The Importance of Genetic Selection in Dairy Cows
for Reducing Lameness and Improving Longevity

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Today’s dairy cow deals with some significant challenges in meeting the expectations of the modern dairy industry. Some of these challenges include the demands associated with unprecedented levels of production, the expectation for superior reproductive performance, the use of high energy rations, and being exposed to the other stresses associated with modern confinement management. The length of a cow’s productive life in a herd directly affects the profitability of that herd; longer herd life reduces replacement costs and increases the proportion of lactations from higher yielding, mature animals. Therefore, it is paramount that we increase the cow’s chance of surviving longer in the herd. The relationship between production and parity can be seen in the following figure:

![Figure 1: The Relationship between Milk Yield and Parity](image)

Traditionally, most of the emphasis in the selection of dairy cattle has been based on milk yield per cow, but efficiency of production is also determined by longevity, fertility, and general health. Dairy cow survival is influenced by many genetic and non-genetic factors. Non-genetic factors include stall size and barn design, bedding type, milk quota restrictions, and the availability and affordability of replacement heifers. Genetic factors include the genetic capability for high production and desirable milk components, the functional conformation necessary for a cow to express her productive and reproductive potential, and the general health and body condition necessary for proper immune function to resist metabolic disorders, mastitis, and lameness.

Many cows never have the opportunity to express their full genetic potential because they don’t live in an environment that maximizes the non-genetic factors. Therefore if a cow is
not provided with the ideal environment, care, and housing that is necessary to achieve the full expression of her genetic potential, she will likely leave the herd prematurely.

Bovine lameness is the symptom of a multi-factorial foot and leg disease complex that results in cows leaving the herd prematurely. Control of lameness and the associated large economic loss is dependent on a comprehensive herd management and breeding program that addresses all of the causative factors. Current estimates of lameness incidence range from 30% in New York to 60% in England and result in a total cost of $300.00 to $450.00 (Canadian) per lameness case. Based on data from Blowey (1998) in England, Guard (1995) in New York, and Boettcher (1998) in Canada, this extrapolates into a cost of greater than $125.00 (Canadian) for every cow in the herd.

Blowey (1998) reported that 88% of lameness cases involved the foot while only 12% involved the leg. Even though the rear feet carry only 40% of the animal’s weight, Blowey reported that 86% of all lameness cases involve the hind feet and that 85% of the hind feet cases involved the outside claw. Shearer (2002) reported that researchers in England and Wales determined that in front feet 46% of the lameness cases involved the inside claw while 32% involved the outside claw.

This pattern of lameness is indicative of the fact that more than just nutrition and feeding management errors are responsible for lameness disorders. The biomechanics of weight bearing and the inter-relationship with housing conditions, cow comfort, calving management, foot trimming, and functional conformation are all potential lameness factors particularly as it relates to laminitis and claw disease.

There is no doubt that bovine lameness is a continuing problem on dairies around the world. In modern confinement dairy herds, the lameness causing foot and leg disease complex has joined infertility and mastitis to become the third major disease of the dairy industry. The heritability of milk production and associated milk components is relatively consistent and is considered to be moderate to high at 0.26 (Muir et al., 2004). However, conformation traits have a wide range of heritability (Kistemaker and Huapaya, 2006) from 0.08 to 0.53, with final score having a heritability, in the same range as milk production. Estimates of the heritability of feet and leg disorders range from near zero to greater than 30%. Even with the variability in the functional trait heritabilities, the incredible genetic and phenotypic progress made in dairy cow conformation over the past 100 years is evidence of the power of genetic selection for these conformation traits. Since bull proofs do not exist for foot and leg disease traits, the next best approach in utilizing genetics to reduce lameness is the use of feet and leg conformation as an indirect selection tool in areas where it is strongly correlated with actual disease traits.

In a recent paper in the Journal of Dairy Science, 2009, Laursen et al attempted to estimate the genetic correlations of claw and leg health with their potential indicator traits of locomotion and foot and leg conformation in Danish Holsteins. The purpose was to establish whether the indicator traits could be used to improve genetic selection for the traits
of main interest. It was noted that claw and leg traits were less heritable (0.01 - 0.06) compared with locomotion and foot and leg conformation (0.09 - 0.27).

