Title: Evaluation of the relationship between hoof abnormalities and breeding herd female longevity and well-being when housed in gestation and farrowing stalls – **NPB #07-051**

Investigator: Anna K. Johnson

Institution: Iowa State University

Co-Investigators: Dr. Robert Fitzgerald, Dr. Locke Karriker

Date Submitted: 16th June 2010

Industry Summary:

Objective I; Increased hoof abnormality prevalence (e.g. toe and dew claw overgrowth, hoof wall cracks, and hoof pad abrasions) in sow populations observed at harvest suggest that these hoof defects may be detrimental to sow performance, and in turn, the sow's productive lifetime. Determining the types of lesions on sows' feet and how this may affect her performance, behavior and overall productivity was examined. Sows were classified into four groups, (1) cracks in the outer hoof wall [CK], (2) length differences between the toes of the hoof [TS], (3) excessive toe growth [OG] or 4) control sows (no visible lesions or concerns associated with the hooves). There was a trend for sows in the CK group to wean fewer piglets per litter than control sows. As OG got more severe, sows weaned a lighter litter than control sows. When sow behavior was collected 45 minutes before feeding and for 1-h after feed had been provided, control sows spent 18.9 % (19.9 min) of the 105 min observation period standing and 12.7 % (13.3 min) of the total time standing and eating. Sows with OG toes spent 50 % less time kneeling as lesion scores got worse. Post feeding, each OG lesion score increase was associated with a 40.0 % decrease in time spent standing and eating. Results from this study demonstrate that foot lesions can impair productivity and behavior of lactating sows. The degree to which foot lesions impair production and behavior is dependent on lesion type and severity.

Objective II; Images of normal and abnormal hooves were collected throughout the previously reported study. Images collected during the study illustrate the range in severity of hoof cracks, overgrown toes, and toe size differences. At least two quality images were obtained for each severity score within each lesion. Images

obtained during the present study will be utilized in extension presentations and publications to educate swine producers on the type and severity of hoof lesions present in swine herds. Further, the pictures will be used in future classification of these specific lesions in an attempt to standardize the lesion identification and scoring process. Also, unique observations were made while photographing sow hooves. In some cases, the lateral claw was observed to be placed between concrete slats in the gestation stalls or between mesh flooring connections in the farrowing stalls. In these cases, sows may use these gaps as anchor points when slipping which may cause hoof cracks. The image library will be maintained at Iowa State University and image requests can be made through the National Pork Board.

Objective III; A targeted, three point, question, was formulated to include the population of interest (adult sows), the condition of interest (lameness) and the intervention (any method of treatment). A comprehensive list of search terms was created to capture all combinations of each point of the targeted question. Seven databases which included agricultural and veterinary based research journals were conducted. Once this expansive and inclusive search identified potential research studies, each report was subjected to additional quality analysis steps to: (1) determine relevance to the question, (2) assess the quality and completeness of the research report data (3) extract and summarize useful data and conclusions for application by producers. The original literature search produced 1560 research reports. A total of 414 duplicate articles were removed. Following removal of the duplicates, the 1146 unique articles were reviewed for relevance. The relevance screen eliminated all but five articles. The five relevant articles were subjected to the quality screening. Two articles were removed because they did not directly test a treatment. Two articles were removed due to failure to randomize treatments which would prevent caretakers from preferentially treating the most clinically affected animals and potentially biasing the outcome. A single article met all of the quality criteria. Wentz et al, detailed the treatment and control populations, the prevalence and severity of lameness at the onset and completion of the trial, and utilized a field setting for this study. Wentz et al, randomized penned groups of sows between two treatments. The intervention treatment utilized a 10% formalin footbath, two or three times a week, applied to the exterior anatomy of the hoof for a five week period. The control group received no footbath treatment. Results showed significant differences in the increased prevalence of sows without clinical lameness and a reduction of ‘severe category’ clinical lameness. This systematic review of the effectiveness of treatment for lameness in sows led to the following conclusions: (1) quality research studies evaluating the treatment of lameness are lacking (2) treatment of lameness has been focused on nutritional manipulation to correct imbalances affecting the feet and legs of sows, but results are variable and take time for maximum benefits to be recognized (3) footbaths may be an option to improving overall foot health, but need to be used at a high frequency to assure maximum benefit (4) producers need tools to treat and prevent lameness in sow herds to improve the animal’s well-being and increase overall herd productivity and (5) since sow welfare is negatively affected by lameness and treatment options need to be fully investigated in a scientifically controlled setting.

