Minimizing Lameness through Genetic Selection

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Take Home Messages

- Lameness in modern confinement dairy herds has joined infertility and mastitis to become the third major disease of the dairy industry.
- The cause of lameness is multi-factorial and includes conformation defects, nutrition, environmental stress, injury, and infection.
- Estimates of heritability for foot and leg disorders range from near zero to greater than 30%.
- Since bull proofs do not exist for foot disease traits, the next best approach for utilizing genetics to minimize lameness is the use of foot and leg conformation as an indirect selection tool.
- Foot and leg appraisals can be influenced by foot care, environmental design/management and nutrition; however non-genetic factors can be eliminated to derive unbiased genetic estimates for animals.
- Continual refinements in the accuracy of foot and leg conformation and trait emphasis by Holstein Canada will increase the power of genetic selection in reducing the incidence of lameness.

Introduction

Today's dairy cow faces many different environmental and management challenges than the cows of the past. High energy rations, confinement on concrete, constant exposure to corrosive conditions, and perhaps even increased body size are all risk factors that increase the probability of lameness. Foot and leg conformation is of even greater significance in the presence of these modern management stressors. We must acknowledge that foot and leg conformation is somewhat subjective, influenced by various management practices such as foot trimming and nutrition, and has a less predictable heritability than measured indices such as milk production or stature. However, despite these shortfalls, the heritability of foot and leg traits is adequate to obtain a reliable estimate of breeding values. The accuracy of the breeding values is increased by the size of the population and the consistency of the conformation evaluation. In order to fully understand the principles of reducing lameness with genetic selection, it is necessary to become familiar with the anatomy and biomechanics of the normal foot and leg.

▪ Anatomy and Biomechanics of the Foot and Leg

The foot consists of two inside digits with the outside claw being slightly larger on the hind feet and the medial claw being slightly larger on the front feet. The claw consists of three basic tissue components**:** **Hoof, Corium,** and **Bone**.

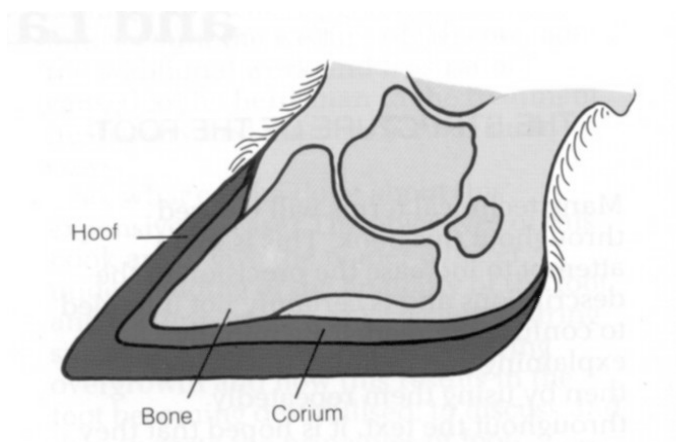

Figure 1: The three basic tissues of the foot
(Blowey, R.W. 1998 Cattle Lameness & Hoofcare)

The hoof can also be subdivided into three components: **Wall, Sole,** and **Heel**. The horn of the wall meets the horn of the sole at a cemented junction known as the white line. It runs from the bulb of the heel to the toe and then back along the first third of the inside wall. The wall is separated into the abaxial or outside portion and the axial or inside portion. The relationship between these components is illustrated in the following diagram:

