas, is the site of the majority of the lameness in dairy cows and levels of haemorrhage in the sole and white line areas of the claw horn have been found to increase during the post-partum period (Offer *et al.,* 2000). This increase in lesions has been related to hormonal changes at parturition that cause the softening of collagen fibres that suspend the pedal bone thus increasing the pressure over the corium on the solar area of the hoof (Tarlton *et al.,* 2002). Score for lesions has been found to be greater also in the hind outer claws when compared to other claws (Offer *et al.,* 2000). The present study aimed to develop mechanical methods of assessment to measure the changes in the mechanical properties of the sole and white line areas of the hoof horn, in order to compare these with standard methods of assessment of lameness *i.e*. locomotion scoring (Tranter & Morris, 1991) and scoring of sole bruising (Leach *et al*., 1998). The mechanical tests were used to assess the changes in the structural strength of hoof horn at differing stages of lactation and levels of horn haemorrhage. In a previous experiment with heifers Winkler & Margerison

(2004) have demonstrated an increase in lesion scores of the sole and white line areas in the post-partum period and a decrease in the punch force of the sole and white line. As a consequence, the aim of this experiment was to study the occurrence of lesions in the sole and white line areas of the hoof horn during the *pre-partum* period of first lactation heifers and compare the lesion score to the strength of the horn of different claws.

MATERIALS AND METHODS

Mechanical tests were completed on hoof sole samples collected from 20 Holstein-Friesian heifers at 144 days pre-partum (The heifers were between 24 and 31 months of age and were housed in a straw-bedded yard up until 172 d pp followed by which they were grazed at pasture All claws were scored for the level of haemorrhage and ulceration of the sole horn. Locomotion score was assessed weekly (Tranter & Morris, 1991) and heifers were professionally scored for the Holstein society breed index (HUKI) once during the first lactation. The hoof samples were collected from all claws from zones 2, 4 and 5 of the sole, according to the International Foot Map (IFM) and the hoof samples were kept in sealed plastic bags and stored at a temperature of 2°C until analysis. The punch force was tested using a P/2N needle probe on a TA.XT2i Texture Analyser (Stable Micro-Systems, Surrey, UK). The thickness of the sample on the tested area was recorded simultaneously. Considering the test piece to be a circular plate clamped around its circumference and with a small thickness (membrane), the elastic modulus of the membrane was calculated according to Blake (1982) from the equation for maximum lateral deflections of circular plates. A total of 6 to 8 tests were completed on the sole and white line areas. Following the completion of the mechanical tests the samples were weighed and placed in the oven (100°C for 72 hours) for the determination of the dry matter. The punch tests and lesion score data was analysed by ANOVA, GLM (Minitab 12.0). The thickness of the samples was used as a covariant when punch force data was analysed. The comparison of means was completed using the Tukeys test (95% confidence interval).

RESULTS

The mean values for punch force, elastic modulus of the diaphragm and lesion score of the sole and white line areas of the claw horn of the front and hind claws are presented in Table 1. The lesion score of the sole area did not differ between claws. The lesion score of the WL area was significantly ($P< 0.001$) greater for the hind outer claws when compared to front claws. The punch force required to fracture the sole horn was significantly greater in front inner claws when compared to hind inner claws ($P<0.05$). The elastic modulus of the diaphragm of the sole horn was significantly greater in front inner claws when compared to hind outer claws ($P<0.01$). The punch force of the WL area did not differ between claws. The elastic modulus of the diaphragm of the WL was significantly ($P<0.05$) greater for the front claws when compared to the hind inner claws. The dry matter did not differ between front (DM 31.4%) and hind claws (DM 32.1% (sem 0.53)).

The locomotion score was found to increase significantly ($p<0.001$) from day 7 up until day 120 of the post-partum period and subsequently decreased after day 150 post-partum. (Locomotion score = -8×10^{-5} days^2 + 0.0212 days + 0.9759, R^2adj. = 0.795). Hoof lesion score was calculated separately for the sole and white line areas of each claw of each hoof. The mean total lesion score of the sole and white line areas was found to increase significantly ($p<0.001$) from the *pre-partum* to the post-partum period and during the post-partum period (-40 days – 764.1 and 584.5; 50 days – 1295.0 and 1180.2; 100 days – 1623.4 and 1636.9 for sole and white line respectively). The days of the *peri-partum* period had no significant effect on mean elastic modulus of the tension test of the white line horn (day -40 – 91.32 N/mm^2, day 50 – 77.78 N/mm^2, day 100 – 78.62 N/mm^2 and day150 – 104.12 N/mm^2). Punch resistance of the white line horn decreased significantly between day 40 *pre-partum* and days 50 and 100 of the post-partum period (day –40 – 6.92N a, day 50 – 5.92N c, day 100 – 5.88N bc and day 150 – 6.24N ab). The punch resistance and elastic modulus of the tension test of the sole horn increased significantly at day 100 post-partum (day –40 – 8.68 N b and 88.76 N/mm^{2}b, day 50 – 8.60 N b and 71.49 N/mm^{2}b, day 100 – 10.57 N a and 97.96 N/mm^{2}b, day 150 – 10.74 N a and 151.60 N/mm^{2}a).

