Lameness in Dairy Cattle: A Debilitating Disease or a Disease of Debilitated Cattle?

Rodrigo C. Bicalho DVM, PhD
Assistant Professor of Dairy Production Medicine
Veterinary College, Cornell University
CUHA Box 29 Ithaca NY 14853-6401

Relevance of Lameness to the Dairy Industry

A growing concern of the dairy industry is to increase dairy cattle wellbeing in anticipation of a demand from the general public of welfare-certified dairy products. Lameness is one of the most important welfare issues of high producing dairy cows in North America (Vermunt, 2007). It is a debilitating condition that challenges sustainability of production systems used in North America because of the pain and subsequent animal welfare consequences (Vermunt, 2007) and also the significant economic losses (Warnick et al., 2001). A study conducted in England concluded that lameness was the second most costly disease in the dairy industry following only mastitis (Kossaibati and Esslemont, 1997).

Lameness results in earlier culling of animals as well as lower carcass weight, conformation class, and fat cover class and hence a lower carcass economic value (Booth et al., 2004; Bicalho et al., 2007c; Fjeldaas et al., 2007). It has also been reported that prevention or early identification and treatment of the problem can improve the value of the carcass and reduce culling rates (Fjeldaas et al., 2007). Several studies have also shown that lameness has a negative effect on the fertility of dairy cows (Sprecher et al., 1997; Hernandez et al., 2001; Garbarino et al., 2004). More recently, it has been reported that cows detected with clinical lameness in the first 70 days in milk (**DIM**) were 25% less likely to become pregnant compared to non-lame cows (Bicalho et al., 2007c). The prevention of lameness is the most important step to reduce its welfare implications for cows and associated economic losses to the dairy farmers (Mill and Ward, 1994). Hence it is important to create a system that accurately predicts the occurrence of lameness, thus allowing farmers to target high risk animals with preventive strategies.

Importance of Lameness to the Wellbeing of Dairy Cows

Lameness is a crucial welfare issue in modern dairy production (Espejo and Endres, 2007; Vermunt, 2007). Lame cows suffer discomfort and pain of long duration (Green et al., 2002). Additionally, the observation of lameness has been classified as the most representative animal-based indicator of welfare in dairy cattle (Whay et al., 2003). There is an increasing societal concern about the moral and ethical treatment of food animals (Fulwider et al., 2008). Lameness is of welfare concern due to its debilitating effects and high prevalence in herds throughout the world (Cook, 2003; Bicalho et al., 2007c). Furthermore, dairy cattle mortality is a major cause of economic losses and is an important animal welfare issue (Thomsen and Houe, 2006). A large retrospective cohort study with over 900 dairy farms reported that dairy operations with high prevalence of lameness (≥ 16 %) had 2.9 higher odds of on farm dairy cow mortality compared to dairy farms with low lameness incidence (McConnel et al., 2008); dairy cows that died on the

farm because of lameness were usually euthanized by a farm employee or veterinarian. Lameness is perhaps the biggest challenge for dairy farmer to overcome as society becomes more concerned with the origin of their food and the welfare of farm animals.

Polls and surveys conducted within the United States show general agreement that there is public support for the protection of farm livestock and poultry (Swanson, 2008). The animal welfare assurance and audit programs developed by the private sector are an attempt to assure consumers that best practice measures and independent oversight result in a reasonable quality of life for food-producing animals. It is a possibility that milk processing plants will start to market and commercialize milk from welfare-certified herds in an attempt to anticipate the demand from welfare-oriented consumers. In fact, the commercialization of bST (bovine somatotropin) free milk is a reality; consumers perceive that welfare of the animals from bST-free herds is better than otherwise. As it happened to bST-free milk, the motivation for marketing welfare-certified milk will come from the concern of the general public (consumers) regarding the wellbeing of dairy cows. Some attempts to voluntarily achieve welfare certification are already in place; The New York State Cattle Health Assurance Program (NYSCHAP) is an example of such a program. The NYSCHAP welfare certification requires that at least 85% of each animal management group must have a locomotion score of two (using a five-point-scale visual locomotion score system). This benchmark would be at the very least a hard to achieve goal for most dairy farms given the reported prevalence of lameness throughout the United States (Cook, 2003; Espejo et al., 2006; Bicalho et al., 2007c).