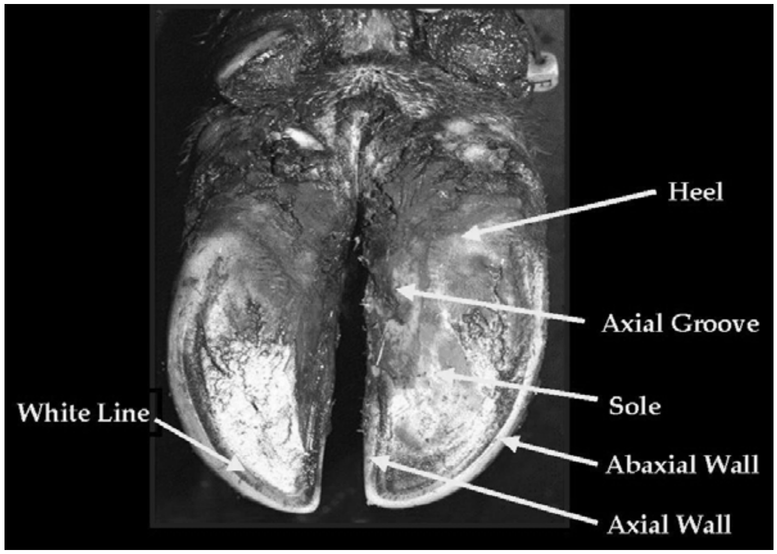

Figure 2: Foot anatomy viewed from the sole

The corium is the support tissue of the foot. It contains blood vessels and nerves for the hoof and pedal bone and it carries the nutrients for the horn and periosteum. The corium is under pressure between the pedal bone and the horny sole of the weight-bearing claw (see Figure 4).

On a smooth hard surface the claw contacts the ground on the abaxial surface of the wall, the axial surface of the wall, and the horn of the heel (see Figure 3). If the walking surface is soft (such as pasture), the sole will also form part of the weight-bearing surface. In the rear feet, the axial part of the heel of the inner claw is usually less developed than the corresponding area of the outer claw and as a result the heel of the medial claw has a smaller weight-bearing surface. The axial weight-bearing border of the wall extends further along the inside of the toe on the outer claw when compared with the inne claw. As a result the outer claw on the hind foot has a larger weight bearing surface and therefore, more stability. This difference is not noted on the front feet where both claws appear to be equally stable and able to bear weight.

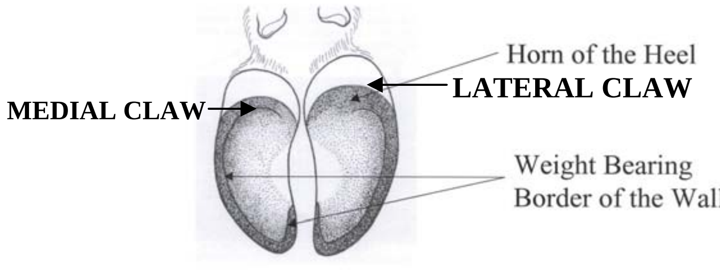

Figure 3: Weight bearing surfaces of each claw of a hind foot
(Blowey, R.W. 1998 Cattle Lameness & Hoofcare)

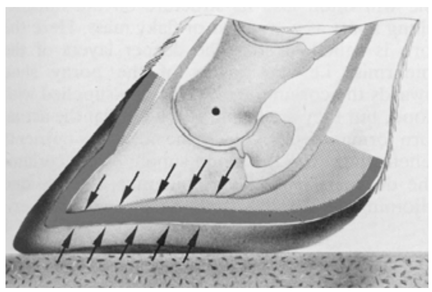

Figure 4: The corium under pressure between pedal bone and the sole
(Raven, E.T. 1989 Cattle Foot Care and Trimming)

The concept of loading of the corium has been supported by the results of microscopic research carried out on the corium and helps to explain the defect that is often found in claws under the axial edge of the posterior margin of the pedal bone (see Figure 5).

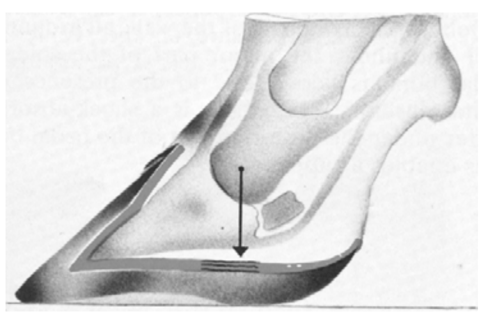

Figure 5: The vulnerable spot for trauma to the corium
(Raven, E.T. 1989 Cattle Foot Care and Trimming)

With overgrowth of the hoof plus the fact that the claw is less developed on the axial side, the result is an unstable claw which tilts backwards and over on the inside. This resulst in a sagging of the pedal bone creating extra pressure on the posterior margin particularly on the inside or axial edge (see Figure 6).

