Development and validation of an objective swine feet and leg conformation procedure using digital imagery

by

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ABSTRACT

The objectives of this thesis were i) to develop and assess repeatability of an objective method for evaluating feet and leg conformation in high parity sows and ii) to validate and examine measurements using the developed objective method with a group of pedigreed gilts from age at selection through their first parity and into their second gestation. For the first objective, 45 multiparous sows (average parity 6.7 ± 2.5; parity range 5 to 14) from two commercial farms (n = 21 farm one and n = 24 farm two) were used. Sows were moved to a pen where digital images of the profile and rear stance were captured. On average, 2.8 and 8.1 final profile images were used per sow at farm one and farm two respectively. Farm two had over twice the number of profile images as farm one, as farm one was taken from the right side only whereas farm two had both left (average 4.2) and right (average 3.9) profile images. Additionally, 2.6 rear stance images were used for measurement per sow. A joint angle measuring system was devised to collect angle measurements on the knee, front and rear pastern, hock and rear stance. Joint measurements were analyzed using mixed model methods, including farm, side of measurement and parity as fixed effects and sow as a random effect. Intraclass correlation coefficients were calculated to evaluate process repeatability. No significant farm or parity differences were observed for joint angles measured except for the knee angle between farms ($P < 0.05$) and the hock angle between sows parity six and ≥ seven ($P < 0.05$). Side was significantly different in all joints measured ($P < 0.05$), except for in the rear stance measurement where side is not applicable. Joint angle measurement repeatability ranged from 0.58 to 0.87. Lowest and highest repeatabilities were observed for the knee and hock angle measurements, respectively. For the second objective, gilts were selected from a single population and moved to three different farms. Profile and rear stance images were obtained from gilts at selection (319; average age 21.6 ± 1.8 weeks; range 19 to 25) and during their second gestation (277; average gestation 26.7 ± 17.2 days; range 0 to 87). Knee, front and rear pastern, hock, and rear stance joint angles were measured using image analysis software. To evaluate symmetry and joint angle differences due to age between the same individual, only females with repeated measures at selection and post first parity, when second gestation days were between 0 to 21 (126 females), were used. Mixed model equations were used including parity (zero or one) and profile side (left or right) as fixed effects. Parity was included as a repeated variable with the animal as the subject. Knee and rear pastern angles decreased (weakened) and hock angles increased (straightened) as age progressed ($P < 0.05$). All joint measurements were symmetric between left and right legs ($P > 0.05$) except for the hock where a difference ($P < 0.05$) was observed. To evaluate gestation age effects on joint angles, only the measurements taken during the second gestation were used. Data was analyzed using mixed model equations including farm and side as fixed effects and gestation age as continuous covariate and animal was included as random effect. Farm was a significant source of variation for knee, front and rear pasterns, and rear stance angle measurements ($P < 0.05$). Additionally, asymmetry was detected in knee, and front and rear pasterns ($P < 0.05$). Front pastern and hock angles increased (straightened) as gestation age increased, while knee angle decreased (weakened) ($P < 0.05$). Heritability estimates were low to moderate for profile angles and was not estimable for the rear stance position. Results suggest that as age increases leg structure changes, with the rear leg joints showing greater variation from selection to first parity. Results also suggest that environmental factors such as farm where animals are housed could contribute to angle

differences. Small angle changes in the front leg could indicate structure may change over the life of the animal; however, rear leg structure and its impact on longevity still require further investigation. Results from this body of work have set the ground work for an objective feet and leg joint conformation method using digital imagery. It is still necessary to look further into the life of the animal and understand the full genetic control over the change in structure until complete physical maturity and its association with lifetime productivity in the sow.

CHAPTER 1: GENERAL INTRODUCTION

The goal of swine production systems should be to achieve the highest possible profitability ensuring high animal welfare throughout the different production stages. Selection of replacement gilts with optimal feet and leg conformation traits is crucial because sows with feet and leg problems could have limited access to food and water and experience discomfort while moving or standing. Additionally, studies (Stalder et al., 2000; Stalder et al., 2003) have reported that a sow is required to remain in the herd for at least three parities in order to cover her initial cost and it is unlikely that sows that are physically challenged would be able to reach the third parity. In fact, studies (Dagorn and Aumaitre, 1979; Stein *et al*., 1990; Cederberg and Jonsson, 1996; Sehested and Schjerve, 1996; Boyle *et al*., 1998; Anil *et al*., 2005; Mote *et al*., 2009) have reported that feet and leg problems are the second most important reason for culling among first sows with up to 20.3% of removals due to leg problems. However, this estimate is likely underestimated because feet and leg problems affect other traits such as return to estrus and body condition which are also associated with longevity and these can be more apparent or more often reported reasons for removal than the underlying cause.

Selection for optimal feet and leg conformation traits such as soft pasterns and away from buck-knees in replacement gilts could improve sow longevity (Jörgensen, 1996; Grindflek and Sehested, 1996) impacting overall herd performance, farm profitability, and improving sow welfare. Rothschild and Christian (1988) demonstrated through selection across five generations how quickly improvement or weakness in leg structure can be realized. Methods for selecting replacement gilts with optimal feet and leg conformation (Van Steenbergen, 1989; Koning, 1996; Grindflek and Sehested, 1996; NSIF, 2002) have been developed as visual appraisal methods that rely on trained individuals to score an animal on a categorical scale for a varying number of traits and across varying scales. Such methods are widely used and have proved to be effective, however because they are subjective methods, they are vulnerable to varying degrees of bias and error associated with the ability and training of the scorers involved (Main et al., 2000; Van Nuffel et al., 2009; D'Eath, 2012).

With the use of advancing technologies in digital imaging and digital image processing, objective methods for feet and leg soundness evaluation could potentially be developed and implemented in pig commercial units. The objective method is based on measuring joint angles of feet and leg conformation traits reported in the literature as being associated with sow longevity. Currently, such objective methods are being investigated in horses and to a lesser extent in dairy cattle; however there is little research about the topic in pigs.

The main objective of this study was to develop an objective method for evaluating feet and leg conformation in replacement gilts. To achieve that, the objective methodology was first evaluated by scoring five feet and leg conformation traits in two groups of "older" (5th parity and above) sows i) to obtain a base line for joint angle measurements in multiparous sows and ii) to evaluate differences in joint angle measurements between parities and iii) to assess the repeatability of the measurement process.

A secondary objective was to validate and examine the developed objective method. To achieve this objective, 320 pedigreed gilts were followed from pre-selection through their first parity i) to assess structural change over time, ii) to evaluate difference among gestation ages following the 1st parity, and iii) to estimate the heritabilities of the joints measured.

Thesis organization

This introduction is followed by Chapter II, a comprehensive literature review about related topics to the overall subject of this thesis. Chapters III and IV are modified versions of two submitted journal articles, titled "Using digital imagery to objectively evaluate feet and leg conformation in swine" and "Objective evaluation of replacement female feet and leg joint conformation at selection and during second gestation and comparison with high parity conformation in swine" to fulfill the objectives stated. Chapter V contains an overall conclusion to the work in this thesis. Lastly, Chapter VI contains the literature cited for the literature review.

CHAPTER 2: LITERATURE REVIEW

I. Sow Longevity

a. Definition

The definition of sow longevity is complex because of the numerous factors involved with this trait and its dependence on where the trait is being observed (i.e. nucleus or commercial breeding herd). Stalder *et al.* (2004) put together an extensive literature review on the subject of sow longevity in which they stated, “The definition can even differ depending on the type of study being conducted. An economic study might be concerned with lifetime productivity whereas genetic, nutritional or other studies might be concerned with length of life, herd life, productive life, parity removed, or some similar measure.” Hoge & Bates (2011) identified six different measures (definitions) of sow longevity from previous studies (Holder *et al*., 1995; Knauer *et al*., 2006; Serenius & Stalder, 2004; Tarrés *et al*., 2005; Tarrés *et al*., 2006; Yazdi *et al*., 2000). Length of productive life or first farrowing to removal, maximum parity at removal, lifetime prolificacy or number of piglets born alive during productive life, ability of a sow to produce four parities, ability of a sow to produce 40 piglets, and total piglets born alive divided by age at removal were all used as definitions for longevity. One of the most commonly used ways to define longevity is sow lifetime productivity.

b. Sow Lifetime Productivity

i. Measuring/Defining

Sow lifetime productivity is an extremely important aspect of swine production. As evidenced previously, sow lifetime productivity may be used to define just a portion or the entire trait of longevity. Sasaki and Koketsu (2008) identified that more litters produced can equate to an extended life. Like longevity, sow lifetime productivity also has multiple ways of being measured or defined. Some definitions may be very basic compared to some that are extremely in depth. Listed next are a few examples that have been previously used to define or measure lifetime productivity.

ii. Breeding Herd Time and Parity at Removal

Lucia *et al.* (1999) analyzed records from almost 10,000 females to develop a lifetime productivity estimate based on time in the breeding herd and parity at removal. The authors used different values to quantify lifetime productivity (lifetime nonproductive days, lifetime nonproductive days as a proportion of herd life, total number of pigs born per litter weaned, number of pigs weaned per litter weaned, number of nonproductive days per year in the herd, number of litters weaned per year in the herd, and number of pigs weaned per year in the herd). The authors found that as parity at removal increased, nonproductive days decreased and number of litters and pigs weaned per year increased. In conclusion, the authors found that while parity at removal has a positive association with lifetime productivity, nonproductive days must be accounted for to be an accurate estimate.