Dairy farmers in North America are not regulated in regards to the welfare of their animals and production standards except in extreme cases of neglect and abuse. In contrast, regulation of food animal production has become part of mainstream life for European Union livestock and poultry producers (Swanson, 2008). The freedom that European producers once had to produce animals as they saw fit gradually vanished by public command. To enable the dairy industry in the United States to effectively anticipate and respond to societal concerns about ethical treatment of animals, there is a great need to identify opportunities to prevent the incidence of lameness in dairy cattle.

The Pathogenesis of Non-Infectious Causes of Lameness

Despite the undeniable relevance of lameness resulting from non-infectious diseases, very little is known about its pathophysiology. Although severe cases of laminitis (inflammation of the laminar tissue of the digit) caused by abnormally high intake of readily available carbohydrates have been described in the literature (Bazeley and Pinsent, 1984), the link between subclinical laminitis and claw lesions has been recently challenged (Logue et al., 2004). To make matters worse, research knowledge on the pathogenesis of equine laminitis was uncritically generalized to the field of bovine lameness without taking into account the profound anatomical and physiological differences between the two species. Thus far, there is limited evidence that claw horn lesions in cattle are caused by subclinical laminitis (Logue et al., 2004; Thoefner et al., 2004; Lischer et al., 2002). Lately, the hypothesis that claw lesions are a consequence of contusions within the claw horn capsule has been suggested (Tarlton et al., 2002; Raber et al., 2004). Raber et al. (2004) reported that it is widely accepted by workers in the Northern Hemisphere that most bovine claw lesions (and thus lameness) originate from contused tissue

within the claw horn capsule. While it has been reported that sole ulcers and white line lesions are caused by subclinical laminitis (Thoefner et al., 2004), there are others who clearly state that the evidence to support this is limited (Logue et al., 2004). The suspensory apparatus in cattle is less well developed than in the horse and the digital cushion must support a considerably higher proportion of the body weight (Raber et al., 2004). The digital cushion is a complex structure composed mostly of adipose tissue located underneath the distal phalanx; it plays an important function of dampening compression of the corium tissue beneath the cushion. The biomechanical importance of the digital cushion in alleviating compression under the tuberculum flexorum of the distal phalanx is well known (Raber et al., 2006; Raber et al., 2004; Logue et al., 2004).

Research Summary

Research currently in progress, or recently completed by key personal, has focused on the impact of lameness on production parameters, validation of lameness detection systems, pathophysiology of sole-ulcers and white-line-diseases, and evaluation of lameness prevention strategies. Our recent research has allowed us to explore a new pathogenesis theory for claw horn disruption lesions (**CHDL**) and consequently envision novel preventive strategies. Historically, lameness researchers and experts believed that CHDL were caused by sub-clinical rumen acidosis and that the poor body condition observed in affected cows was a consequence of lameness and not a cause of lameness. We currently demonstrated that cows with low BCS have significantly thinner digital cushions and therefore a lower capacity to protect the corium tissue from compression by the third phalanx. Details about our recently completed significant activities and its link to our proposed project are described below.