Keywords: Behavior, Overgrown Hooves, Sow Productive Lifetime, Systematic review.

Scientific Abstract:

The objective of study I was to evaluate the effects of cracks in the outer hoof wall [CK], length differences between the medial and lateral toe of the hoof [TS], and excessive toe growth [OG] on sow lactation performance and behavior in mid-lactation. Sows from each treatment group were assigned a severity score (1 to 3), and control sows were assigned a 0 score. Lactation sow performance from 223 litters was collected over 2 experiments; each experiment was conducted on a different 4200-sow operation using the same protocol and performance data were combined for analyses. Total born, number born alive, stillborn, and mummies were recorded for each sow as well as the farrowing date. Sow behavior was scored continuously for 45 min prior to and 1 h post feeding in experiment 1 (150 sows) and for a 24 hr period in experiment 2 (10 sows). The ethogram contained 4 postures (standing, sitting, kneeling, and lying down) and a maximum of 4 behaviors within each posture (eating, drinking, defecating/urinating, or other). Performance and behavior data were analyzed using a multiple linear regression. Sows of each treatment began the experiment with similar litter weights ($P > 0.15$) and number of piglets per litter ($P > 0.15$). A significant, negative partial regression coefficient was observed for piglets weaned per litter for sows in the CK and TS groups. A trend ($P = 0.10$) was observed for the association of sows in the CK group to wean -0.21 fewer piglets per litter than control sows. An increase in OG lesion severity score was associated with lighter adjusted litter wean weights compared to control sows. Sows in the control group spent 18.9 % (19.9 min) of the 105 min observation period standing and 12.7 % (13.3 min) of the total time standing and eating. The amount of time spent standing and eating before feed presentation was negatively associated with time spent eating after feeding ($b = -0.24$, $P < 0.01$); that is, for each percent increase in time spent eating prior to feeding was associated with a 79 % decrease in time spent standing and eating post feeding. Sows with overgrown toes spent 50 % less time kneeling for each incremental increase in OG lesion score. Post feeding, each OG lesion score increase was associated with a 40.0 % decrease in time spent standing and eating. This observation held true for total time spent standing and eating during the observation period [Odds Ratio (OR) = 0.45]. In Experiment 2, sows were observed standing and eating between 3.3 and 9.1 % of the observation period, and, of the variables collected, eating was the primary activity performed while standing. Sows spent a very small percentage of their time kneeling (0.11 %). Results from this study demonstrate that foot lesions can impair productivity and behavior of lactating sows. The degree to which foot lesions impair production and behavior is dependent on lesion type and severity.

The objective of study II was to collect pictures and illustrations of hoof abnormalities to be used as a future training tool for pork producers to visually score overgrown hind hooves, uneven toes and cracked

hooves in parity matched sows. Images of normal and abnormal hooves were collected throughout the previously reported study. Images collected during the study illustrate the range in severity of hoof cracks, overgrown toes, and toe size differences. At least two quality images were obtained for each severity score within each lesion. Images obtained during the present study will be utilized in extension presentations and publications to educate swine producers on the type and severity of hoof lesions present in swine herds. Further, the pictures will be used in future classification of these specific lesions in an attempt to standardize the lesion identification and scoring process. Also, unique observations were made while photographing sow hooves. In some cases, the lateral claw was observed to be placed between concrete slats in the gestation stalls or between mesh flooring connections in the farrowing stalls. In these cases, sows may use these gaps as anchor points when slipping which may cause hoof cracks. The image library will be maintained at Iowa State University and image requests can be made through the National Pork Board.