iii. **Net Present Value**

Studies have used net present value to evaluate sow lifetime productivity (Stalder *et al.*, 2000, Stalder *et al.*, 2003; Rodriguez-Zas *et al.*, 2003). This approach provides the benefit to include a metric for nonproductive days. These studies evaluated animals across multiple age ranges to demonstrate potential economic impacts for removal across multiple parities, regarding volatility in production costs and market prices. Using these economic drivers the researchers identified ranges in which the female could be removed and had recovered her initial cost, with averages being after her third parity. The conclusion of these three studies was that females with increased longevity are capable of greater economic stability and better lifetime productivity than those who were removed early.

iv. Extended Lifetime vs. Genetic Progress

Estimates in 2010 have the U.S. average herd age at 2.73 parities (Rix and Ketchem, 2010). This age level is a reflection of several factors. Genetic improvement over the last 5 years has moved rapidly to improve the swine production industry in all levels of production, except for piglet mortality which has risen by 3.1% between 2008 and 2013. (Stalder, 2014). Genetic improvement pushes the need to replace animals in the nucleus herd, but replacement rates (culling + death) have seen a decline over the last 8 years. For 2014, the average replacement rate in females was 52.3% in comparison to 61.9% for 2006 (PigCHAMP 2006; PigCHAMP 2014). Stein *et al.* (1990) identified key differences between high and low productivity herds based on pigs weaned per female per year. In contrast the higher productive herds were older (2.8 vs. 2.6), had a lower proportion of gilts (16.8% vs. 23.3%), had a higher sow:gilt ratio (6.0 vs. 3.5), and higher parities per sow lifetime (6.1 vs. 4.6). While this study is somewhat dated the ramifications of having an older herd are still apparent.

v. Factors that Affect Lifetime Productivity

Age at first estrus / farrowing - Many studies (Le Cozler *et al.*, 1998; Koketsu *et al.*, 1999; Babot *et al.,* 2003) have identified that an older age at first conception and farrowing results in lower farrowing rates and decreased lifetime productivity. Similarly, Holder *et al.* (1995) found that gilts selected for decreased age of puberty had overall increased lifetime productivity. Serenius and Stalder (2004) suggested that selection for decreased first farrowing interval would likewise increase lifetime productivity.

Gilt development and nutrition - Other studies have instead investigated the effects of development and nutrition of the gilt. Boyd *et al.* (2002) identified a list of important aspects for the developing gilt for increased longevity and subsequent lifetime productivity. Among those components listed were controlled growth, growth through first farrowing, nutrient requirements during first litter to minimize body reserve losses, proper health acclimatization and stimulation to cycle at an early age.

Nonproductive days - Lucia *et al.* (2000) analyzed data and culling records for almost 8000 females to look at individual productivity for animals that had specific removal reasons across parities. Similar to their previous findings those removed in later parities (classified as old) had lower annual nonproductive days and higher annual piglets weaned. Those that were removed for reproductive problems had the highest average annual nonproductive days and were removed in early parities. The authors concluded that minimizing nonproductive days in young females was critical for enhanced lifetime productivity.

Feet and leg problems encompass their own set of challenges to lifetime productivity and longevity and will be discussed in depth in the next section.

c. Longevity and Leg Problems

Feet and leg problems are one of the main causes for sow removals from the breeding herd (D'Allaire *et al.,* 1987; Stein *et al.*, 1990; Cederberg and Jonsson, 1996; Kangasniemi, 1996; Pedersen, 1996; Sehested and Schjerve, 1996; Boyle *et al.*, 1998; Lucia *et al.*, 2000; Anil *et al.*, 2005; Mote *et al.*, 2009). Within these studies feet and leg problems are subdivided into many underlying conditions of leg problems, such as lameness, conformation deformity, and leg weakness. It was been reported that up to 20% of selected gilts were removed due to lameness (Lucia *et al.*, 2000) and that removals due to lameness decline to approximately 6% in older sows. Similar results were found by Tarrés *et al.* (2005), in a study investigating factors affecting longevity in maternal Duroc lines, found lame sows were more likely to be removed from the breeding herd during the first 300 days of productive life when compared with non-lame sows. However, the risk of removal after that period did not differ between lame and non-lame sows. Similarly, Anil *et al.* (2005) reported that removal due to lameness was greater for sows at first parity when compared with gilts and second parity sows. Mote *et al.* (2009) separated age into two separate categories of parity zero to five and five to ten plus. Among the zero to five parity range, leg problems were the second leading cause of removal behind reproduction. Among the five to ten plus parity range, leg problems were fifth. Furthermore, Engblom *et al.* (2007) reported that up to 32% of sow euthanasia is due to lameness.

i. Acute and chronic lameness

Lameness can have either, or both, an acute or chronic condition that causes a deviation to the animal's normal stance or movement patterns. Anil *et al.* (2009) stated, "Acute, severe lameness can result in immediate removal of sows from herds. However, a chronic, less severe form of lameness can affect the performance of sows and indirectly lead to sow removal." The chronic cases have been investigated with many underlying causes present. Osteochondrosis is commonly referred to as the leading cause of lameness in swine (Nakano *et al.*, 1987; Dewey *et al.*, 1993; Heinonen *et al.*, 2006). However, according to Nakano *et al.* (1987) attempts to control for osteochondrosis have been unsuccessful. Likewise, Van Der Wal *et al.* (1987) stated that degrees of leg weakness could not be used across breeds or sexes of the same breed, further making selection against leg weakness difficult. Goedegebuure et al. (1988) stated that osteochondrosis was not the leading cause of front-leg weakness in a selection experiment that diverged generations for front-leg weakness. This result puts more weight on attempting to fix animal structure to attempt to at least diminish the effect of osteochondrosis or lameness similar to those studies previously mentioned in connection with longevity.

d. Longevity and conformation

Some studies have associated individual joints as well as whole leg conformation to play significant roles in increasing or decreasing sow longevity. Jörgensen (1996) scored 187 gilts on a four point scoring system (1 normal to 4 severe) at six months of age and followed through six parities or culling. No animals were removed for production purposes to achieve a lifetime length capability to define longevity. They reported that buck knees and upright rear pasterns were negatively associated with longevity, while soft front pasterns were positively associated with their definition of longevity. In a similar study, Grindflek and Sehested (1996) scored 7,500 sows and 4,000 boars around age at selection based on a correct/defect assessment of the exterior traits that they evaluated. For their analysis increased longevity was considered anything that produced 2 or more litters. They reported the same results for pasterns as was seen by Jörgensen (1996) in regards to their own longevity definition.

Tarrés *et al.* (2006) evaluated the relationship between risk of culling and feet and leg conformation. The authors evaluated front (profile and pastern) and rear (profile, pastern and a view from the rear stance for angulation) leg scores on over 16,000 Large White sows based on a seven point scoring system where the extreme values in the scoring scale represented extreme phenotypes. Sows that received low scores for rear stance leg angulation were 1.4 times more likely to be culled earlier than animals with midline scores. The authors go on to state that the indirect selection away from extreme feet and leg scores was likely responsible for a 6% reduction in replacement rate and an additional 100 days of life in the 4 year span of the study. In conclusion the authors noted that the extreme phenotypes for conformation should be eliminated to achieve similar results.

Tiranti and Morrison (2006) analyzed leg conformation and retention through two parities or until the removal event if animals were removed before 2nd parity on 961 sows. Using a nine point system that analyzed each limb (front / rear, single score per limb with extremely poor conformation as one and desired conformation as nine), the authors reported that animals with bucked to straight knees had a greater risk of removal when compared with sows with a slight curve. Additionally, sows with sickle hocks or with the rear leg positioned farther forward were also at greater risk of removal when compared with sows that received better conformation scores. Furthermore, 29% of sows were removed by the end of the second parity due to undesirable leg conformation.

Fernàndez de Sevilla *et al.* (2008 and 2009) analyzed leg conformation from a 4 point system to estimate the effect of leg conformation on longevity in multiple swine systems. Poor leg conformation scores were associated with a greater risk of removal when compared to sows that received greater or higher leg conformation scores. For instance, Large White sows with upright pasterns were 2.5 times more likely to be removed from the herd earlier while the risk of removal was 3.6 times more likely for Duroc sows with sickle-hocked legs. This study shows results similar to a study by Serenius and Stalder (2007) when overall leg conformation was also examined. In the present study, the authors used a five point system (1 worst to 5 best) to evaluate leg conformation. Sows scoring less than a three were found to be at greater risk of removal than their counterparts.

e. Conformation change across age

Fernàndez de Sevilla *et al.* (2010) examined conformation changes from the end of the growth period through the second parity. The authors examined percentages of their population for negatively associated conformation traits with longevity, specifically straight pasterns and sickle-hocked rear legs. Likewise an overall conformation score (0 - poor conformation to 2 - good conformation) was assigned to each animal at each age level. Leg conformation deteriorated as age progressed in both breeds examined. Similarly, both negative conformation traits increased in population prevalence with age. Increased prevalence of feet and leg problems can add to the risk associated as described above with longevity. What is more problematic with this particular study is that even with proper selection against negative traits in the gilt population there still remains a potential for joint conformation to move towards these negative traits through at least the first two parities if not into later parities. This was the only study found that followed conformation change specifically as age progressed.

f. Financial ramifications of decreased longevity due to feet and leg problems

Wilson *et al.* (2012) stated, "High incidences of involuntary culling of the younger parities cause problems with the herd parity profile and minimize the ability to cull because of production parameters or age." Willgert (2011) used an economic model to quantify the potential losses of lameness in English breeding herds. In the study the potential impact of lameness ranged from $29.00 (converted from the British pound) to $404.00. The lowest value was modeled for simple cases in which treatment was administered and was successful with no loss of productivity. Alternately the greatest value was for the worst case scenario, where the animal was identified late resulting in lost production, treated but did not respond resulting in euthanasia (no reclaim cull value) and had to be replaced. As can be seen in this example, the range is quite wide in the potential circumstances of lameness for any reason.