Impact of Lameness on Reproduction, Survivability, and Milk Production of Dairy Cows (Bicalho et al., 2007b; Bicalho et al., 2008):

Previously, we estimated the detrimental effects of lameness on calving-to-conception interval and hazard of dying or being culled in lactating Holstein cows. Data were collected from 5 dairy farms located in upstate NY from November 2004 to June 2006. The study design was a prospective observational cohort study. Cows were assigned a visual locomotion score (VLS) using a 5-point scale ranging from 1 = normal, 2 = presence of a slightly asymmetric gait, 3 = the cow clearly favored 1 or more limbs (moderately lame), 4 = severely lame, to 5 = extremely lame (non-weight bearing lame). In total 1,799 cows were enrolled. In 2 alternative categorizations, cows were considered lame if at least 1 VLS was ≥ 3 during the first 70 DIM and secondly, if at least 1 VLS was ≥ 4 for the same period. Lameness (VLS ≥ 3) was detected at

Figure 1: *The effect of lameness on reproduction (Bicalho et al., 2007)*

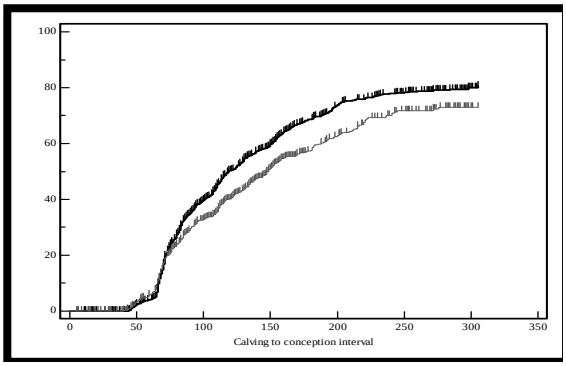
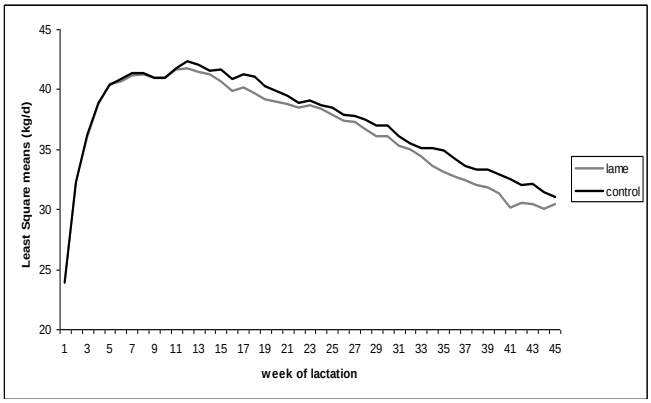


Figure 2: *The effect of lameness on milk production (Bicalho et al., 2008)*



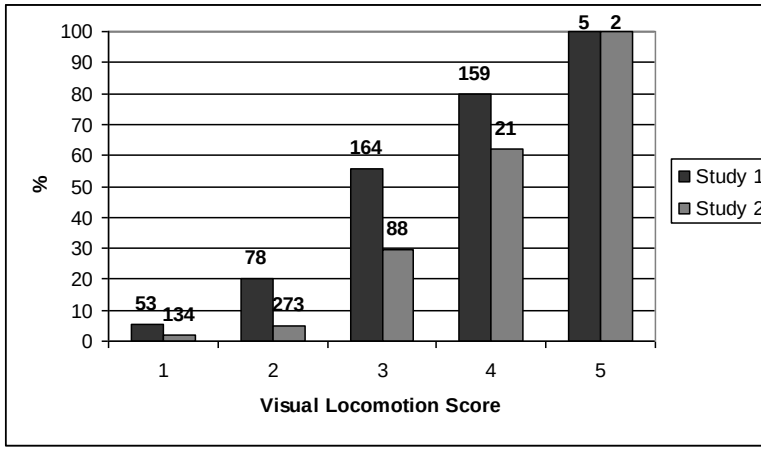
least once in 26.5%, 54.2%, 33.9%, 51.8%, and 39.3% of all cows in farms 1 to 5, respectively. The hazard ratio of being detected pregnant was 0.85 for lame cows (VLS ≥ 3) versus non-lame cows; hence, lame cows were at a 15% decreased risk of pregnancy than non-lame cows. When lameness was redefined as VLS ≥ 4, the hazard ratio having been detected pregnant was 0.76 for lame cows versus cows with VLS < 4 (Figure 1). Lameness increased the hazard ratio of culling/death, 1.45 and 1.74 for VLS ≥ 3 and VLS ≥ 4, respectively, versus cows with VLS < 3 and VLS < 4, respectively. The detrimental effects were amplified when considering only severely lame and non-weight-bearing cows.