The objective of study III was to determine the relationship between hoof abnormalities and breeding herd female longevity when housed in gestation and farrowing stalls. The systematic review process is recognized in human medicine to evaluate available research on specific medical conditions. The systematic review process is becoming more accepted in agricultural and veterinary research as well. The systematic review process allows for transparent and repeatable evaluation of studies. The systematic review process includes: developing a targeted question, conducting a comprehensive literature search from appropriate sources, identification of relevant articles, conducting a quality screen of all relevant articles, extraction of data from selected studies which meet relevance and quality criteria, and then subsequently summarizing the extracted data in a concise format. This systematic approach helps to reduce bias in the final selection of the studies for analysis and sets this approach apart from a narrative review. A comprehensive search of PubMed (1965-2009), CAB Abstracts (1910-2009), AGRIS (1975-2009), AGRICOLA (1970-2009), BioSis Previews (1980-2009), Biological and Agricultural Index (1983-2009) and Medline (1950-2009) and the 2006 Swine Information CD compiled by the American Association of Swine Veterinarians identified 1560 articles for analysis. Following removal of the duplicates, the 1146 unique articles were reviewed for relevance. The relevance screen eliminated all but five articles. The five relevant articles were subjected to select quality screening criteria. A single article met all of the quality criteria. Wentz et al, detailed the treatment and control populations, the prevalence and severity of lameness at the onset and completion of the trial, and utilized a field setting for this study. The trial reported by Wentz et al randomized penned groups of sows between two treatments. The intervention treatment utilized a 10% formalin footbath, two or three times a week, applied to the exterior anatomy of the hoof for a five week period. The control group received no footbath treatment. Results showed significant differences in the increased prevalence of sows without clinical lameness ($P < 0.05$) and a reduction of 'severe category' clinical lameness ($P < 0.05$). Clearly there is a need for more rigorous evaluation of a number of potential lameness interventions to investigate potential tools for caretakers to employ with confidence.

Introduction:

Sow productive lifetime continues to challenge U.S. commercial swine herds and worldwide pork operations in general. The increased prevalence of hoof abnormalities (e.g. hoof and dew claw overgrowth, hoof wall cracks, and foot pad abrasions) in cull sow populations observed at harvest lend evidence to the hypothesis that these abnormalities are detrimental to sow performance. U.S. pork producers have expressed the need for research identifying hoof abnormalities and plausible causal factors as well as measuring the correlated response in performance of sows exhibiting these abnormalities.

Sow Productive lifetime: Economics or Welfare?

Sow productive lifetime refers to the ability of the sow to remain in the breeding productive herd for a period of time before being removed or culled. Decisions that a producer makes on if a sow remains in the productive herd can be broadly divided into two categories. Category one are based on Sow Economical Productive Lifetime (SEPL) decisions. Category two is based on Sow Welfare Productive Lifetime (SWPL) decisions. An example of what defines the difference between SEPL and SWPL: A sow could be classified as being disease free and noted as consuming her daily feed ration (indicators of good welfare), but a sow that can not provide an economical return on investment through pigs per sow per year (PPSPY) will often be culled by a producer using an SEPL decision. Another example could be a sow that undertakes extensive postural adjustments in the farrowing phase that results in unacceptable pre-weaning mortality will again be culled for SEPL reasons even through the root of the problem is more so related to SWPL. In regards to SWPL, few studies have comprehensively tackled producer decisions for culling over multiple parities and across different production systems. Some research has focused on SWPL factors which may result in culling, for example detrimental behaviors (i.e. enhanced aggression or cannibalistic behavior) but little attention has correlated the sows feet and leg health back to her behaviors and how this could affect her longevity within the productive herd.

Locomotion of pigs and sows and definition of lameness

Lameness in swine, poultry, horses, and cattle have a large negative economic impact to livestock producers (Corr et al., 2003). The abnormal locomotion of pigs have been described as having a shorten stride length, stiff movements, and lowered ability to accelerate and change direction (Main et al., 2000). Lameness has been defined as "*having a body part and especially a limb so disabled as to impair freedom of movement*" or as "*impaired movement or deviation from normal gait*" (Wells, 1984). Locomotor disorders can be associated with neurological disorders, lesions of the hoof or limb, or a mechanical-structural problem, trauma, or metabolic and infectious disease (Smith, 1988; Wells, 1984). A recent evaluation of cull sows by Knauer (2006) found that 85 % of sows evaluated at harvest have at least one lesion impacting at least one foot, and further notes that lameness is a common reason why sows leave the breeding herd.