Estimates of genetic correlations between locomotion and claw health and between Rear Leg Rear View (RLRV) and claw health were positive, which means that good locomotion and parallel rear leg placement were genetically associated with healthy claws. The moderate size of these correlations combined with higher heritabilities of indicator traits, showed that locomotion and RLRV are useful indicator traits for improved claw health. In addition, the genetic correlation between locomotion and RLRV is favorable at 0.73.

Although much focus has been placed on functional conformation through livestock shows and classification systems, only a small component of scientific literature has been devoted to studying the association between improvement in functional conformation and improvement in longevity and profitability (Caraviello et al., 2004; Sewalem et al, 2004; Larroque and Ducrocq, 2001). The focus of this paper is to look more closely at how the conformational traits for feet and legs are evaluated and identify the usefulness of these traits to reduce lameness and improve longevity.

**Understanding Weight Distribution and Locomotion**

As mentioned before, lameness involving the lateral claw of the rear leg is by far the most common type of lameness seen in dairy cattle. To understand the reason for this unique finding, it is necessary to evaluate the biomechanics of movement in the hind legs. It is important to recognize that the femur articulates with the pelvis by the relatively inflexible coxofemoral joint. While standing, the weight should be distributed equally on each hind leg and equally on each claw assuming good level trimming. During motion the centre of gravity shifts from side to side and the weight bearing by each hind foot varies with the movement. The diagram below shows the approximate weight distribution on each hind foot with a 500 kg heifer and 200 kg being carried by the hind feet.
Figure 2: (Raven, E.T. 1989 Cattle Foot Care and Trimming)

Figure 3: (Raven, E.T. 1989 Cattle Foot Care and Trimming)
In addition, the weight bearing of the individual claws also varies widely. The outside claw of the weight bearing hind leg carries considerably more weight than the inside claw. It can therefore be concluded that the outer hind claw is more heavily stressed. The cow has responded to this by producing an outside claw that is usually slightly larger than the inside claw, and the horn of the heel and sole may be thicker. Even with these adaptations, the increased stress on the outside claw still results in a significantly greater incidence of lameness.

It is useful to examine a cow’s stride, as described by Telezhenko in 2002 and referenced in Figure 4, to identify some of the important parameters of mobility. He described **Stride length** as the distance between two consecutive imprints of the same rear hoof (eg. RL – RL). **Step length** was the distance between two consecutive rear hoof imprints (eg. RL – RR). **Step angle** was described as the angle between the lines connecting three consecutive imprints of the rear hooves (eg. (RL – RR – RL). **Step asymmetry** was the length difference between two consecutive steps and **step abduction** was the lateral distance between the front hoof imprint and the next placement of the same side hind hoof. Finally, **overlap** was the vertical distance between the front hoof imprint and the imprint of the next placement of the same side hind hoof.

**Stride Evaluation**

(Telezhenko E. 2002)

The evaluation of a cow’s mobility has now become a significant part of the feet and leg evaluation within the Canadian dairy cattle conformation classification system and it is referred to as **Locomotion Scoring**. Locomotion scoring is therefore a qualitative evaluation of a cow’s ability to walk normally and the scoring is documented on a 9 point linear scale with 9 being the best possible free flowing movement and 1 being the poorest and usually associated with some form of pain. Although several other evaluations are conducted on feet and leg conformation traits, locomotion scoring is perhaps the most comprehensive evaluation of a cow’s motion biomechanics and her freedom from lameness. Locomotion scoring in the Canadian classification system should not be confused with the 5 point scoring system often used to quantify the magnitude of lameness in dairy herds. Even though the two systems are both referred to as “locomotion scoring” the classification system is focused on evaluating the freedom of motion before lameness is present in an attempt to identify the cows that will be most resilient to all the lameness risk factors. It should be recognized that locomotion is influenced by the type of footing and that in Canada scores are not entered into the genetic evaluations if the cows are housed on slatted floors or extremely slippery surfaces.
Other Functional Feet and Leg Traits