The mean values for punch force and lesion score of the sole and white line areas of the claw horn and elastic modulus of the claw horn of the front and hind claws at 40 days pre-partum and 100 days post-partum, are presented in Table 2. No difference was obtained between the measurements of elastic modulus of front and hind claws in any measurement period. No difference in the punch resistance and lesion score of claws was obtained in the pre calving period. The punch resistance of the sole and white line areas of the claw horn were significantly greater in the front claws when compared to the hind claws in the post-partum period ($p<0.01$), but no significant difference was

Table 1: Mean lesion score, punch force (P.force)and elastic modulus of the diaphragm (EMd) of the sole and white line horn of sole and white line (WL) areas of front and hind, left and right, inner and outer claws 6 months before parturition.

	Front				Hind					
	Left		Right		Left		Right			
Claws	**Outer**	**Inner**	**Inner**	**Outer**	**Outer**	**Inner**	**Inner**	**Outer**	**sem**	**P**
Lesion score										
Sole	74.4	96.0	77.8	95.8	92.3	96.1	112.2	92.3	21.06	NS
White line	106.0^{b}	113.5^{ab}	109.5^{ab}	123.4^{ab}	168.5^{ab}	148.4^{ab}	159.9^{ab}	187.4^{a}	18.47	0.05
Punch force										
Sole (N)	9.72^{ab}	10.83^{a}	9.99^{ab}	10.52^{ab}	9.72^{ab}	9.71^{ab}	8.77^{b}	9.18^{ab}	0.474	0.05
White line	6.25	6.74	7.37	7.09	6.46	6.78	6.22	6.36	0.34	NS
Elasticity										
Sole (N/mm^2)	8.85^{ab}	14.17^{a}	12.61^{ab}	14.42^{a}	13.45^{ab}	6.20^{b}	9.48^{ab}	7.32^{b}	1.784	0.01
White line (N/mm^2)	14.81^{ab}	15.53^{a}	13.93^{ab}	16.75^{a}	14.56^{ab}	12.54^{ab}	9.69^{b}	13.48^{ab}	1.242	0.05

$^{a, b, c}$ – different letters in the same row indicate values that differ significantly,
NS – not significantly different

Table 2: Punch resistance and lesion score of the sole and white line (wl) areas of the claw horn and elastic modulus of the claw horn of front and hind claws 40 pre- and 100 days post-partum in first lactation heifers.

Claw	**Front**	**Hind**	**sem**	***P***
Lesion score				
At 40 d pre partum	71.09	75.05	6.21	NS
At 100 d post-partum	149.32	223.72	9.00	0.001
Increase in lesion score 40 to 100 d pp	78.23	148.67	10.59	0.001
Punch resistance sole (N)				
At 40 d pre partum	8.24	7.41	0.46	0.01
At 100 d post-partum	11.06	10.32	0.24	0.05
Punch resistance of white line (N)				
At 40 days pre partum	6.25	5.95	0.48	NS
At 100 d post-partum	6.43	5.69	0.24	0.01
Elastic modulus (N/mm^2)				
At 40 d pre partum	92.78	86.80	17.0	NS
At 100 d post-partum	96.17	101.26	12.73	NS

NS – Not significantly different

obtained between the inner and outer claws of front and hind feet. At 100 days *pos- partum,* the lesion score of the sole and white line areas was significantly greater in the hind claws when compared to the front claws ($p<0.001$) and the increase in the lesion score was also significantly greater in the hind claws when compared to the front claws ($p<0.001$). In the hind feet the outer claws presented a significantly ($p<0.05$) greater lesion score when compared to the inner claws in the post-partum period. In the front feet the lesion score was significantly higher ($p<0.05$) in the outer claws before parturition and in the inner claws ($p<0.01$) after parturition. The elastic modulus of the tension test of the sole at day 100 post-partum was significantly ($P<0.01$) negatively correlated to locomotion score at day 154 post-partum ($R^2 = -0.61$). The number of days the heifers were lame throughout the lactation, corresponding to heifers with a locomotion score > 3, and the number of days animals were severely lame, corresponding to heifers with a locomotion score > 4, throughout the lactation were significantly ($P <0.01$) negatively correlated to the punch resistance of the sole horn at 100 days post-partum ($R^2 = -0.50$).