II. Structural Appraisal

a. Subjective examples in swine

A recent subjective evaluation procedure was developed for producers as a collaborative project by the National Swine Improvement Federation (NSIF, 2002). This project used previous research, much of which is listed previously here, to enable widespread use by all producers and to achieve similar selection standards across this wide range of producers. This is in contrast to the multitude of selection examples that were developed and used in Europe in the late 80s and 90s.

Van Steenbergen (1989) and Lundeheim (1996) both used nine-point scales in assessing a number of separate traits. Van Steenbergen (1989) used a nine point scale with half measures to be able to measure the score as linear in contrast to smaller scales. This study used conformation traits front view front legs, side view front legs (knee and pastern), rear view rear legs, side view rear legs, side view rear legs (hock and pastern) in combination in a 21 trait selection assessment. Grindflek and Sehested (1996) and Koning (1996) each used three point scales to assess similar traits to the two scales previously mentioned with slight deviations based on the difference in scale.

b. Intra and Interpersonal Scoring Variation

Several studies (Main *et al.*, 2000; Van Nuffel *et al.*, 2009; D'Eath, 2012) have shown that subjective measurements have a large deviation of reliability when measuring individual animals whether for lameness or conformation score. What was identified was that reliability is based on levels of training, experience and familiarity with other individual evaluators scoring within the same system.

Main *et al.* (2000) used two observers that were experienced and trained within the system and five untrained individuals and compared them with one another using the kappa coefficient. The kappa coefficient measures the agreement between scorers when chance agreement is taken into consideration. The two trained observers received a high kappa statistic when compared with one another, while the untrained in comparison received low kappa statistic scores when compared to all individuals. Van Nuffel *et al*. (2009) reported that individuals are capable of detecting abnormalities of gait within dairy cattle to a high degree. However, significant differences were observed between unfamiliar individuals and those familiar with the system, similar to the Main *et al*. (2000) study. Familiar observers were able to identify slight defects to a greater degree than unfamiliar observers. In the study performed by D'Eath (2012) the largest disagreements were found between locomotion scores closest to one another, as seen above. The author reported moderate agreement between evaluators, especially when lameness scores were grouped into two categories. Likewise, score agreement improved as the evaluators gained experience as the study progressed.

c. Swine Conformation Heritability Estimates and Use of Selection

Swine feet and leg conformation traits have been shown to be lowly to moderately heritable in previous studies (Bereskin, 1979; Rothschild and Christian, 1988; Serenius *et al.*, 2001; Fan *et al.*, 2009). Serenius and Stalder (2006) noted that the variation is dependent on the population being evaluated. It is important to note that these studies focus on different traits as well. For example; Bereskin (1979) and Rothschild and Christian (1988) looked at overall leg structure, while other studies (Serenius *et al.*, 2001; Fan *et al.*, 2009) have also focused on the individual joints that make the leg structure.

If heritability estimates were low for individual traits, selection for or against a particular trait would not make much progress. However, Rothschild and Christian (1988) demonstrated that within a population, selection for structure in divergent directions is attainable. In that study, three separate lines were selected for front leg structure across five generations; a high line representing good conformation, a control line, and a low line representing poor conformation. As long as genetic variation remains, the ability to influence feet and leg structure has been shown.

III. Objective Measurement Studies

Human research on objective structural measurement is ahead of all domesticated livestock industries. While this research is a good model for the domesticated animal industry to adopt, there are clearly apparent differences between livestock and human subjects. Humans are much easier to measure considering they can understand positioning instructions and can be asked to remain stationary whereas animals can’t.

Of all domesticated livestock species, dairy and equine were found to have the most published research regarding objective scoring systems using the latest technologies, such as digital imaging or three dimensional measurements. These animals have much smaller replacement pools to choose from, considering on average only a single offspring once per year per female. Swine in contrast have a much larger pool when they produce litters in excess of 10 slightly over twice per year. Remembering that on average only half of these progeny are female. Therefore, it is of much more importance for the dairy and equine systems to get their selections correct based on conformation, however, the swine industry should not overlook the potential for implementation within their own programs.

a. Objective measurement studies using physical measurements

Draper *et al.* (1988) physically measured individual leg joint angles from the divergent lines produced from the Rothschild and Christian (1988) studies. In this study, the authors were able to identify significant differences in joint measurements between the three lines of pigs produced. For example, the low-line pigs were found to have smaller angles at the carpal joint and greater angles at the hock while in normal stance position than both control and high-line. Likewise, extension and flexion differences at the elbow and carpal joints were observed between the low-line versus control or high-line.

Boisot *et al.* (2002) used physical measurements from the rear leg of dairy cows to objectively evaluate conformation and structure. The study used three untrained evaluators to take the measurements to evaluate the measurement process repeatability. When measuring distances, repeatabilities were relatively high (0.63 to 0.89). However, when measuring angles, repeatabilities were extremely low (0.00 to 0.24), but possibly misrepresented due to one individual evaluator having a range of 0.00 to 0.02 while the other two were between 0.20 and 0.24 for the three angles measured. These values, as stated by the authors, are smaller than values reported in previous literature of categorical measurements.

b. Objective measures using digital imagery

i. Dairy

Qian *et al.* (2008) developed a semi-automated analysis procedure for dairy cattle using digital imagery. The process required an individual to select particular body points on the animal for analysis. The authors stated that the main requirement of their program was the use of high quality images for analysis. The remaining items that authors stated that could contribute to error within the process were cleaned within the software program. The authors showed agreement between the image analysis system and manual evaluation, however only length was measured.

Tasdemir *et al.* (2011) investigated the use of digital image analysis for body measurements and estimation of live weight by regression on these traits. For this study, multiple camera locations were used and multiple formulas were filtered through image analysis software to account for expected error through two-dimensional conversion of a three-dimensional subject. Accuracies between image analysis and manual measurement for all traits were found to range from 95 to 98 percent. The estimated live weight using the regression equation from image analysis measurements and true live weight returned a correlation of 0.98.

ii. Equine

Hunt *et al.* (1999) investigated the merits of a measurement process using digital images to objectively quantify structural traits in horses. This study used two methods of measuring from the images. The first required the palpation of the animals' joints and bones of interest and markers were placed on the palpated structural protrusions for reference from the images. In the second method the markers were excluded and an outline of the horse was used. Camera placement and location were also investigated to determine potential errors associated with improper camera placement. The main advantage that the markers had over the outline method was that while the outline method measured with high precision, it showed dependency on finding suitable markers from the image, where with palpation this was already achieved. Camera placement also showed significant differences when the camera was placed above or below the midline of the horse, showing the need for a stable level height when recording the videos.

Weller *et al.* (2006) used markers on horses in connection with motion analysis software to study joint measurements as well as motion. The purpose of 3-D imagery analysis was to correct for the errors and dependence on certain criteria from a two dimensional standpoint such as camera position and reduction of structure from 3-D to 2-D. Likewise preplaced markers did not require any further examination from the 3-D images. These methods according to the author provide a measurement system with high accuracy for joint measures. However, the authors did note that joints with large ranges of motion were the most variable when repeated measures was applied, leading the authors to believe these joints or areas will be less meaningful than those with high repeatability.

Thomas *et al.* (2014) performed a similar study in Lipizzan horses but instead evaluated joints two dimensional digital images. The authors used anatomical positions of the animals from the images to measure joints of interest, but were not satisfied that the two-dimensional images were sufficient in capturing the anatomical range variances or in adequately modeling the shape of the horse. This was in part due to the two-dimensional image not being completely capable of capturing the natural curve around the areas that were measured. Unfortunately however, the values for the anatomical range variances were not published in their article, so there is no clear numerical perspective relative to how their criteria were not satisfied. What is of interest however is their further recommendation to use three-dimensional image measurements in place of two-dimensional measurements to account for these shortcomings, which was explained by Weller *et al.* (2006).

iii. Swine

A study conducted by McFarlane *et al.* (2007) built on a 3-D imagery program originally created by Wu *et al.* (2004), in which the authors demonstrated a system that was capable of measuring the shape and volume of the animal in a three-dimensional model. While these studies focused on the technical aspects including the computer program and the ability to measure the pig in three dimensions, it demonstrates the advances that technology is making to improve measurement techniques.

Pluym *et al.* (2013) developed a system to objectively appraise rear leg structure through digital images. Angle of the claw, pastern bone, and hock were examined between the animals left and right sides by placing a mark on palpated structural positions of selected joints, similar to the previous work described in dairy and equine. Five images were measured to assess the objective image analysis measurements repeatability. The coefficients of variation ranged between 3 for the hock and 13 for the pastern, representing high repeatability for the objective analysis process. Similarly, no differences were found between the left and right measurements from the same animal.

iv. Human

Original video analysis used markers, similar to the work done in equine and dairy above, on human subjects to be able to evaluate a structural pattern similar to that in dairy and equine. Chang *et al.* (2000) developed a system that bypasses the required marker use to achieve an effective measurement technique for measuring posture parameters, specifically swing distance and joint angles. The study yielded a 90% success rate in classifying control and Parkinson patients through video image analysis.