Lameness

Lameness in swine, chickens, horses, and cattle has a large negative economic impact to livestock producers (Corr et al., 2003; Stalder et al., 2003; Stalder et al., 2004). A recent evaluation of over 3000 cull sows by Knauer (2006) reported that 85 % of sows evaluated at harvest have at least one lesion impacting at least one foot. Previous research (Stalder et al., 2004) further notes that lameness is a common reason why sows leave the breeding herd. This study reported that front and rear cracked hooves were observed in 22.6 % and 21.1 % of the cull sows evaluated, respectively. These observations are concurrent with those reported by Ritter et al., (1999) who found 59 % of 1,747 sows had either front or rear foot lesions. While both trials used different hoof scoring methods, the main argument that hoof cracks and/or lesions are widespread among breeding sows is clear. Norwegian researchers Gjein and Larssen (1995a) performed an observational study characterizing hoof and claw abnormalities in a total of 36 loose and confinement housing systems. From their reports, sows were found to have significantly more ($P < 0.05$) side wall cracks and heel lesions and tended to have more overgrown hind heels in loose housing systems compared to confinement housing systems. Additionally, the researchers noted a trend of claw lesions increasing with parity in confinement housing. This trend was most noticeable as sows increased from parity 1 to parity 2. Moreover, this investigation reveals hoof injuries are frequent in both housing systems and must be addressed from both a well-being and production standpoint.

In modern swine management systems, gilts and sows are primarily housed on partially or fully slatted concrete floors. Both types of flooring provide little if any cushion for the sows' feet and legs. Concrete is known to have an abrasive surface, that when wet can become slippery underfoot. This can result in reduced traction and an increase in swollen tendons, and leg and hoof abnormalities (MAFF, 1981). Gjein and Larssen (1995b) analyzed the impact of loose and confinement systems on claw lesions. Three different flooring materials were evaluated, plastic and concrete slats and deep litter bedding. Both slatted flooring materials produced similar percentages of claw lesions on rear legs, 68 % for sows on concrete and 69 % for sows housed on plastic slats. Furthermore, partially slatted loose housing systems yielded significantly more ($P < 0.05$) major claw lesions, as described by greater than superficial cracks or lesions in the epidermis compared to their confined (stalled) sow counterparts housed either on partially slatted or solid concrete flooring. However, straw bedding in loose housing systems reduced the prevalence of major claw lesions compared to both loose-and confinement-housed sows. It should also be noted that there is a strong relationship between differing sow compositional structure, the types of housing system and prevalence of leg and hoof problems. Anil et al., (2001) correlated injury levels to physical measurements of sows and found that injury scores increase as the sow increases in mass proportionate to her stall; sows have less space to move around within the stall and injuries are a direct result. Knauer (2006) found that an increase in body condition scores was associated with increased hoof lesions, and explained this observation as sows increased body weight, the pressure applied to the ground increased and damage may result. Therefore, the wide prevalence of claw lesions in sow populations irrespective of housing or flooring systems is alarming and must be evaluated more thoroughly to improve longevity of gilts and sows.

Housing and how it influences the sows productive lifetime

A primary premise made by an individual producer for "acceptable" behavior(s) may be highly dependent on the type of housing system that a producer utilizes. For example, a sow that may be aggressive at the time of parturition towards a caretaker could be kept within a system that is more confined (farrowing stalls), but this behavior may become more problematic or even intolerable and dangerous to caretakers and other animals in a loose housed farrowing system. Gestation and farrowing stalls limit sow behaviors, postures and overall locomotion (Davies et al., 1996; Rountree et al., 1997) compared to other housing systems. In addition, floor surface has been shown to influence abnormal lying-down behavior, interruptions, and slipping (Bonde et al., 2004; Boyle et al., 2000). All these subtle changes in gilt and sow behavior will place stress onto her feet and limbs which may result in less time spent eating (Leonard et al., 1997) and hypothetically poorer lactation performance and lower reproductive rates after lactation. This in turn may reduce the length of time that sow is kept in the breeding herd. Some research has been conducted on gilts and sows in regards to how hoof and leg health may impact her behavior through gestation, lactation and her overall longevity. Anil et al., (2001) compared gestation sow injuries in proportion to stall size; the authors noted that stall size can predict the activity level of sows. The authors also suggested that sows require more time to rise up and rise a fewer number of times as sow length increases in proportion to sow stall size. Unpublished work by Stienezen et al. (1996) looked at 24 mixed parity sows (average parity was 4.7) prior to farrowing and then through lactation on behavioral impacts and changes when sows have over grown claws. The authors reported no behavioral (percentage standing, dog-sitting or lying) differences ($P < 0.05$) in the 6 hours leading up to the first piglet being born. Some differences were seen when observing the sows immediately before, during, and after their morning feed. Phenotypically normal (control) sows spent more ($P = 0.02$) time feeding (14.5 vs. 8.2 mins) and more ($P = 0.009$) time standing (11.4 vs. 4.2 mins respectively) than their over grown claw counterparts. There were also some differences in the number of slips of the rear legs between control (0.11) and overgrown claws (0.51; $P = 0.05$), and in addition control sows also had fewer number of rising attempts (1.33 vs. 2.33; $P = 0.02$) than their control counterparts. Claw or hoof overgrowth has also been shown to alter normal sow behaviors.