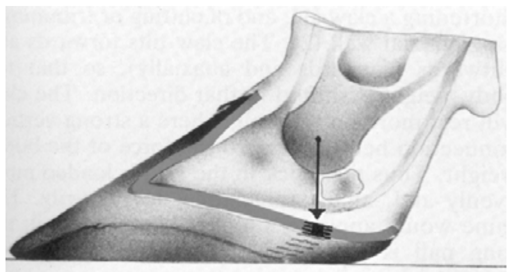

Figure 6: Hoof overgrowth resulting in increased trauma to the corium
(Raven, E.T. 1989 Cattle Foot Care and Trimming)

The resulting bleeding from the corium disrupts the integrity of the horn formation and results in the significant hoof defect portrayed in Figure 7.

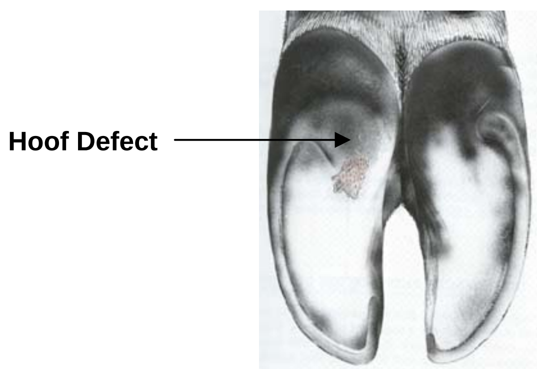

Figure 7: Typical sole defect resulting from trauma to the corium
(Raven, E.T. 1989 Cattle Foot Care and Trimming)

Research indicates that 86% of all lameness involves the hind foot and that 85% of all hind leg lameness involves the outside claw (Blowey, R.W. 1998). To understand the reason for these unique results, it is necessary to evaluate the biomechanics of movement in the hind legs. The hind legs are connected to the pelvis by a fixed and relatively inflexible ball and socket joint. While standing, the weight should be distributed equally to each hind leg and equally to each claw (50 vs. 50 in Figure 8) assuming good level trimming.

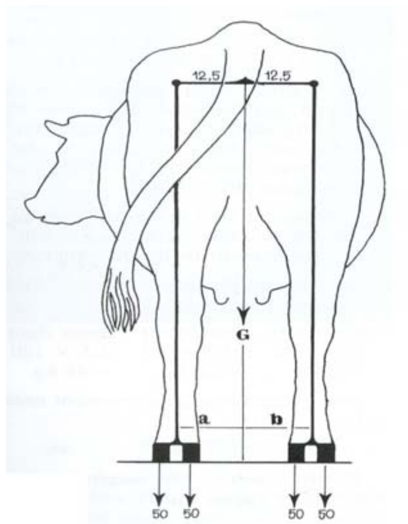

Figure 8: (Raven, E.T. 1989 Cattle Foot Care and Trimming)

During motion the centre of gravity shifts from side to side and the weight bearing by each hind foot varies with the movement (120 vs. 80 in Figure 9).

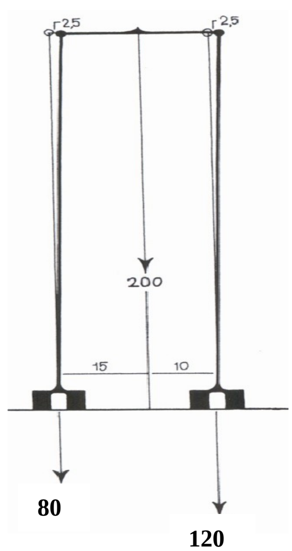

Figure 9: (Raven, E.T. 1989 Cattle Foot Care and Trimming)

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 (72 vs. 32 in Figure 10). The load on the inner claw of each hind leg is far more even (48 vs. 48 in figure 10). 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 larger than the inside and the horn of the heel and sole are thicker. Even with these adaptations, the result of increased stress is increased lameness.