Foot Angle is a valuable tool for evaluating the functional conformation of the foot. It can be measured for research purposes using a universal protractor on the anterior wall of the hoof and the ideal angle for the hind foot is considered to be about 50 degrees. Over the years, much effort has been expended to find the most accurate practical method of assessment for foot angle. It is a trait where the accurate measurement can be influenced by such factors as hoof trimming, bedding, stall mats, and manure pack. Although the trait represents the angle the hoof wall makes with the sole, Holstein Canada classifiers have determined that the trait is highly correlated with the angle of the hairline and assessment of this angle generates the most consistent foot angle data. The foot angle is recorded on a 9 point linear scoring system (1 is very shallow and 9 is very steep) that recognizes that a hoof angle that is too straight is undesirable and leads to more concussion transmitted to the joints above. As a result, a hoof angle with a code 7 is the most ideal and provides a walking angle that, when considering the internal anatomy of the foot, is most desirable. If one was to extend an imaginary line from the hairline of a code 7 hind foot, it would intersect the front leg just above the carpus. The heritability of this trait is only 13% (Boettcher et al. 2001) meaning that of all the variation in the population only 13% can be attributed to genetics. However, with the wide use of sires through A.I. this is still adequate to have a significant impact on the population.

Figure 5: Foot Angle as measured by the angle of the hairline (Holstein Canada 2009)

Heel Depth is another foot trait used in the Canadian Classification System but surprisingly few other countries evaluate the trait and use it in their genetic evaluations. Even though geneticists feel it is closely linked to the foot angle, the Canadian System recognizes that it is the heel that makes the first contact with the ground and that the elasticity of the fat pads in the digital cushion of the heel are extremely important in the absorption of concussion and the protection of the vital structures beneath. Since the depth of heel is a focus of many Canadian Holstein breeders, and since future lameness research in the identification lameness risk factors may involve the anatomy of the heel, Holstein Canada continues to use the trait to encourage deeper heels. The ideal weighting is given to a code 9 (the deepest heel) and the most undesirable weighting is given to a code 1 (the most shallow heel). Some recent Holstein Canada data (Figure 11) would suggest that, similar to an excessively straight foot angle, an excessively deep heel may also be undesirable and thus
the most desirable linear score may have to be revisited. The heritability of this trait (10%) is similar to other foot traits (Boettcher et al. 2001). Bedding and manure pack can complicate the assessment of heel depth which is identified as the perpendicular distance from the hairline at the heel to the floor. A code 9 has a reference depth of at least 3.8 cm while code 1 has a depth of 0.6 cm.

**Figure 6: Heel Depth (Holstein Canada 2009)**

*Rear Leg Side View* is often referred to as the set of the hind leg and is an assessment of the degree of curvature of the hock when viewed from the side. It is identified by the angle formed by the intersection of lines through the tibia and the metatarsus. McDaniel (1994) using data collected in both North America and Europe indicated that an intermediate set could be correlated with increased herd life. Work done by Holstein Canada indicates that the set of the hock ranges from 135 degrees to 170 degrees with the ideal range being 150-155 degrees. The ideal set is a code 5, code 9 is extremely curved (135 degrees), and code 1 is extremely straight (170 degrees). It should be understood that the set of the hock is determined by soft tissue as it is the balance between the flexors and the extensors that produce the angle we measure. However, there are several other conformational characteristics that influence the set of the hock. One of those is the position of the thurls or the coxofemoral joint. Ideally, the thurls should be located in a position that represents a 60:40 ratio from the hook bone to the thurl and the thurl to pin bone. The heritability of the rear leg side view trait is the largest of all feet and leg traits at 26% (Boettcher et al. 2001).