CHAPTER 3: USING DIGITAL IMAGERY TO OBJECTIVELY EVALUATE FEET AND LEG CONFORMATION IN SWINE

Modified from a paper to be submitted to the Journal of Animal Science and Biotechnology

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Abstract

The objectives of this study were to characterize joint angles for knee, hock, front and rear pasterns and a rear stance position in multiparous sows using digital imaging technology and to assess the repeatability for the objective measurement process. Forty-five multiparous sows (average parity 6.7 ± 2.5; parity range 5 to 14) from two commercial farms (n = 21 farm one and n = 24 farm two) were used. Sows were moved to a pen where digital images of the profile and rear stance were captured. On average, 2.8 and 8.1 final profile images were used per sow at farm one and farm two respectively. Farm two had over twice the number of profile images as farm one, as farm one was taken from the right side only whereas farm two had both left (average 4.2) and right (average 3.9) profile images. Additionally, 2.6 rear stance images were used for measurement per sow. A joint angle measuring system was devised to collect angle measurements on the four feet and leg joints previously mentioned and the rear stance. Joint measurements were analyzed using mixed model methods, including farm, side and parity as fixed effects and sow as a random effect. Intraclass correlation coefficients were calculated to evaluate process repeatability. No significant farm or parity differences were observed for joint angles measured except for the knee angle between farms ($P < 0.05$) and the hock angle between

sows parity six and ≥ seven ($P < 0.05$). Joint angle measurement repeatabilities ranged from 0.58 to 0.87 for all joints measured.

Keywords: *Digital imagery, feet and leg conformation, joint measurements, sows*

Implications: Feet and leg conformation evaluation using digital images could be used as an objective tool to aide in selection of replacement gilts. This could have a beneficial impact on sow longevity and farm productivity and profitability.

3.1 Introduction

Several methods that are widely used in the pig industry have been developed to visually score feet and leg conformation in candidate replacement gilts and sows using a numerical scale. However, several studies have reported that the reliability for subjective observational methods depends on the observers' training and experience (Main *et al.*, 2000). A more objective method to evaluate feet and leg conformation in replacement females could help to reduce premature culling due to feet and leg problems; thereby improving sow longevity, farm productivity and farm profitability. Digitally measuring joint angles could provide a more accurate approach for evaluating feet and leg conformation traits in pigs. However, there have been only a few studies investigating digital imagery use for measuring joint angulation in any livestock industry with some examples in dairy cattle (Qian *et al.*, 2008) and horses (Thomas *et al.*, 2014). In pigs, to our knowledge, there is only one previous study regarding measurements of joint angles using digital images (Pluym *et al.*, 2013); however, that study focused only on the rear leg joints. The objectives of this study were to measure joint angles for knee, hock, front and rear pasterns and a rear stance position in multiparous sows using digital imaging technology and to assess the repeatability for the objective measurement process.

3.2 Materials and Methods:

3.2.1 Animals

This study was approved by the Iowa State University Institution of Animal Care and Use Committee (protocol number 2117083-S). Additionally, this study was conducted in accordance with the Guide for the Care and Use of Agricultural Animals in Research and Teaching as issued by the American Federation of Animal Science Societies (FASS, 2010). Only sows having produced five or more litters were used in this study under the hypothesis that sows that remain in the breeding herd for longer time periods would have feet and leg conformation traits that are conducive to improved longevity compared to sows culled in earlier parities. Forty-five crossbred, multiparous sows, parity 5 and older (hereafter referred to as older sows) were evaluated on two separate breed-to-wean farms for this study. At farm one, 21 sows (average parity = 5.2 ± 0.4, range five to six) were housed in gestation stalls in North Carolina. At the time of data collection, farm one had a sixth parity forced culling practice in place, which limited the maximum parity from this operation. The remaining 24 sows (average parity = 8.0 ± 2.8, range six to 14) were housed in gestation stalls located in Iowa (farm two). Due to limited number of sows from parity seven or greater from this farm (only one to two per parity), all sows from parity seven and older were placed into a single group labelled seven+.

3.2.2 Image Collection

Sows were moved to a gestation pen and feed was provided (approx. 0.5 kg/sow) on opposite sides of the solid flooring to assist with sow positioning to obtain “ideal” photos. When necessary, the sow was guided using a sort board to place her body parallel with the edge of the solid flooring, where the solid met the slatted portion of the pen and where profile image capturing occurred. The camera was held in position by the observers. Two separate observers recorded the images for the two separate farms (observer one recorded farm one, observer two recorded farm two) using the same technique as described below. Profile images were obtained from the opposite side of the gestation pen. The camera was held approximately 2.4 m from the sow and 1.0 m from the floor (Figure 3.1a). The sow was repositioned in the opposite direction for the remaining profile images. Rear stance images were collected from behind the sow. The camera was held approximately 1.2 m from the rear of the sow and 1.0 m from the floor (Figure 3.1b). Digital images (i.e. pictures) of the sows’ left profile, right profile and rear stance were taken using a Samsung PL20 digital camera (Samsung Electronics Co., Ltd. Yongin-City, Gyeonggi-Do, South Korea). In order to maintain image consistency for analysis, all images were captured using camera default settings portrait mode with no zoom. To increase measurement accuracy, several images were captured from each position for each animal, each animal measurement was included in the analysis and measurements were not averaged per individual. Images were reviewed for quality and position, first at the time of collection on the cameras preview screen, and subsequently on a computer monitor. Images were discarded from further analysis if the sow was not standing squarely on all four legs, if the image was completely distorted, or the complete joint was not visible in the image (Figure 3.2). On average, 2.8 and 8.1 final profile images were evaluated per sow at farm one and farm two respectively. Farm two had over twice the number of profile images as farm one, as farm one was taken from the right side only whereas farm two had both left (average 4.2) and right (average 3.9) profile images. Additionally, 2.6 rear stance images were used for measurement per sow, yielding 398 total images that were used to evaluate the objective scoring methods applied to various joint angles.

3.2.3 Trait Evaluation Procedures

Feet and leg conformation traits such as knee, pasterns, hock, and rear stance were evaluated in this study, as they have been reported to be associated with sow longevity (Serenius and Stalder, 2004; Tiranti and Morrison, 2006; Fernández de Sevilla *et al.*, 2008; Nikkilä *et al.*, 2013). All digital images measurements were evaluated using the angle measurement tool in ImageJ (ImageJ, National Institute of Health, Bethesda, MD, USA) following modified methodology of the scoring method developed by The Norwegian Pig Breeders' Association (Norsvin, Hamar, Norway).

The knee and pastern from the front leg profile image were measured (Figure 3.3, angles a to d). Angles (a) and (b) corresponded to the knee, the joint between the radius/ulna and carpals, with the anterior contour top of the radius and posterior contour tip of the olecranon (dorsal) and the anterior and posterior positions of the carpal/metacarpal joint (ventral) acting as anchor points (i.e. a common position on the joint for all animals that is easily referenced and used for measurement purposes). Angles (c) and (d) corresponded to the front pastern measured in reference to the floor. The anterior and posterior joint positions between the carpals and metacarpals are the anchor points for the front pastern measurement that places a line down the top and bottom of the hoof to a straight edge that traces a line back creating the angle measurements that provide the mean for the front pastern angle value.

Hock and rear pasterns were measured from the rear leg profile images (Figure 3.3, angles e to h). Angles (e) and (f) corresponded to the hock, tracing on the front and back of the joint between the fibula/tibia and tarsals, with the anterior and posterior positions acting as the anchor. Angles (g) and (h) corresponded to the rear pastern measured in reference to the floor. The anterior and posterior joint positions between the tarsals and metatarsals are the anchor points for the rear pastern measurement that places a line down the top and bottom of the hoof to a straight edge that traces a line back creating the angle measurements that provide the mean for the rear pastern angle value.

Rear stance pattern (Figure 3.4, angles a and b) included two measurements that trace lines from between the hooves and to the back of the hock from the same leg and across to the back of the hock from the opposite leg. This was replicated on the opposite leg and the two measurement average was calculated to use as an individual angle value for rear stance.

3.2.4 Data Analyses

Each sow was considered an experimental unit from two different crossbred genetic suppliers. Each joint angle measurement was analyzed using mixed model equation methods (PROC MIXED, SAS v9.3; SAS Inst. Inc., Cary, NC). Models included farm, parity and side as fixed effects. Sow was included as a random effect. It should be noted that there is the potential for an observer effect, but due to confounding between farm and observer (farm and different observers can’t be separated) only farm was included in the model. Statistical differences were reported when individual model main effects were a significant source of variation $P \leq 0.05$.

Further, when an individual model main effect was a significant source of variation, main effect levels were separated using the PDIFF option, which displays the *P* values for differences for pairwise comparisons between all levels within a given class variable. Results for fixed effects are reported as least squares means ± standard error (LS Means ± SE).

Repeatability for the measurements was estimated using the intraclass correlation coefficient (ICC), which measures the reliability or reproducibility for the joint value measurements controlling for unordered observations. For this study, the individual animals measurements within each joint were considered unordered as any individual measurement within a joint within an animal could be ordered one through n. ICC and its standard deviation were calculated using the following formulas (Wolak *et al.*, 2012):

$$ICC = \frac{\sigma_\alpha^2}{\sigma_\alpha^2 + \sigma_\epsilon^2}$$

where σ_α^2 = variance among measurements and σ_ϵ^2 = variance within measurements;

$$SD_{ICC} = \sqrt{\frac{2(1-ICC)^2(1+(k-1)ICC)^2}{k(k-1)(n-1)}}$$

where k = number of observations and n = number of individuals

3.3 Results

Joint measurement LS Means ± SE by farm and parity are reported in Table 3.1. No differences (*P* > 0.05) were observed for the different joint angles measured between sows from the two farms, except for the knee measurement, where knee angle was seven degrees greater for sows from farm one when compared to sows from farm two (*P* < 0.05). Additionally, there was no difference (P > 0.05) between parities for any of the joints measured except for the hock angle, where hock angle was seven degrees less for sows parity seven+ when compared to sows parity six (*P* < 0.05). Side of measurement differences were shown to be two degrees less on the right side in all joints measured (*P* < 0.05) where side was an applicable measurement. Intraclass correlation analyses showed that the objective method described in the present study is repeatable (Table 3.2) as the ICCs were between 0.58 (knee - lowest) and 0.87 (hock - highest) for the different joint angle measurements.