Recently, we have shown that high milk production in the beginning of the lactation is an important risk factor for CHDL; lame cows produced an excess of 3 kg/d more milk during the first three weeks of lactation compared to non-lame cows. However, when using an ANOVA that included the average milk production for the first 3 weeks of lactation as an independent variable, it was revealed that lameness incidence was associated with a milk production loss of up to 424 kg\cow per 305-day lactation (Figure 2). In summary, lameness significantly decreased the hazard of pregnancy, increased the hazard of culling/death, and was associated with significant milk loss.

The Accuracy of Visual Locomotion Score (Bicalho et al., 2007a)

Visual locomotion scoring of cows is normally used in lameness research as a method to identify lameness. To define the accuracy of such system and also to define the best cut-off for lameness classification, we designed and conducted a large field trial on two commercial dairy farms. Of the cows diagnosed with foot lesions, 33% were detected with sole ulcer, 26% with white line disease, 14% with white line abscess, and 27 % with other diseases. A strong increasing trend in the proportion of cows with painful lesions was detected as VLS increased. The proportion of cows with painful lesions were 6% (n = 53), 20% (n = 78), 55% (n = 164), 80% (n = 159), and 100% (n = 5) for VLS 1 to 5, respectively (Figure 3). A receiver operating characteristic curve analysis was performed and the optimal sensitivity specificity relationship was determined when a cutoff point of VLS $\geq$ 3 was used to detect PL. When the cut-off of VLS $\geq$ 3 was used a sensitivity of 67% and a specificity of 86% was achieved for the identification of painful foot lesions. This study validated the use of VLS to diagnose painful foot lesions.

Figure 3: *The association of visual locomotion scores and incidence of painful foot lesions. (Bicalho et al., 2007)*



Association of Digital Cushion Thickness with Lameness and Body Condition Scores (Bicalho et al. 2009)

Sole ulcers and white line abscesses are ubiquitous diseases with a chronic nature that have the highest associated economic losses amongst all foot lesions. Their underlying causes are still not fully understood. The digital cushion is a complex structure composed mostly of adipose tissue located underneath the distal phalanx and plays an important function of dampening compression of the corium tissue beneath the cushion. The biomechanical importance of the digital cushion in alleviating compression under the tuberculum flexorum of the distal phalanx is well known (Raber et al., 2006; Raber et al., 2004; Logue et al., 2004).

We recently conducted an observational cross-sectional study to investigate the association between claw horn lesions and the thickness of the digital cushion. The thickness of the digital cushion was evaluated by ultrasonographic examination of the sole at the typical ulcer site (Figure 4). A total of 501 lactating Holstein dairy cows were enrolled in the study. The prevalence of sole ulcers was 4.2% and 27.8% (P-value <0.001) for parity 1 and parity greater than one, respectively. The prevalence of white line disease was 1.0 and 6.5% for parity 1 and parity greater than one, respectively. The prevalence of lameness (visual locomotion score ≥ 3) was 19.8% and 48.2% (P-value < 0.001) for parity 1 and greater than 1, respectively. The prevalence of sole ulcers and white line diseases

Figure 4: *Sagital section of the bovine digit illustrating the site of ultrasonography. (Bicalho et al., 2009).*