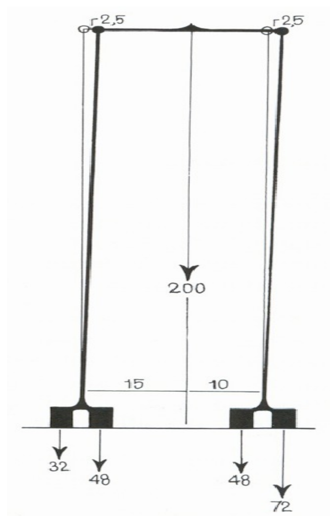

Figure 10: (Raven, E.T. 1989 Cattle Foot Care and Trimming)

▪ Herd Conformation Analysis

Conformation appraisal is a detailed evaluation of the observable physical structure of an animal's conformation, partitioned into the main structural components called the animal's scorecard: Frame/Capacity, Rump, Feet and Legs, Mammary System and Dairy Character (Holstein Association of Canada 2001).

Traditionally, the primary focus of the classification system was the overall Final Class. Great importance was placed on whether an animal was GP, VG or EX, and not as much emphasis on the detailed appraisals that describe the strengths and weaknesses. Classification was mostly used for valuing livestock and providing elite breeders with an official stamp that an animal was worthy of becoming future breeding stock. Detailed appraisals were often ignored with little effort made to use the information to develop average herds.

The past decade has seen a dramatic shift in the use of classification as a herd improvement tool. Though final class is still important and prestigious, the main focus of the program today is on a comprehensive set of descriptive traits that describe the strengths and weaknesses of an animal and their contribution in sire proofs.

If you equate a dairy cow to a piece of machinery in a factory, increased output in a more stressing environment places more wear and tear on the parts. The environment and machine operation can be enhanced, however the optimal solution might be to build a better machine that is more resistant and lasts longer. In terms of cows, advances in management, housing, nutrition, and genetics have pushed the cow to levels far beyond what was thought possible. Similar to building a better machine, the goal through genetic selection should be to modify the structure (conformation) of the animal to be more resistant and functional in the modern confinement systems so maximum genetic and management gains can be sustained.

The result is a strong relationship between conformation and herd life, where early observations on conformation can be used as good predictors of future limitation in animal herd life. Conformation can be used for management and culling, but most commonly, in corrective mating to improve the health and longevity of future generations.

▪ Principles of Foot and Leg Conformation

In terms of involuntary culling, after reproductive problems (6.1% of all reasons for culling), the next most common reasons for culling are udder breakdown and milking problems (2.8%), mastitis and high somatic cell count (2.3%) and lameness (1.9%) (Duur et al 1997). For this reason, Feet and Legs receive a 20% weighting in final score, second only to Mammary System at 40%. Feet and Legs consist of foot traits and leg traits. Two official foot traits are foot angle and heel depth. Legs are evaluated based on their bone quality and the views of the rear legs from the side and rear. Each of these traits will be considered.

Foot Angle

Foot Angle receives a 25% weighting in the Feet and Legs score. It measures the angle between the front of the hoof wall and the sole. McDaniel (1994) concluded that three separate comprehensive studies showed higher claw angles were positively correlated with increased herd life. Foot angle can be measured for research purposes using a universal protractor and the ideal angle for the hind foot is about 50-55 degrees. Over the years, much effort has been exhausted to find the most accurate practical method of assessing foot angle. It is a trait that can be influenced by hoof trimming, and such factors as bedding, mats, and manure pack can make it more difficult to assess. Although the trait represents the toe angle, Holstein Canada has determined that the most accurate method of assessment is to evaluate the angle of the hairline at the top of the foot (see Figure 11). This procedure generates the most consistent foot angle data and is least biased by hoof trimming and bedding. The reference point for the trait is to follow the angle of the hairline on the rear foot, and extend this line forward to the point it intersects the cow's front leg or her abdomen. A code 7 (ideal) produces a line from the hairline that intersects the front leg at the knee (see Figure 12).