3.4 Discussion

Subjectively scoring feet and leg conformation traits has and continues to serve the swine industry commercial and breeding sectors when selecting replacement gilts with acceptable conformation. However, they depend on observers' training with the scoring system used and the observers' experience. In fact, studies have shown that scores between two individuals can widely vary (Main et al., 2000; Van Nuffel *et al.*, 2012). Advancing technologies, such as digital imagery, could allow for the development of new and more accurate procedures to assist in gilt selection through an objective scoring process for the important feet and leg traits. Leg problems are reported as the second most important reason for involuntary sow culling in breeding herds before the fourth parity (D'Allaire *et al.*, 1987; Boyle *et al*., 1998; Mote *et al.*, 2009). The development of an objective method to select replacement gilts with the most desirable structural soundness could decrease the likelihood a gilt would be culled due to leg problems. This in return would likely increase profitability for commercial swine breeding herds as fewer replacement gilts will be needed. Additionally, retaining sows in the herd for multiple parities allows the sow to pay for herself and to spread the initial cost over a greater number of piglets produced (Stalder *et al*., 2000). Joints have a certain typical range of motion; however, those ranges have not been widely investigated in sows. Draper *et al.* (1988) measured knee and hock angles in finishing Duroc pigs while standing as part of a study on divergent selection for front leg weakness (Rothschild and Christian, 1988). In the latter study, a low line (increased front leg weakness), a control line (intermediate front leg weakness), and a high line (no front leg weakness) were developed over five generations. Draper *et al.* (1988) reported knee joint angles of 167.8 (low), 173.5 (control) and 174.5 (high) degrees and hock joint angles of 151.0 (low), 142.7 (control) and 144.5 (high) degrees. These results are similar with the joint angle measurements found in the present study. The results suggested that a seven degree separation in either the knee or the hock is significant enough to be a potential risk indicator within the joint for leg weakness. However, while this seven degree separation in those joints may be a risk factor, they should not be isolated from the remaining important joint measurements for leg conformation. For instance Draper *et al.* (1988) did not measure pasterns which have been reported to be strongly associated with sow longevity (Grindflek and Sehested, 1996; Jorgensen, 1996).

There is limited research regarding feet and leg conformation changes as parity number progresses and the few studies have focused on gilts and young parity sows (i.e. sows parity one to two). For instance, Fernàndez de Sevilla *et al.* (2009) reported that in gilts, feet and leg conformation deteriorated from the end of finisher period to the first parity as well as from first parity to second parity. Additionally, the authors reported that the incidence rate for straight pastern position doubled between the end of finisher period and the first parity in the Large White population, but no further change was observed by the second parity. These results would suggest that feet and leg conformation could change as a sow ages although the implications for sow welfare and sow longevity are still unknown.

The objectives of this study were to measure joint angles for knee, hock, front and rear pasterns and a rear stance position in multiparous sows using digital imaging technology and to assess the repeatability for the objective measurement process. To achieve this, it is necessary to know what would be considered an optimal joint angle measurement, as well as to understand the typical joint values range that can be found in a sow herd. It has been suggested that sows that are involuntarily culled due to leg problems in early parities may have undergone a selection process for good feet and leg conformation (Calderón Díaz *et al*., 2014). The animals chosen for this study represented the oldest sows among the two farms. Their joint angle measurements could provide a reference point for determining optimal joint angle measurements in gilts as there was no difference between any of the angles among parities or farms, except for the hock (parities six and seven) and the knee (farms). However, the biological significance of these results require further investigation. Based on the results from the side comparison, each side should be examined separately, but the two degrees of separation also requires further investigation regarding biological significance. It should also be noted that farm differences, while informative, were not the main basis for the study. Repeatability of the measurement process is considered the most important findings from the study.

Furthermore, genetic parameter studies (Bereskin, 1979; Rothschild *et al*., 1988; Serenius *et al*., 2001; Fan *et al*., 2009) have reported feet and leg conformation traits to be lowly to moderately heritable (with most based on a categorical scale system). An objective scoring system could enhance the heritability estimates and produce greater accuracy and repeatability associated with them by creating a more consistent joint score regardless of evaluator. However, this yet remains to be tested. Considering that conformation traits are moderately heritable and linked to longevity, which is an important welfare and economic parameter (Serenius and Stalder, 2004; Tiranti and Morrison, 2006; Fernàndez de Sevilla *et al*., 2008; Nikkilä *et al.*, 2013), it could be possible to include these traits in selection programs to improve sow longevity and increase herd potentials, such as increasing sow longevity, farm productivity and farm profitability.

Based on the results from the ICC analyses, the objective method used to measure feet and leg conformation described in the present study is repeatable, but seems to depend on the range of motion for the different joints. For instance, repeatability may depend on a given angles available range of motion. This could be related to the anatomical function of the knee and hock, where the knee has the capability to move either anteriorly or posteriorly from a centralized resting position to a varying degree as opposed to the hock which can move anteriorly, but is restricted in moving posteriorly past the normal resting point, if at all. Van Steenbergen (1989) used a nine-point linear visual scoring system, which included half point measurements, to determine repeatability for various feet and leg joint angle measurements including the front leg side view, hock, pasterns, and rear leg views (similar to rear stance from the present study). Repeatabilties ranged from 0.40 for the rear pastern, 0.47 for the rear view of rear legs, 0.49 for both the hock and front leg side view, to 0.54 for the front pastern (Van Steenbergen, 1989), which are lower than the repeatabilities achieved in the present study for the same joint measurement. Differences between studies are likely due to the different measuring methods used in both studies.

3.5 Conclusions

Measuring joint angles when selecting replacement animals that possess desirable feet and leg conformation traits appears feasible as measurements were consistent across parities and farms. All levels within a genetic implementation program, from grandparent to maternal cross, could execute the measurement system described. Objective feet and leg conformation trait measurement could be successfully implemented as an alternative to subjective methods as it is repeatable and provides an accurate representation of the joint. However, the methods described in this research are time consuming and are most likely not cost effective until further automation is achieved. Similarly, by having the observer select the images for inclusion, there is a potential for bias an error associated with this method as well. To alleviate image selection bias and error, this system would need to look at incorporating an automated system that could take images when the system detected that the individual is standing squarely on all four feet. To effectively implement the proposed measuring procedure, further refinement of the process and automation is necessary.

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Table 3.1 *Feet and leg conformation trait joint angle Least Squares Means (±SE) from 45 multiparous crossbred gestating sows from two different farms*

	Knee[1]		**Front Pastern**[2]		**Rear Pastern**[3]		**Hock**[4]		**Rear Stance**[5]	
Variable	LS Means	SE	LS Means	SE	LS Means	SE	LS Means	SE	LS Means	SE
Farm[6]										
1	161.1^{a}	1.9	57.8^{a}	2.9	51.6^{a}	3.0	147.7^{a}	2.2	88.9^{a}	2.0
2	153.8^{b}	1.4	54.4^{a}	2.1	53.0^{a}	2.1	146.2^{a}	1.6	88.3^{a}	1.5
Parity[7]										
5	157.5^{a}	1.9	56.7^{a}	2.9	53.9^{a}	3.0	$149.5^{a,b}$	2.2	89.9^{a}	2.0
6	158.4^{a}	1.5	55.0^{a}	2.2	52.4^{a}	2.3	149.3^{a}	1.7	88.0^{a}	1.5
7^{+}	156.4^{a}	2.0	56.5^{a}	3.0	50.7^{a}	3.1	141.9^{b}	2.4	87.7^{a}	2.1
Side										
L	158.5^{a}	0.9	57.4^{a}	1.3	53.4^{a}	1.4	147.8^{a}	1.0	NA	NA
R	156.3^{b}	0.8	54.8^{b}	1.2	51.2^{b}	1.2	146.0^{b}	0.9		

[1]Joint between the radius/ulna and carpals, with the anterior contour top of the radius and posterior contour tip of the olecranon (dorsal) and the anterior and posterior positions of the carpal/metacarpal joint (ventral) acting as anchor points with the mean representing the angle value

[2] Measured in reference to the floor, with the anterior and posterior positions of the joint between the carpals and metacarpals as the anchor point that places a line down the top and bottom of the hoof to a straight edge that traces a line back creating the angle measurements that provide the mean for the angle value

[3] Measured in reference to the floor, with the anterior and posterior positions of the joint between the tarsals and metatarsals as the anchor point that places a line down the top and bottom of the hoof to a straight edge that traces a line back creating the angle measurements that provide the mean for the angle value

[4] Tracing on the front and back of the joint between the fibula/tibia and tarsals, with the anterior and posterior positions of that joint acting as the anchor

[5] Measured from the hooves and to back of the hock of same leg and across to back of other hock, replicated on opposite side and averaged

[6] Commercial breed-to-wean farms. Farm 1 (n = 21) sows are culled after parity 6. Farm 2 (n =24) allows sows to "cull itself" based on production

[7] Parities ranged from 5^{th} to 14^{th} for all sows measured. Sows parity 7 and above were grouped into a single category "7+"

[a,b] Within columns, values with different superscripts indicate significant differences between predictor variables; $P < 0.05$

Table 3.2 *Intraclass correlation coefficients (SD) for the repeatability of measuring the angulation of five feet and leg conformation traits from 45 multiparous gestating sows from two different farms*

