J. Dairy Sci. 100:1–14
https://doi.org/10.3168/jds.2016-12012


# A prospective cohort study of digital cushion and corium thickness. Part 1: Associations with body condition, lesion incidence, and proximity to calving

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## ABSTRACT

Claw horn disruption lesions (CHDL) are a major cause of lameness in dairy cattle and are likely a result of excessive forces being applied to the germinal epithelium that produces the claw horn. The digital cushion is a connective tissue structure, containing depots of adipose tissue, that sits beneath the distal phalanx and has been shown to be thicker in fatter cows. Body condition score (BCS) loss is a risk factor for CHDL, and one possible explanation is that fat is mobilized from the digital cushion during negative energy balance, causing the digital cushion to thin and lose force-dissipating capacity, leading to disruption of claw horn growth. This prospective cohort study investigated the association between measures of body fat and sole soft tissue (SST) thickness (a combined measure of the corium and digital cushion beneath the distal phalanx) in a longitudinal manner. The SST of 179 cows in 2 high-yielding dairy herds were measured at 5 assessment points between 8 wk before and 35 wk postcalving. The BCS, back fat thickness (BFT), and lesion incidence were recorded. Data were analyzed in a 4-level mixed effects regression model, with the outcome being SST thickness beneath the flexor tuberosity of the distal phalanx. Data from 827 assessment points were available for analysis. The overall mean of SST was 4.99 mm (standard deviation: 0.95). The SST was thickest 8 wk before calving (5.22 mm, standard deviation: 0.91) and thinnest 1 wk postcalving (4.68 mm, standard deviation: 0.87), suggesting an effect of calving on SST. The BFT was positively correlated with SST in the model with a small effect size (a 10 mm decrease in BFT corresponded with a 0.13 mm decrease in SST), yet the nadir of BFT was 11.0 mm at 9 to 17 wk postcalving (when SST was ~4.95 mm), rather than occurring with the nadir of SST immediately after calving. The SST also varied with other variables [e.g., cows that developed a sole ulcer or severe sole hemorrhage during the study had thinner SST (−0.24 mm)], except when a sole ulcer was present, when it was thicker (+0.53 mm). Cows that developed lesions had a thinner digital cushion before the lesion occurrence, which became thickened with sole ulcer presence, perhaps representing inflammation. Furthermore, although BFT was correlated with SST over time, SST may also have been influenced by other factors such as integrity of the suspensory apparatus, which could have a major effect on CHDL. Measures of body fat likely contributed to having thin SST, but other factors including calving, herd, and lesion presence also had an effect.
**Key words:** dairy cow, lameness, body condition, digital cushion

## INTRODUCTION

Claw horn disruption lesions (**CHDL**: sole hemorrhage, sole ulcer, and white line disease) cause a large proportion of lameness in dairy cattle and have a high rate of recurrence (Hirst et al., 2002; Reader et al., 2011; Green et al., 2014). These diseases are prevalent in developed dairy systems worldwide (Barker et al., 2007; Dippel et al., 2009; Foditsch et al., 2016), significantly affect cow welfare and farm profitability (Booth et al., 2004; Sogstad et al., 2006; Cha et al., 2010), and have a plethora of associated risk factors (Cramer et al., 2009; Chapinal et al., 2013; Solano et al., 2015). Sole ulcers and sole hemorrhage appear to be different presentations of a similar disease process, which is likely through insult to the germinal epithelium of the sole and poor quality horn production, as a result of inappropriate transfer of forces through the foot (Bicalho and Oikonomou, 2013; Nuss, 2014); white line disease may also precipitate from the same disease process where contusions occur in the soft tissues around the

Received September 18, 2016.
Accepted February 19, 2017.
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periphery of the base of the foot (Le Fevre et al., 2001; Newsome et al., 2016).