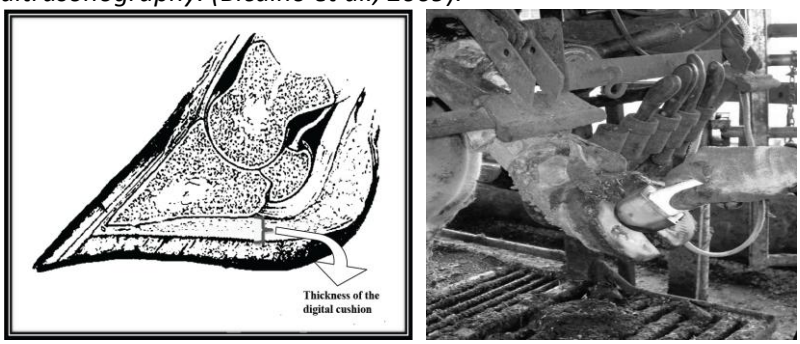
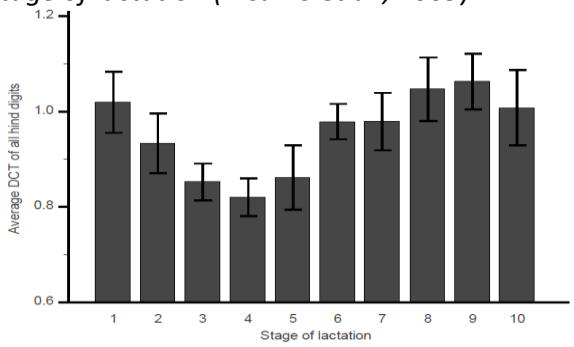


Figure 5: *Adjusted mean digital cushion thickness (MDCT) of all four hind digits by stage of lactation.(Bicalho et al., 2009)*

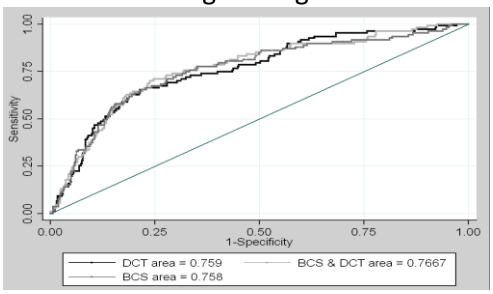


was significantly associated with thickness of the digital cushion; cows in the upper quartile of digital cushion thickness had an adjusted prevalence of lameness that was 15 percentage points lower than the lower quartile (24.4% versus 8.6% prevalence). Body condition scores were positively associated with digital cushion thickness. The mean gray value of the sonographic image of the digital cushion had a negative linear association with digital cushion thickness (R^2 = 0.14) indicating that the composition of the digital cushion may change with its thickness. Furthermore, digital cushion thickness decreased steadily from the first month of lactation and reached a nadir 120 days after parturition (Figure 5). These results give support to the concept that sole ulcers and white line abscesses are related to contusions within the claw horn capsule and such contusions are a consequence of the lower capacity of the digital cushion to dampen the pressure exerted by the third phalanx on the soft tissue beneath.

Predicting the Probability of Lameness in the Subsequent Lactation Using a Logistic Regression Model with Predicting Variables Collected at Dry-Off:

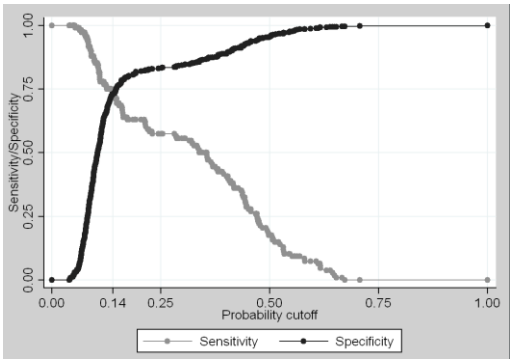
The objective of this study was to select the most economical statistical model that could accurately predict the incidence of lameness in the subsequent lactation by using information available at the dry-off hoof trimming. Our hypothesis was that digital cushion thickness, body condition score, age, and the presence of CHDL at dry-off are associated with the incidence of foot lesion (sole ulcers and white-line-disease) in the subsequent lactation. Data were collected from a dairy farm located near Ithaca NY from September 11th of 2008 until January 15th of 2009. A prospective cohort study design was used. The data were collected at dry-off by the research team and throughout the subsequent lactation by trained farm employees. The following data were collected at dry-off: body condition score which ranged from one to five with a quarter point system as described by Edmonson (1989), cow height measurement which was assessed as the distance in centimeters from the floor to the dorsal aspect of the caudal sacral joint, and visual locomotion score as described by Bicalho (2007). Additionally, all cows were hoof trimmed by one of the research team members and digital cushion thickness and digital lesions were recorded as described by Bicalho (2009). After the onset of lactation, cows were monitored on a daily basis for visual signs of lameness (presence of a limp) by trained farm employees. Cows that were limping were taken to the hoof trimming table for therapeutic hoof-trimming. Therapy was applied according with the diagnosed foot disorder and following a

Figure 6: Receiver operating characteristic curves for all 3 logistic regression models.



protocol designed by the Cornell Ambulatory and Production Medicine Clinic; data were recorded and entered into Dairy Comp 305. To predict the incidence of CHDL in the subsequent lactation logistic regression models were fitted to the data using Stata (StataCorp LP, Texas, USA). After variable selection steps the following variables were significant (*P*-value ≤ 0.10); digital cushion thickness (**DCT**), BCS, CHDL at dry-off, and age in days (**AGED**).

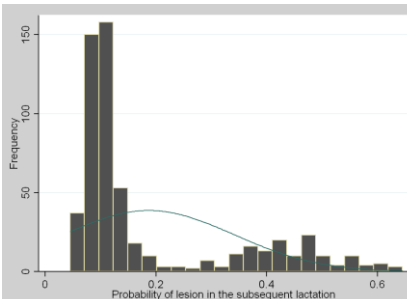
Figure 7: Sensitivity and specificity analysis for the third logistic regression model which included the variables BCS, AGED, and lesion at dry-off as independent variables.



To select the most parsimonious logistic regression model with good predictability of CHDL in the subsequent lactation three different models were evaluated. All three logistic regression models predicted the incidence of CHDL in subsequent lactation with good accuracy; the area under the ROC curves were 0.76, 0.76, and 0.77 for the first, second and third logistic regression models, respectively (Figure 6). There was no significant difference between the areas under the ROC curves for the three models. When the recommended probability cut-offs were used to dichotomize cows into high risk and low risk for lameness in the sub-sequent lactation an overall accuracy of 0.74, 0.76, and 0.76 was estimated for models 1, 2, and 3 respectively.

To illustrate the dynamics of the sensitivity and specificity as the probability cut-off is gradually incremented from 0 until 1, a graphical analysis was performed for the third logistic regression model (Figure 7). The intersection of the sensitivity and specificity lines indicates the recommended cut-off probability for defining lameness. Further analysis and predictions were completed for the third logistic regression model. Predicted probabilities calculated with the probability equation described in Table 4 had a bimodal distribution, likely because of the effect of the binomial independent variable CHDL at dry-off (Figure 8). Older cows with low BCS at dry-off and a CHDL detected at dry-off hoof trimming had the highest probability of CHDL incidence in the subsequent lactation (predicted probability = 0.65, 95% C.I. 0.49 – 0.78, Table 4). Whereas the lowest predicted probability of lameness was for a young cow with high BCS and without CHDL at dry-off (predicted probability = 0.03, 95% C.I. 0.01 – 0.08, Table 4). In conclusion, we were able to predict lameness in the subsequent lactation with an overall accuracy of 0.76 using a the simple logistic regression equation described below:

Figure 8: Frequency distribution plot of the predicted probabilities from the third logistic regression model.