Joint	Intraclass correlation coefficient[1]	SD[2]
Knee[3]	0.59	0.11
Front Pastern[4]	0.67	0.12
Rear Pastern[5]	0.70	0.12
Hock[6]	0.87	0.10
Rear Stance[7]	0.72	0.13

[1]Calculated as $ICC = \frac{\sigma_\alpha^2}{\sigma_\alpha^2+\sigma_\epsilon^2}$, where σ_α^2 = variance among measurements and σ_ϵ^2 = variance within measurements

[2] Calculated as $\sqrt{\frac{2(1-ICC)^2(1+(k-1)ICC)^2}{k(k-1)(n-1)}}$, where k = number of observations and n = number of individuals

[3] Joint between the radius/ulna and carpals, with the anterior contour top of the radius and posterior contour tip of the olecranon (dorsal) and the anterior and posterior positions of the carpal/metacarpal joint (ventral) acting as anchor points with the mean representing the angle value

[4] Measured in reference to the floor, with the anterior and posterior positions of the joint between the carpals and metacarpals as the anchor point that places a line down the top and bottom of the hoof to a straight edge that traces a line back creating the angle measurements that provide the mean for the angle value

[5] Measured in reference to the floor, with the anterior and posterior positions of the joint between the tarsals and metatarsals as the anchor point that places a line down the top and bottom of the hoof to a straight edge that traces a line back creating the angle measurements that provide the mean for the angle value

[6] Tracing on the front and back of the joint between the fibula/tibia and tarsals, with the anterior and posterior positions of that joint acting as the anchor

[7] Measured from the hooves and to back of the hock of same leg and across to back of other hock, replicated on opposite side and averaged

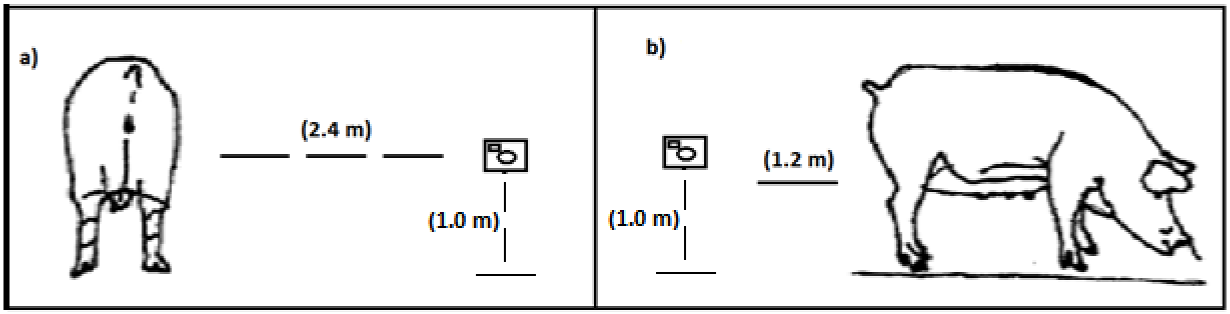

Figure 3.1 Digital image collection: sow and camera position

a) the profile image of the sow
b) the rear stance image of the sow

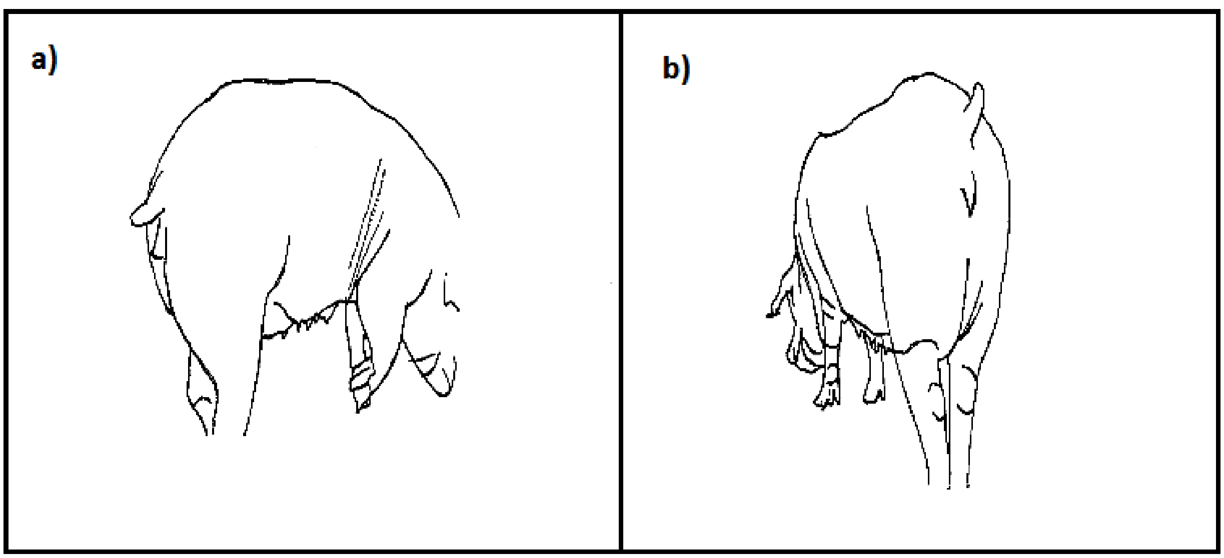

Figure 3.2 Sample rejected images due to leg position and body position in reference to the camera.

a) Rejected profile image because the front leg is flexed and the hock and rear pastern were not captured
b) Rejected rear stance image because the sow was not standing in a square position

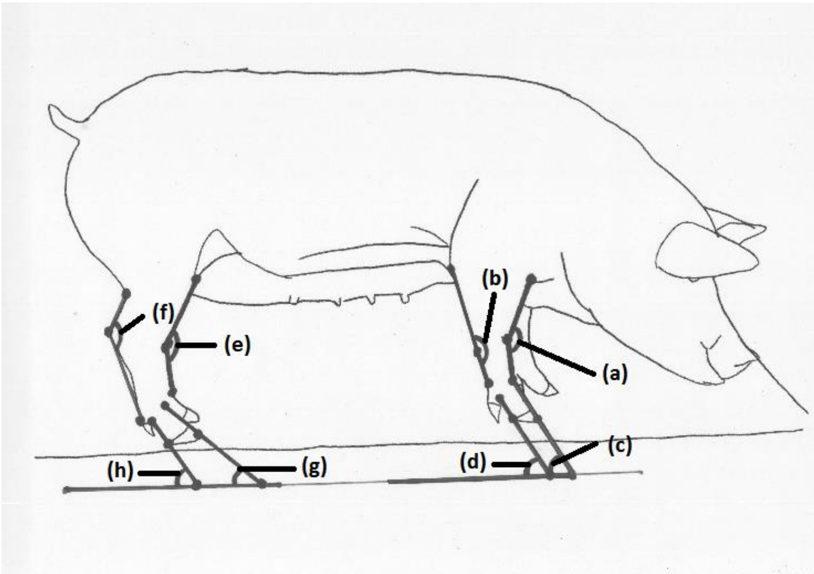

Figure 3.3 Topographical representation for locations of the joint angles measured in a study using digital imagery to evaluate feet and leg soundness in multiparous sows.

(a) and (b) **knee** measured running on the front and back of the joint between the radius/ulna and carpals, with the contour sides of that joint acting as the anchor.

(c) and (d) **front pastern** measured in reference to the floor, where the contour of the joint between the carpals and metacarpals is the reference point for the front pastern measurement that runs a line down the top and bottom of the hoof to a straight edge that traces a line back.

(e) and (f) **hock** measured running on the front and back of the joint between the fibula/tibia and tarsals, with the contour sides of the joint acting as the anchor.

(g) and (h) **rear pastern** measured in reference to the floor, where the contour of the joint between the tarsals and metatarsals is the reference point for the rear pastern measurement that runs a line down the top and bottom of the hoof to a straight edge that traces a line back.

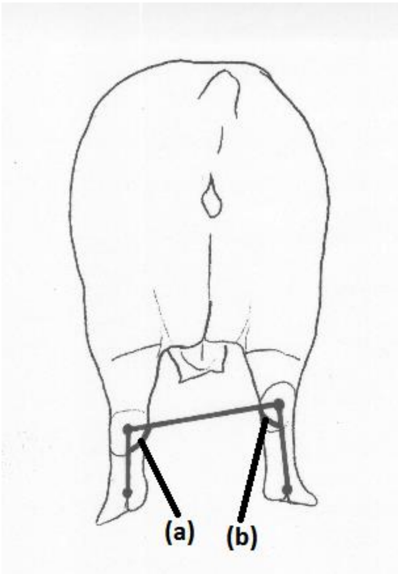

Figure 3.4 Topographical representation for locations of the joint angles measured in the rear stance in a study using digital imagery to evaluate feet and leg soundness in multiparous sows.

(a) and (b) Rear stance included two measurements that ran from in between the hooves and to the back of the hock of the same leg and across to the back of the other hock.

CHAPTER 4: OBJECTIVE EVALUATION OF REPLACEMENT FEMALE FEET AND LEG JOINT CONFORMATION AT SELECTION AND DURING SECOND GESTATION AND COMPARISON WITH HIGH PARITY SOW CONFORMATION IN SWINE

Modified from a paper to be submitted to the Journal of Animal Science and Biotechnology

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Abstract:

The first objective was to identify feet and leg joint angle ranges in gilts at selection through their first parturition. The second study objective was to use measures during second gestation to identify patterns between farms and gestation days. Finally, the last objective of this study was to obtain genetic parameter estimates for feet and leg conformation angles. Gilts were selected from a single gilt population and moved to three different farms. Profile and rear stance images were obtained from gilts at selection (319 gilts; average age 21.6 ± 1.8 weeks; range 19 to 25) and during their second gestation (277 sows; average gestation 26.7 ± 17.2 days; range 0 to 87). Knee, front and rear pastern, hock, and rear stance were measured using image analysis software. To evaluate symmetry and joint angle differences due to age between the same individual, only females with repeated measures at selection and 0 to 21 days of second gestation (126 females) were used. Mixed model methods were used including parity (zero or one) and side where images were taken (left or right) as fixed effects, with parity as a repeated effect.