The HUKI score for rear legs was significantly ($P<0.05$) and positively correlated to the punch resistance of the sole and white line horn at 40 days pre-partum ($R^2 = 0.55$ and 0.50) and to the elastic modulus of the sole area at 50 days post-partum ($R^2 = 0.53$). The HUKI score for feet was significantly ($P<0.01$) and positively correlated to the punch resistance and negatively correlated to lesion score of the white line area at 40 days pre-partum ($R^2 = 0.50$) and to the number of days the animals were severely lame throughout the lactation, corresponding with a locomotion score > 4 ($R^2 = 0.50$). The HUKI locomotion score was significantly ($P<0.05$) and positively correlated to the punch resistance of the white line horn at 100 days post-partum ($R^2 = 0.50$). The HUKI total score for legs and feet was significantly ($P<0.05$ to 0.01) negatively correlated to the punch resistance

of the white line horn at 150 days post-partum (R^2 = - 0.50) and the number of days the animals were severely lame throughout the lactation, corresponding with a locomotion score > 4 (R^2 = - 0.48). The HUKI total final score was significantly (P<0.05 to 0.01) negatively correlated to the punch resistance of the white line horn at days 50 and 150 post-partum (r = -0.50) and to the punch resistance of the sole horn at day 150 post-partum (R^2 = - 0.60).

DISCUSSION

The increase in lesion score and in locomotion score after calving was reported before in heifers and cows (Offer *et al.*, 2000) and is related to physiological and management changes around parturition. The increase in the punch resistance and elastic modulus of the sole horn at 100 days post-partum was not expected due to the increase in lesion score of the sole area at this period. The decrease in punch resistance of the white line horn at days 50 and 100 post-partum was expected. The increased resistance to puncture in front claws when compared to hind claws, is likely to be related to the different pressure distribution in these claws, predisposing the hind claw to suffer lesions through contusion. The higher lesion scores found in the hind feet indicate that this sole bruising occurred in heifers feet as early as 144 days (6 months) *pre-partum*, due to the greater pressure exerted on the white line area of the hind outer claw when compared to other claws.

Hoof horn conformation is related to the pressure exerted by the weight distribution on the claws that is related to the conformation of feet and legs. Winkler & Margerison (2004) reported lower punch resistance and elastic modulus of hoof horn from heifers with lower foot angle, poor locomotion score and lower scores for the composite (HUKI) trait legs and feet. The higher values for punch force and elastic modulus of the sole area and elastic modulus of the white line area of different front claws when compared to hind claws can be related to morphological differences between those claws. Leopold & Prietz (1980) found a significantly higher density of tubules in the wall horn of the hind claws (8.7% more tubules/area) when compared with the front claws. The mean diameter of the tubular medula of the wall horn was also 12.1 % significantly greater for the hind claws when compared to the front claws (Leopold & Prietz, 1980).

Higher hoof hardness (Schmid, 1995) and higher elastic modulus values (Zoscher *et al.,* 2000) have been reported for front claws when compared to hind claws. In both these experiments the dry matter of the front claws was significantly higher than that of the hind claws and the higher hardness values may have been in some part due to differences in horn DM content. Mechanical tests reflected the changes in housing and in haemorrhage levels that occurred between the pre-partum and post-partum period. The correlation between the HUKI conformation traits and punch resistance and elastic modulus of the horn indicate that certain types of conformation may predispose the heifers to have a weaker hoof horn properties.

Sole horn properties are related to the pressure exerted by the weight distribution in the claws that is related to the conformation of feet and legs (Touassaint-Raven, 1985). In systems were cows walk long distances, the selection of dairy cattle with stronger hoof horn and conformation of the feet and legs provide the opportunity to reduce sole wear rates and increase sole thickness, thus reducing the risk of hoof penetration and the incidence of lameness.

CONCLUSIONS

In this present experiment, hardness of hoof horn of the hind claws was significantly lower compared with front claws, while the dry matter did not differ between front and hind claws. Lower punch resistance and elastic modulus was found in heifers with straighter rear legs, lower foot angle, poor HUKI locomotion score, lower scores for the composite trait legs and feet and a higher final total score. Using a combination of scoring for conformation traits, mechanical tests and lesion scoring there is a potential for selection for better hoof horn quality at the start of the first lactation. This provides the opportunity to reduce lameness in dairy cattle by selecting cattle that have lower wear rates and lameness related to thin sole, sole bruising and sole penetration.

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