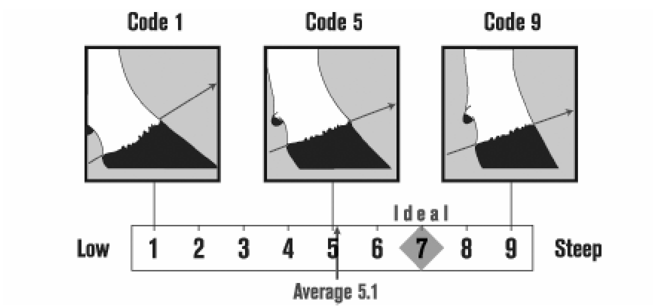

Figure 11: Foot Angle (angle of hairline)
(Holstein Canada Type Classification Fact Sheet)

Figure 12: Intersection of the extension line generated from the hairline
(Holstein Canada Type Classification Fact Sheet)

Heel Depth

Heel Depth also receives a 25% weighting in the Feet and Legs score. The reference point for this trait is the distance from the hairline, at the back outside portion of the rear foot, straight down to the floor (see Figure 13). A depth of at least 4 centimeters is required to receive the ideal code of 9. Canada is one of the few countries evaluating heel depth as geneticists in numerous other countries feel it is closely linked to the foot angle. Since the depth of heel is a focus of many Canadian Holstein breeders, and since several sires have been identified with less than usual links between heel depth and foot angle, Holstein Canada continues to use the trait to encourage deeper heels. Code 9 in Figure 13 is the ideal for this trait and the heritability, defined as the percentage of variance in the population resulting from genetics, (0.10 for heel depth), is similar to other foot traits (Boettcher et al. 2000). Bedding and manure pack can complicate the assessment of heel depth.

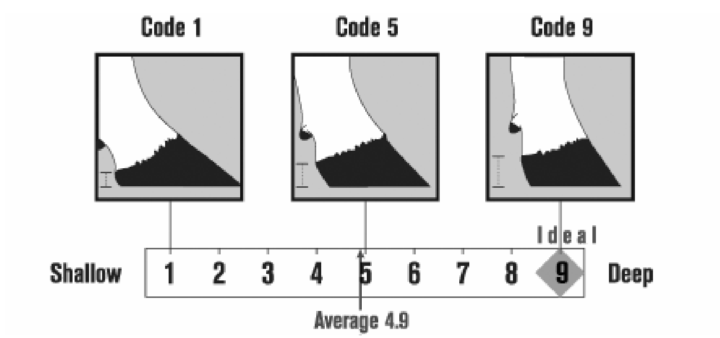

Figure 13: Heel Depth (from posterior hairline of rear foot)
(Holstein Canada Type Classification Fact Sheet)

Bone Quality

Bone Quality receives a 15% weighting in the feet and legs score. It is assessed by the flatness and cleanness of bone in the shank, hock, and thigh regions. An ideal code of 9 reflects bone quality that is extremely flat with cleanness throughout and tendons well defined. Bone quality is an indication of fitness and good circulation through the legs without excessive swelling in the joints. A strong positive correlation exists between bone quality, dairyness and milk production.

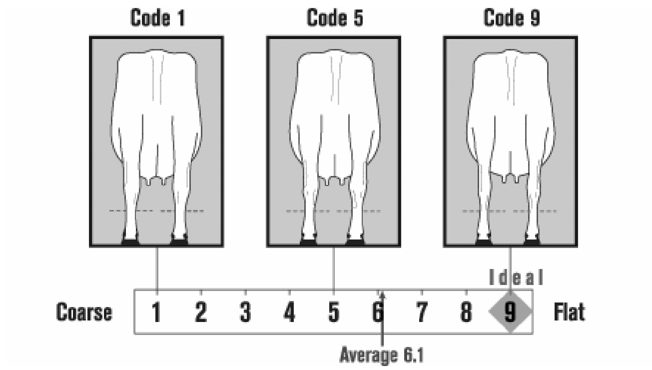

Figure 14: Bone Quality - degree of flatness in shank, hock and thigh
(Holstein Canada Type Classification Fact Sheet)

Rear Leg – Side View

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 receives a 15% weighting in the Feet and Legs score. McDaniel (1994), using data collected in both North America and Europe, indicated that an intermediate set could be correlated with increased herd life, however, he suggested the heritability was lower for leg traits than foot traits. Work done by Holstein Canada indicates that the set of the hock ranges from 135 degrees to 170 degrees with the ideal being 150-155 degrees. It would appear that the ideal set in the U.S. classification system is slightly straighter than in the Canadian system.