Knee and rear pastern angles decreased (weakened) and hock angles increased (straightened) as age progressed ($P < 0.05$). There were no joint measurement differences between left and right sides ($P > 0.05$) except for the hock ($P < 0.05$) where a two degree difference was observed. To evaluate gestation age effects on joint angles, only the measurements taken during the second gestation were used. Data was analyzed using mixed model methods including farm and side as fixed effects and gestation age as continuous covariate. Animal was included as random effect. Differences in mean response were observed across farms for knee, front and rear pasterns, and rear stance angle measurements ($P < 0.05$). Additionally, asymmetry was detected in knee, and front and rear pasterns ($P < 0.05$). Front pastern and hock angles increased (straightened) as gestation age increased, while knee angle decreased (weakened) ($P < 0.05$). Heritability estimates were low to moderate for profile angles and was not estimable for the rear stance position. Results suggest that as age increases leg structure changes, with the rear legs joint showing greater variation from selection to first parity. Results also suggest that environmental factors such as farm where animals are housed can contribute to angle differences. Small angle changes in front leg could indicate structure that carries over the life of the animal, however, rear leg structure still requires further investigation for longevity implications.

Keywords*: Digital imagery, feet and leg conformation, joint measurements, gilts*

4.1 Introduction

Replacement gilt selection occurs at a single point in time of an animal’s life. Feet and leg conformation comprises a significant portion of this selection process. However, when the replacement gilts are selected for proper feet and leg conformation, they are still undergoing rapid growth (Robison, 1976). Studies on conformation changes between selection and the height of the growth curve are limited. Feet and leg problems are commonly listed as the second leading cause of removal of females before fourth parity from breeding herds (D’Allaire *et al.*, 1987; Boyle *et al.*, 1998; Mote *et al.*, 2009). Several feet and leg conformation traits, such as pasterns, knees and hock position, are associated with improved longevity and survivability in sows (Stalder et al., 2004). Identifying angles from these joints, that when selected upon early in life and are maintained could help make more informed feet and leg selection decisions, especially if using accurate objective methods to access these joints. Likewise, understanding key feet and leg conformation changes in these joints that occur either during maturity or during subsequent gestation periods could potentially help culling decisions as well.

The first objective was to identify feet and leg angle ranges in gilts at selection through their first parturition using digital imaging tools. The second objective was to use digital image feet and leg joint angle measures during second gestation to identify patterns between farms and gestation days. Finally, the last objective was to obtain heritability estimates for feet and leg conformation angles obtained using digital imaging methods.

4.2 Materials and Methods:

Care and Use of Animals

This study was conducted in accordance with the Guide for the Care and Use of Agricultural Animals in Research and Teaching as issued by the American Federation of Animal Science Societies (FASS, 2010).

4.2.1 Animals

Three hundred nineteen pedigreed gilts, from 19 to 25 weeks of age from a Fast Genetics gilt development unit were included in the study. Gilts were selected for inclusion in the study based on the following criteria: i) mobility, ii) no severe injuries, iii) exclusion of females too small for selection. Gilt feet and leg images were captured at the gilt development unit. The gilts were later randomly separated and transferred to three breed-to-wean sow units. Pedigree was traced two generations back, when possible, and the final pedigree file included 318 of the 319 gilts. Knee, front and rear pastern, hock and rear stance were digitally captured and measured at time of selection and once again during second gestation unless the animal was removed prior for health or well-being.

4.2.2 Image Collection

Gilt image collection and image processing followed similar procedures described in Chapter 3.2.2. The only differences between the two studies is that instead of using a still frame camera, digital video was recorded using a Bell + Howell Take 1 HD Digital Camcorder (Bell and Howell, US, 760 South Wolf Road, Wheeling, IL, 60090) on HD 1280 x 720P settings. Videos were reviewed for standing position and digital image frames were extracted from the videos using AVCutty (AVCutty v3.5, Andreas von Damaros, Krefeld, Germany, www.avcutty.de) using the same image standards as described in the chapter 3.2.2. Multiple images were captured for each individual gilt. On average, 6.4 profile and 2.1 rear stance images per gilt were used for measuring joint angles for the different feet and leg conformation traits studied. For further information regarding image selection and image quality review, please refer back to Chapter 3.2.2.

4.2.3 *Trait Evaluation Procedure*

The trait evaluation procedure has been previously described in Chapter 3.2.3. The joints examined included the knee, front and rear pasterns and the hock. A rear stance position was evaluated. Figure 3.3 and Figure 3.4 show the profile joint and rear stance pattern measurements obtained, respectively. The knee and front pastern from the front leg profile image were measured (Figure 3.3, angles a to d). The average of angles (a) and (b) correspond to the knee. The average of angles (c) and (d) correspond to the front pastern measured in reference to the floor. The hock and rear pastern were measured from the rear leg profile image (Figure 3.3, angles e to h). The average of angles (e) and (f) correspond to the hock. The average of angles (g) and (h) correspond to the rear pastern measured in reference to the floor. Rear stance pattern was measured (Figure 3.4, angle a and b) and is the average of angles (a) and (b).

4.2.4 Data Analysis

Each animal was considered an experimental unit. Each joint angle measurement was analyzed using mixed model equation methods (PROC MIXED, SAS v9.3; SAS Inst. Inc., Cary, NC). A repeated measures model using compound symmetry covariance structure was used for the comparison of feet and leg conformation traits measured in gilts at selection and during second gestation when gestation days were between 0 and 21. Model included breed, parity and side as fixed effects. ID was included as a repeated effect. Lastly, a model was created for evaluating the effects of gestation age on feet and leg conformation angles during second gestation. Model included breed, farm and side as fixed effects and gestation age as a continuous covariate. Animal was included as a random effect. Statistical differences were reported when individual model main effects were a significant source of variation ($P \leq 0.05$). Further, when individual model main effect was a significant source of variation, main effect levels were separated using the PDIFF option, which returns the *P* value differences between least squares means of fixed class effects. Results for fixed effects are reported as least squares means ± SE (LSMeans ± SE). Results for covariates are reported as regression coefficients ± SE.

4.2.5 Heritability Estimation

Variance components for each joint angle were estimated using restricted maximum likelihood methods in ASREML (Gilmour et al., 2009). Heritability estimates for each joint at the time of selection (i.e. age 0) were calculated as the additive genetic variance divided by total phenotypic variance. Standard errors for the heritability estimates were returned from the heritability calculation in ASREML. This is computed using the following formula:

$$\sqrt{\left(\frac{n}{p}\right)^2}\left(\frac{var(n)}{n^2} + \frac{var(d)}{d^2} - 2\frac{cov(n,d)}{nd}\right)$$

where n = estimate of the additive genetic variance and d = estimate of the phenotypic variance. Animal genetic effect included the full pedigree back to the grandparent generation.

4.3 Results

Of the initial gilts, 277 remained through the subsequent mating after the completion of their first parity. This accounts for 42 total animals being removed from the study with only eight of those animals having a leg deficiency (bad legs, downer, lame) code for removal. Fourteen animals were removed for reproductive problems, four for both sudden death and illness/injury and the remaining 11 for unknown reasons. Measurements were taken of the 277 remaining females during second gestation with average gestation day at 26.7 ± 17.2 days (range 0 to 87).

4.3.1 Genetic line, age and side comparison when gestation age during second gestation is 0 to 21 days

Of the original 319 gilts, 126 were between gestation days 0 to 21 of their second gestation. Gestation days greater than 21 were excluded to account for any joint changes that could be related to extra weight from gestating piglets. In table 4.1 is shown the LSMeans (± SE) for age and side for the different joint angles measured. Difference between sides was only observed in the hock ($P < 0.05$) however, this difference was small. Age was a significant source of variation for the knee, rear pastern, hock and rear stance where angles decreased (softened) in the knee, rear pastern and rear stance and increased (straightened) in the hock as age progressed from selection to after the first parity ($P < 0.05$). Angle differences were small in the knee, but were between five and six degrees for the rear leg angles.

4.3.2 Second gestation farm, side and gestation age comparison

In table 4.2 is shown the joint angle LSMeans (± SE) for farm and side and the regression coefficient (± SE) for gestation age. There were significant differences in joint angles between farms, however, such differences were small (one to four degrees) except for the difference between farm A and farms B and C rear stance position, where farm A was six degrees less than both B and C ($P < 0.05$). Asymmetry was observed between the left and right hand sides for the knee and front and rear pasterns, however, these values were also small (0.8 to 1.6 degrees) and the biological meaning of these differences is still not clear. Gestation age was a significant source of variation in the knee, front pastern and hock angles with the knee angle decreasing as gestation progressed and the front pastern and hock increasing as gestation progressed.

4.3.3 Heritability Estimates

Heritability estimates for the joint angles ranged from low to moderate. Hock angle had the lowest heritability estimate (0.13 ± 0.06), followed by the knee (0.17 ± 0.06). The front and rear pastern had moderate heritability estimates of 0.27 ± 0.06 and 0.20 ± 0.06, respectively. A heritability estimate was not estimable for the rear stance pattern as the additive genetic variance component was near zero, as breed within the animal model accounted for nearly all of the estimated variance.