**Figure 7: Rear Leg Side View showing curved, ideal & straight legs (Holstein Canada 2009)**
**Rear Leg Rear View** evaluates the straightness of the rear legs when viewed from behind and is measured by the degree of inward deviation of the hocks and the corresponding degree to which the toes point outward. These reference points are assessed in relation to plumb lines going straight down to the ground from the pin bones. There is a strong relationship between the rear leg rear view and the general health and soundness of the foot. Normally the legs should be straight from behind facilitating fluid, “straight ahead motion” with the outer claw carrying a greater share of the weight. Contusions to the heel or sole of the outer claw will create sensitivity and pain and the cow will attempt to compensate by shifting more weight onto the inner claw. This results in a “toeing out” and “hocking in” posture as evaluated from the rear leg rear view. Cows also develop this posture from undesirable rear foot and leg conformation and the result is a paddling gait and loss of the normal straight, fluid motion. Therefore the rear leg rear view scores are influenced both by management and genetic factors. Although the heritability of rear leg rear view is only 11% (Boettcher et al. 2001), it must be recognized that the genetic components contributing to outer claw heel depth and the claw’s resiliency to injury and claw disease also factor into proper rear leg rear view conformation. The nutrition and cow comfort management components impact rear leg rear view scores less in two-year old heifers than mature cows and bull proofs are based only on first lactation classifications that usually are completed early in the first lactation. A code 9 (ideal) is given to legs that are wide apart and track in a straight line for ease of movement, while a code 1 is given to a cow that severely hocks in and toes out. Many dairymen consider this trait to be one of the most important predictors of longevity.

![Figure 8: Rear Leg Rear View showing hock & toe placement (Holstein Canada 2009)](image)

In recent years the dairy industry has seen a reduction in purebred breeders and an increase in larger herds and commercial types of operations. The commercial producers challenge the breed associations to provide data to substantiate the importance of breeding for improved functional conformation. The following three figures show the relationship between first lactation first classification scores and
production in the first lactation for overall type classification scores, combined scores for all feet and leg scores, and each individual feet and leg component score:

Figure 9: First Lactation Production vs. First Lactation First Classification (Holstein Canada 2008)

Figure 10: Phenotypic Relationship of Combined Scores for Feet and Leg Linear Traits and First Lactation Production for All First Lactation First Classification Holstein Heifers Born After 2004 and On Test in Canada

Note: The data set involves over 171,000 heifers for all traits except locomotion and about 60,000 heifers for locomotion.
Longevity

In the minds of many people, especially producers, longevity is the most important trait associated with dairy production. This belief is quite understandable since the length of time that a cow remains in the herd reflects her ability to meet or surpass the herd owner’s minimum expectations. The bottom line is that a cow would normally stay in the herd only as long as she is perceived by the owner to be profitable and she remains above the culling thresholds for various criteria.

The major underlying problem with genetic selection for longevity is that it is only observed at the end of each cow’s productive life, which is usually too late to be of practical value for evaluating their sire’s genetic potential. To address this problem, the Canadian genetic evaluation system has broken the measure of true longevity into four separate stages.

1. The first stage of evaluating a bull’s genetic potential for longevity is the estimation of a predicted value (from the pedigree) based on traits that have shown to be useful indicators of true survival. Such a prediction formula is derived based on proofs for various traits that exist for older bulls (at least 8 years of age) that have many daughters with actual survival information. Canadian Herd Life Proofs are designed...
to be independent of production levels and therefore only non-production traits are used in the prediction formula. Figure 9 shows the relative emphasis that will be placed on the various indicator traits as predictors of Herd Life.

2. The second stage is survival through the first lactation.

3. The third stage is survival through the second lactation.

4. The fourth stage is survival through the third lactation.

At any point in time, a bull's published Herd Life proof is a combination of his predicted value based on proofs for the indicator traits shown in Figure 9 plus his evaluation for each of the three stages of daughter survival. Bulls with daughters only in first lactation would not yet have actual survival data available so their published Herd Life proof is heavily based on the predicted value. Older bulls with daughters that have progressed through their first three lactations would have a Herd Life proof dominated by the actual survival data. Proofs vary from about 2.50 to 3.50 lactations and bulls with a Herd Life greater than 3.14 are considered to be significant breed improvers for longevity.

Besides the actual Herd Life proofs, it is useful to know the relationship between Herd Life and the other traits of importance. Various type traits such as Mammary System, Udder Depth, Feet & Legs and Overall Conformation are highly associated with improved Herd Life as a measure of longevity independent of production (Van Doormaal B.J., 2004). Auxiliary traits related to calving ease, fertility and milking speed have a moderate relationship (Van Doormaal B.J., 2004). Capacity is the only trait that shows a slight negative correlation of 12 percent with Herd Life, suggesting that bulls excelling for this trait tend also to produce daughters that have shorter productive lives.
It is evident that when discussing the topic of longevity, there are numerous ways to define and measure it. Some people simply want to know the age at disposal, others refer to the length of time between first calving and disposal (i.e. productive life), and others are most interested in the number of lactations achieved. In addition, longevity is highly affected by herd management and other non-genetic factors. The easiest example to stress this point, which affected all Canadian dairy cattle populations, was the US border closing in 2003 due to BSE. Since this event abruptly shut down all opportunities for Canadian producers to export surplus animals, the general reaction of producers in this supply management system was to remove older cows from the herd to make room for the group of younger heifers to calve and enter the milking line-up. Clearly, the genetic potential of Canadian dairy cattle did not suddenly change with the border closing and this example demonstrates why such phenotypic measures of longevity are not comparable across countries.