Figure 15: Rear leg side view (curved, ideal and straight legs)

A line can be visualized from the pastern, up the middle of the shank through the center of the hock and upward to the rump. A code is determined by the position where the line intersects the rump. A line that intersects with the pin bone is coded 5 – intermediate curve with an angle between 150 and 155 degrees. Lower codes are assigned to straight legs where the line intersects between the pin and hip. When the line goes to the rear of the pins, it indicates excessive curve and receives higher codes.

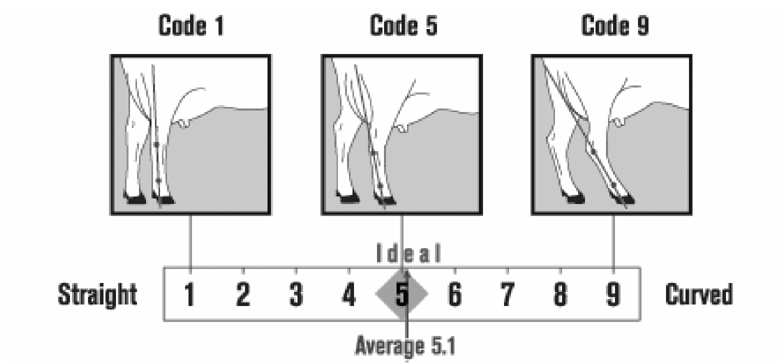

Figure 16: Rear Leg - Side View (set of legs when viewed from side)
(Holstein Canada Type Classification Fact Sheet)

Rear Leg – Rear View

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 corium 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 with this posture have a paddling gait and lack the normal straight, fluid motion. Similar to the other feet and leg traits, the rear leg rear view scores are influenced by genetic and environmental factors. The genetic component involves not only the conformation of the foot but also its resistance to injury and disease. The environmental component is less significant in two-year old heifers and can be zeroed out by statistical genetic calculations based on within herd and between herd comparisons. A code 9 (ideal) is given to legs that are wide apart and track in a straight line for ease of movement. Rear Leg - Rear View receives a 20% weighting in the Foot and Leg score calculation. Many dairymen consider this evaluation as an excellent predictor of longevity and consider it an evaluator of both their breeding program, nutrition and cow comfort management.

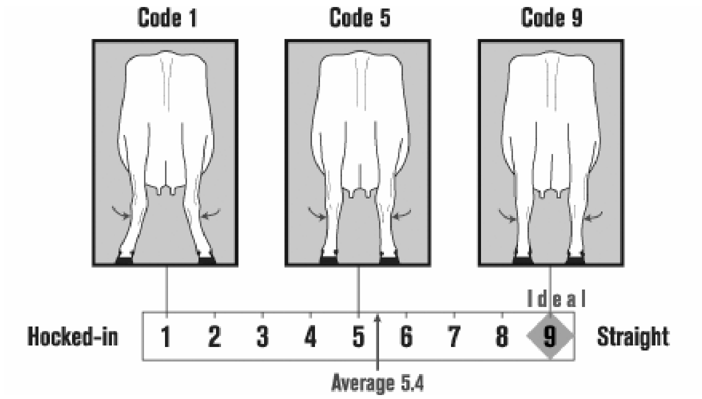

Figure 17: Rear Leg - Rear View (turn of hock and placement of toes)
(Holstein Canada Type Classification Fact Sheet)

■ Genetic Estimates Adjusted for Non-Genetic Factors

Genetic evaluation for conformation traits is processed on a quarterly basis. In addition to age and stage of lactation, the model adjusts for herd management/environmental factors by accounting for herdmate contemporaries and herd variance. These adjustments attempt to remove any non-genetic influences from the field observations, such that only genetic differences remain.