4.4 Discussion

The different feet and leg conformation traits included in the present study were chosen as they have been reported to be associated with sow longevity. For instance, soft (or often referred to as weak) front pasterns are associated with improved sow longevity (Grindflek & Sehested, 1996; Jorgensen, 1996). However, several studies have reported a negative association between sow longevity and buck knees, straight rear legs, and upright rear pasterns (Jorgensen, 1996; Tiranti *et al.*, 2006; Fernàndez de Sevilla, 2008). However, there is limited research regarding feet and leg conformation changes over time within an animal.

The few studies that have documented such changes were conducted using a visual feet and leg conformation scoring system. Fernàndez de Sevilla *et al.* (2009) studied six feet and leg conformation traits in the front and rear legs to identify feet and leg deficiency prevalence over time. The authors observed that the presence of sickled hocked rear legs became more prevalent with age for both Landrace and Large White females. They also observed that pasterns became straighter between the end of the grower period and first parity for Large White females. However, our results disagree with these findings as the hock became straighter and rear pastern angles decreased from time of selection to first parity within this study. This could be due to underlying genetic control as to how the joint changes as age progresses. Fernàndez de Sevilla *et al.* (2009) stated, “The detection of genetic components in leg conformation and specific leg defects in sows should prompt further research into the genetic architecture of morphological traits in sows.” This could be a likely explanation as to how the two studies differed in regards to joint changes over time.

Farm differences for joint angles are difficult to explain; however, it is likely that the observed differences are due to management and environmental factors as similar genetic lines were used across farms.

Heritability estimates have been previously reported for feet and leg conformation in multiple studies. However, to our knowledge, this is the first time that heritability has been estimated using joint angles calculated using an objective measuring system. Our findings are similar to those reported by Fan et al. (2009) of low heritability estimates for the knee and hock and moderate heritability estimates for the front and rear pasterns.

4.5 Summary and Implications

Results from the present study suggest that feet and leg conformation traits change little in the front leg, but have some change in the rear leg from the time the gilts are selected and shortly after their first parity. The changes in the rear leg were in a direction that could potentially increase longevity according to other studies (Grindflek and Sehested, 1996; Jorgensen, 1996) as the hock became less angular (away from sickled) and the pastern became softer. However, this represents a short time period and studies have shown that females continue to grow until around the third parity or later (Robison, 1976). Further research is necessary to understand the changes from selection until the end of their growth cycle. Likewise what remains to be identified is a range of starting values at selection that even after conformation changes would allow for proper feet and leg structure through older parities. Based on the results of this study, drastic changes in feet and leg conformation traits do not occur after the first parity. If this remains true into later parities, objective angle evaluation could be incorporated early in a replacement female’s life into selection programs to further improve accuracy of selection for feet and leg soundness traits and to help increase sow longevity and sow lifetime productivity.

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Table 4.1 *Differences in feet and leg conformation trait joint angles Least Squares Means (± SE) from 126 gilts at selection and post first parity*[1]

	Knee[2]		**Front Pastern**[3]		**Rear Pastern**[4]		**Hock**[5]		**Rear Stance**[6]	
Variable	LS Means	SE	LS Means	SE	LS Means	SE	LS Means	SE	LS Means	SE
Parity[7]										
0	160.1[a]	0.2	57.0[a]	0.5	58.6[a]	0.5	140.5[a]	0.4	91.4[a]	0.6
1	159.5[b]	0.2	56.1[a]	0.5	53.3[b]	0.5	146.4[b]	0.4	86.5[b]	0.6
Side[8]										
L	160.0[a]	0.2	56.9[a]	0.5	56.0[a]	0.5	142.8[a]	0.4	NA[8]	
R	159.4[a]	0.2	56.2[a]	0.5	55.8[a]	0.5	144.1[b]	0.4		

[1]Gestation age 0 - 3 weeks

[2]Joint between the radius/ulna and carpals, with the anterior contour top of the radius and posterior contour tip of the olecranon (dorsal) and the anterior and posterior positions of the carpal/metacarpal joint (ventral) acting as anchor points with the mean representing the angle value

[3] Measured in reference to the floor, with the anterior and posterior positions of the joint between the carpals and metacarpals as the anchor point that places a line down the top and bottom of the hoof to a straight edge that travels back creating the angle measurements that provide the mean for the angle value

[4] Measured in reference to the floor, with the anterior and posterior positions of the joint between the tarsals and metatarsals as the anchor point that places a line down the top and bottom of the hoof to a straight edge that travels back creating the angle measurements that provide the mean for the angle value

[5] Traveling on the front and back of the joint between the fibula/tibia and tarsals, with the anterior and posterior positions of that joint acting as the anchor

[6] Measured from the hooves and to back of the hock of same leg and across to back of other hock, replicated on opposite side and averaged

[7] Parity is repeated from selection (0) to first parity (1)

[8] Side is measured from the left and right profile images for the knee, front and rear pastern and the hock, rear stance does not have a side variable

[a,b] Within columns, significant differences between predictor variables ($P < 0.05$)

Table 4.2 *Differences in feet and leg conformation trait joint angles (LSMeans ± SE) from 277 sows during their 2[nd] gestation[1] housed in three different farms*

Variable	Knee[2]		Front Pastern[3]		Rear Pastern[4]		Hock[5]		Rear Stance[6]	
	LS Means	SE	LS Means	SE	LS Means	SE	LS Means	SE	LS Means	SE
Farm[7]										
A	159.0[a,b]	0.3	55.6[a]	0.6	51.4[a]	0.6	146.4[a]	0.5	82.5[a]	0.7
B	158.5[a]	0.3	58.2[b]	0.6	54.5[b]	0.6	147.4[a]	0.5	88.4[b]	0.7
C	159.5[b]	0.3	57.5[b]	0.6	55.8[b]	0.6	147.6[a]	0.5	88.5[b]	0.7
Side[8]										
L	159.4[a]	0.2	57.9[a]	0.4	54.5[a]	0.4	147.8[a]	0.3	NA	
R	158.6[b]	0.2	56.3[b]	0.4	53.3[b]	0.4	147.5[a]	0.3		
Gestation Age[9]	-0.02 ± 0.01*		0.04 ± 0.02*		0.02 ± 0.02		0.05 ± 0.02*		-0.01 ± 0.02	

[1]Average gestation age 26.7 ± 17.2 days; range 0 to 87 days
[2]Joint between the radius/ulna and carpals, with the anterior contour top of the radius and posterior contour tip of the olecranon (dorsal) and the anterior and posterior positions of the carpal/metacarpal joint (ventral) acting as anchor points with the mean representing the angle value
[3]Measured in reference to the floor, with the anterior and posterior positions of the joint between the carpals and metacarpals as the anchor point that places a line down the top and bottom of the hoof to a straight edge that travels back creating the angle measurements that provide the mean for the angle value
[4]Measured in reference to the floor, with the anterior and posterior positions of the joint between the tarsals and metatarsals as the anchor point that places a line down the top and bottom of the hoof to a straight edge that travels back creating the angle measurements that the provide the mean for the angle value
[5]Traveling on the front and back of the joint between the fibula/tibia and tarsals, with the anterior and posterior positions of that joint acting as the anchor
[6]Measured from the hooves and to back of the hock of same leg and across to back of other hock, replicated on opposite side and averaged
[7]Sows were distributed across three farms, farm A (82), farm B (98), and farm C (97)
[8]Side is not measurable for the rear stance position
[9]Results for continuous covariates are presented as the regression coefficient ± SE
[a,b]Within columns, significant differences between predictor variables ($P<0.05$)
*$P<0.05$

CHAPTER 5: GENERAL CONCLUSIONS

Structural soundness, as described in this thesis, is one of the most important aspects to sow longevity, either directly or indirectly. Researchers continue to search for ways to better explain this complex trait with a number of different opinions. Research continues to be directed at the major cause for removal, reproductive problems. This thesis has instead looked at ways to better improve longevity through a technological tool to effectively measure joint angles commonly associated with longevity. Visual scoring systems have been widely developed to already accomplish this goal. However, the risk for error that these subjective systems can produce when staff are not trained properly or have potential bias towards one phenotype produces cause for concern. As Rothschild and Christian (1988) have shown, as long as phenotypic variation remains within your selection population, these scoring systems have a major impact to feet and leg conformation in a relatively short amount of time. Systems should also be able to compare conformation equally. The present research has provided the groundwork for a feet and leg evaluation system that can be used across populations and can be used in the same fashion time and time again. Training within the measurement system defined here would not take hours of repetition to become “a trained eye” as visual scoring systems require. However, this objective system is still labor intensive and requires further refinement. Additionally the objective evaluation system used in this study does require some upfront cost and additional expenses for maintenance. Automation is the end goal of the research described in this thesis, and with technology advancing at an astounding rate, the potential outcomes of objective feet and leg conformation research are unlimited. The results from this study have provided an opportunity to further explore objective evaluation of feet and leg conformation and morphology across time. By identifying changes as age increases, albeit small, these changes can be more thoroughly investigated in later projects. Specifically in a genetic component that has variation in a change towards or away from negatively associated feet and leg joint angles that could be examined using this objective scoring method.

This objective measurement tool could eventually be used by the swine breeding industry on all levels. Objective phenotypic measurements are another measure that could be added to the selection process. The gain that could be made across all levels of the breeding pyramid could be realized by implementation in all tiers of the pyramid. However, until this system becomes more automated and less time consuming, the nucleus herd is the first step in the process of adding this tool, which would effectively reach all levels underneath. Further research is still necessary to understand in greater detail the joint angle changes over time and what impact that has on longevity when animals with optimal feet and leg angle values are selected at an early time point in life.

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