Given the fact that each country has its unique situation in terms of herd management, environmental and political factors that affect longevity, the only way to make comparisons across countries is on the genetic level. From a genetic perspective, the aim is to breed dairy cows that will have the genetic potential to withstand any voluntary culling. Given that voluntary culling does occur in all dairy herds, which prevents cows from staying in the herd as long as they are physically able to, perhaps the best measure of longevity in a population is the average age of cows that die of natural causes such as old age? Using this measure of longevity, the average Holstein cow in Canada has the potential to survive to 9.1 years of age, 6.8 years of productive life and just shy of six lactations of production.

In terms of bull proof expression, the Relative Breeding Values (RBVs) used in Canada for Herd Life have a breed average of 100 and an approximate range from 85 (undesired) to
To facilitate the interpretation of Herd Life evaluations, the Canadian Dairy Network provides five measures of actual daughter survival on a sire by sire basis, along with breed averages for comparison. Of these five measures, those of greatest interest to producers are the daughter survival rates to each of second, third and fourth calving, which average 70, 50 and 31 percent, respectively, for the Holstein breed (Van Doormaal B.J., 2009).

Therefore, when discussing Herd Life, the focus should be given to genetic comparisons across countries. The data shown below in figure 11 indicates that desired progress has been made in recent years for most major Holstein populations globally, with Canada leading the way.

Even though the emphasis given to feet and legs is small in the formula for predicting herd life (3%), it was evident in Figure 10 that there was a high degree of correlation between the feet and leg proofs generated from the Canadian Classification system and the Canadian Herd Life proofs. It is unfortunate that we have only a minimal amount of feet and leg clinical data available to correlate with herd life proofs and feet and leg confirmation traits. However, until more actual foot and leg disease data is available, the next best solution is to identify the feet and leg conformation traits that have a high degree of correlation with the limited actual clinical lameness and reduced herd life data and continue using this valuable classification data to drive the genetic progress of the industry.
LPI Formula

One of the main drivers of genetic progress in the industry is the Lifetime Profit Index Formula (LPI). This formula continually responds to new research data that is made available and represents the essence of the Canadian Balanced breeding philosophy where there is a unique balance given to the production, functional conformation, and health traits.

The main goal of the LPI formula in each breed is that it results in desired rates of genetic progress for traits of importance in achieving the overall breed improvement objectives. The last LPI update, in January 2008, increased the weighting of the Health and Fertility component from 10% to 15%, reduced the Production component from 54% to 51% and reduced the Durability component from 36% to 34%. Within the Health and Fertility Component, the emphasis on Daughter Fertility was increased and Udder Depth was added as a new trait. Depending on the breed, specific attention was placed on evaluating the importance of Daughter Fertility and Herd Life in the LPI formula since these are traits of growing importance to most producers. A summary of the current LPI formula for Canadian Holsteins is shown in Figure 15 below:

Figure 15: Lifetime Profitability Index Formula
The LPI formula has become a major selection tool in the genetic selection of Canadian Holsteins. Even though all traits are not included in the LPI formula, the selection for LPI can also lead to genetic progress for traits not in the formula as long as they have a positive genetic relationship with LPI. Daughter Calving Ability is such a trait that has a positive correlation with LPI and is improved through LPI selection even though it is not directly in the LPI formula.

References

Muir, B. 2009. Phenotypic relationship of individual feet and leg traits and combined scores for feet and leg linear traits with first lactation production for all first lactation first
classification Holstein heifers born after 2004 and on test in Canada. Personal communication based on review of Holstein Canada classification data.