Epidemiological studies have demonstrated that body condition loss preceded lameness events, whether lameness was defined by visual detection of impaired mobility (Lim et al., 2015; Randall et al., 2015) or by CHDL treatment incidence (Green et al., 2014). The distal phalanx is suspended from the hoof wall by strong ligamentous attachments, referred to as the suspensory apparatus of the distal phalanx, and is supported by the digital cushion, which is a modified layer of the subcutis that is situated beneath the caudal aspect of the distal phalanx. The cushion and associated structures are considered to be important in absorbing impact and dissipating forces during foot strike and limb loading, protecting the germinal epithelium that produces the sole horn (Lischer et al., 2002). Thickness of the digital cushion has been assessed in several studies that used ultrasonography to measure the distance from the inner aspect of the claw horn to the distal surface of the distal phalanx, beneath the flexor tuberosity. The measurement incorporates 2 tissue layers: the subcutis (i.e., the digital cushion) and the dermis (corium). Previous works have termed combined measurements of the 2 tissue layers as "digital cushion thickness," where the measurement was taken beneath the axial aspect of the flexor tuberosity (Bicalho et al., 2009; Machado et al., 2011), or "sole soft tissue thickness," where the measurement was taken in the midline of the sole (Toholj et al., 2014).

Bicalho et al. (2009) reported that BCS was positively associated with digital cushion thickness. This association could be biologically plausible because the digital cushion contains adipose tissue (Räber et al., 2004, 2006); therefore, lipid could be deposited to and mobilized from the digital cushion during periods of positive and negative energy balance. Further, having a thin digital cushion and corium thickness appears to predispose subsequent lameness from CHDL (Machado et al., 2011; Toholj et al., 2014). A possible mechanism for the temporal association between body condition loss and lameness is that fat is mobilized from the digital cushion during negative energy balance, which leads to depletion of the digital cushion, poorer force dissipation of forces during foot strike, greater peak forces on the germinal epithelium, leading to hemorrhage and interrupted epidermal differentiation and cornification, the formation of poor quality sole horn, and subsequent lameness. However, previous works assessing the digital cushion and corium have assessed their combined thickness at a single time point (Bicalho et al., 2009; Machado et al., 2011; Toholj et al., 2014), and whether the digital cushion becomes thinner as body fat is mobilized is yet to be demonstrated. This is a key step in demonstrating whether digital cushion depletion with body condition loss is a mechanism by which cows develop CHDL.

The current article presents a prospective cohort study of the sole soft tissues (a combined measure of thickness of the digital cushion and the corium), lameness and lesions, and analyses of associations between sole soft tissue thickness and measures of body fat. The aim of this analysis was to determine how the digital cushion changes throughout lactation and with changes in measures of body fat.

## MATERIALS AND METHODS

### *Study Design*

A prospective cohort study assessed the combined thickness of the digital cushion and corium (termed sole soft tissue thickness) on the hind claws at 5 time points (termed assessment points; **AP**) between approximately 8 wk before and 35 wk postcalving. The null hypothesis stated that sole soft tissue thickness did not vary with measures of body fat. Animals were studied during first, second, third, or fourth lactation, from before calving. On the hind feet, the sole soft tissues were measured ultrasonographically and foot lesions were recorded at each AP, and cows were locomotion scored every 2 wk from calving. Local ethical approval was granted by the University of Nottingham School of Veterinary Medicine and Science Ethical Review Committee.

### *Timing of Assessment Points*

Animals were enrolled at the first AP, which was at approximately 8 wk before their predicted calving date, termed **AP−8**. The second AP occurred between 4 and 10 d postcalving and was termed **AP+1** (approximately 1 wk postcalving). The third AP was at 6, 8, or 10 wk after AP+1 and this period was assigned sequentially within each lactation group, such that cows from each lactation group were studied across the range of likely timings of peak yield. This third AP occurred on average 9 wk postcalving and was termed **AP+9**, and the variation in this timing was accounted for by testing a polynomial function of DIM in the statistical analysis. Assessment points 4 and 5 were 8 and 20 wk after AP+9 (**AP+17** and **AP+29**, respectively).

### *Study Farms*

Two high-producing herds were selected and were visited weekly from November 13, 2013, until May 19, 2015. The farms were selected for convenience to