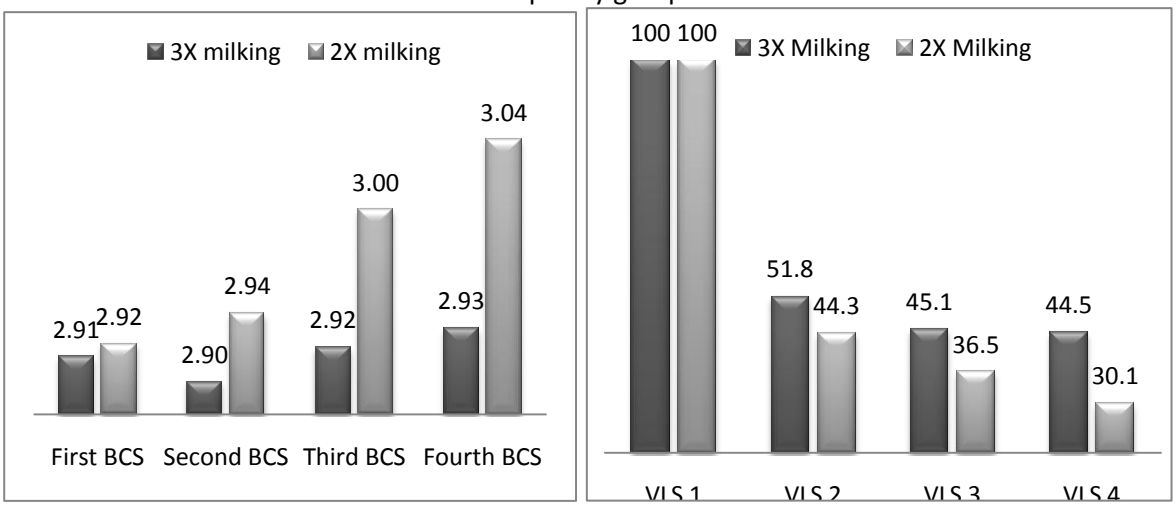
$$P(lesion) = \frac{e^{-1.05 - 0.57*BCS + 0.0005*AGED + 1.64*Lesiondry}}{1 + e^{-1.05 - 0.57*BCS + 0.0005*AGED + 1.64*Lesiondry}}$$

Demonstration that a Lower Milking Frequency (Twice Daily Versus Thrice Daily) Decreased the Prevalence of Lameness, and Improved Body Condition Score of Lame Cows:

We recently conducted a pilot study using a randomized clinical trial design to determine the effect of milking lame cows (VLS>2) twice daily versus thrice daily on milk production, culling, body condition score, and prevalence of lameness. The study was conducted on a large commercial dairy farm (3,000 milking cows) near Ithaca NY from January 1st until May 20th of 2009. Our hypothesis was that lame cows would benefit from a lower frequency milking schedule because they would spend less time standing on their feet, and consequently intra-claw corium concussions caused by the third phalanx would be decreased. Visual locomotion score and BCS of the entire milking herd were performed by two trained veterinarians. A total of 700 clinically lame cows were randomly assigned to one of two treatments: twice daily milking group and thrice daily milking group. Enrolled cows were VLS and BCS scored monthly for a total of 4 months. Additionally, daily milk production and culling information was recorded.

A mixed general linear model was used to assess the effect of milking frequency of lame cows on milk production. Lame cows that were milked twice daily produced a total of 3.5 lb/day more milk compared to the lame cows that were milked thrice daily. It is possible that the lower milking frequency allowed lame cows to spend time resting and eating which resulted in better

Figure 9: Lame cows that were milked twice daily recovered from lameness and poor BCS better then lame cows that were milked thrice daily. The left graph illustrates median BCS by milking frequency groups and the graph on the right illustrates the % of lame animals (VLS > 2) by milking frequency groups.



milk production. Additionally, lame cows in the 2X milking group significantly improve BCS and had a lameness prevalence that was 14.4 percentage points lower than the controls by the end of the study period (Figure 9).

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