Fatehi et al. (2001) studied the genotype-by-environment interaction for feet and leg traits scored in different environments, including free versus tie stalls, slatted versus solid flooring, and untrimmed versus trimmed hooves. Although actual feet and leg scores were lower in cows in tie stalls, on slatted floors and in herds without trimming, there was little impact on genetic parameters as genetic correlations for feet and leg traits across pairs of management systems were >0.85 with the exception of rear leg – rear view. They concluded the effects of genotype-by-environment were not important for foot and leg conformation, indicating non-genetic factors are adequately eliminated in the current procedures for appraising the traits in the field and the subsequent processing of genetic evaluations.

▪ Indirect Selection for Minimizing Lameness

Lameness is considered to be the third most costly health problem in dairy cattle. A 1996 survey in the U.S. by the National Animal Health Monitoring System reported that 15% of all culling was directly due to lameness or injury. Only reproduction (26.7%), and udder and mastitis problems (26.5%) were more common reasons for culling. Additionally, culls for reproduction may be related to reduced heat detection caused by foot and leg problems, as Sprecher et al. (1996) found a lameness score greater than 2 on a 1 to 5 scale predicted extended intervals from calving to first service and conception, required more services per pregnancy and caused the animal to be 8.4 times more likely to be culled. Boettcher and Fatehi (2001) indicated feet and leg problems affect about 25% of the cows in an average herd, with half the cows having repeat episodes.

Environmental factors such as nutrition, housing and other management practices play a large role in lameness. In addition, genetic factors are also significant. Specific claw disorders have heritabilities ranging from near zero to greater than 30% (Distl et al. 1990; Huang and Shanks, 1993). Unfortunately, disease traits and a measure of lameness are not routinely recorded on a national basis making it unfeasible to select directly for foot and leg disease traits as a genetic strategy. However, several conformation traits have been found to have a strong relation with lameness such that a combination of foot and leg traits could be used indirectly to select for resistance to lameness. Heritability of clinical lameness and genetic correlations with foot and leg conformation traits are listed in table 1. Heritabilities and genetic correlations between feet and leg conformation traits and herd life are listed in table 2.

Table 1: Genetic correlation between lameness and foot and leg conformation

	Heritability	Genetic Correlation with:		
		Feet and Legs	**Foot Angle**	**Rear Leg Rear View**
Lameness	0.10	+0.46	+0.59	+0.65

(Boettcher et al. 1998, Van Dorp and Boettcher, 1999)

Table 2: Foot and Leg heritabilities and genetic correlations with herd life

Trait	Heritability	Genetic Correlation with Herd Life
Feet and Legs	0.21	+0.52
Foot Angle	0.13	+0.41
Heel Depth	0.10	+0.44
Bone Quality	0.28	+0.45
Rear Legs - Side View	0.26	-0.02
Rear Legs - Rear View	0.13	+0.67

(Schaeffer 1998; Boettcher et al. 2000; Fatehi and Boettcher 2001)

Due to the strong relationship between lameness and some foot and leg conformation traits, Boettcher and Fatehi (2001) derived a selection index to predict locomotion based on foot and leg conformation traits. Solving of the selection index equations resulted in weights of 1.0 for Feet and Legs, 2.25 for Foot Angle and 2.94 for Rear Legs – Rear View.

Locomotion Index =
1.0*Feet and Legs + 2.25*Foot Angle + 2.94*Rear Leg – Rear View

The use of indirect selection using the locomotion index resulted in an accuracy of 97.5% relative to direct selection for clinical lameness. The Canadian Genetic Evaluation Board has recommended the locomotion index (based on feet and leg conformation traits) be incorporated into the Canadian national selection index, Lifetime Profit Index, in 2002 with an approximate weighting of 12.6%. Lifetime Profit Index is a genetic selection index that combines the economic merits of production, durability and health traits into the national selection strategy for all dairy breeds in Canada.

■ Conclusion

The genetic component of minimizing lameness can be significantly improved by selecting for the desirable foot and leg conformation traits as discussed in this paper. Accurate analysis of foot and leg conformation is essential in order to identify the sires with superior genetic transmitting ability for these specific traits. Breeders must look beyond a sire's general foot and leg proof and focus on his specific component traits if maximum genetic benefit is to be achieved. A combination of good management practices, improved cow comfort and intense selection on foot and leg conformation can substantially reduce the incidence and costs associated with lameness in dairy cattle.

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