A study by Leonard et al. (1997) found that time spent feeding and time spent standing decreased and weight shifts and slipping increased in sows with overgrown rear claws. These results indicate that sows with overgrown rear claws exhibited discomfort and thus decreased the amount of time weight was distributed on the limb. Bonde et al. (2004) visited six sow herds and assessed hoof length and leg disorders and how this impacted lying down behavior. Sows were observed during spontaneous lying down maneuvers within 30 min after a clinical examination. Recordings were conducted on 555 of the 570 sows. The authors noted that 41 % of the sows showed difficulties in lying down in a gestation stall. Parity also seemed to affect slipping behavior. Sows in their 4th and 5th parity were less likely to slip when lying down compared to younger or older sows.

Systematic review

The systematic review process is recognized in human medicine to evaluate available research on specific medical conditions (Cochrane Collaboration (2009. The systematic review process is becoming more accepted in agricultural and veterinary research as well (Stalder et al., 2004). The systematic review process allows for transparent and repeatable evaluation of studies. The systematic review process includes: developing a targeted question, conducting a comprehensive literature search from appropriate sources, identification of relevant articles, conducting a quality screen of all relevant articles, extraction of data from selected studies which meet relevance and quality criteria, and then subsequently summarizing the extracted data in a concise format (Stalder et al., 2004). This systematic approach helps to reduce bias in the final selection of the studies for analysis and sets this approach apart from a narrative review (Anil et al., 2005).

The use of systematic reviews in agricultural and veterinary studies presents a challenge because studies are routinely performed in field settings. This setting is not always conducive to designing a blinded, randomized control study. Many agricultural studies include convenience samples based on the natural grouping or availability of study subjects. These points can introduce bias into the studies and may also lead to smaller sample sizes. When the systematic review process is applied to these types of studies, the available study designs need to be taken into account and not discounted based solely on the level of evidentiary value.

Lameness in adult sows can shorten the animals' productive lifetimes. Anil et al. have shown that lameness affects reproductive production parameters which lead to a higher risk of being removed from the herd prematurely (Anil et al., 2005). Foot lesions in conventionally raised sows have been shown to be the most prevalent lesion observed in US sow herds (Knauer et al., 2007a). This study summarized that up to 85% of culled sows were observed to possess at least one foot lesion at slaughter. A follow up study by Knauer et al. further summarized that lameness was not listed as the prevalent cause of culling in this study population (Knauer et al., 2007b). Stalder et al. (2004) reported that poor performance can contribute up to 24% of the culling reasons in sows. Lameness can add up to another 15%. These two reasons may be interconnected or not fully defined in the referenced studies which may lead to a misrepresentation of the true impact of lameness in these situations. Anil et al. (2005) showed that there is a parity association with the onset of lameness. Parity 1 sows just completing their first lactation showed a significantly higher representation of culling due to lameness. This is much earlier than the projected economic breakeven timeline for the sow. The economic impact of lameness and the true prevalence of the condition may be underrepresented based on the available research.

Lameness is considered a painful condition in other species and should be considered the same in sows. Treatment of lameness in sows can be both labor and cost intensive. This could lead to lameness conditions going untreated, which could negatively affect the well-being of the sow and further contribute to a sow being culled prematurely. Many of the available studies list improvements in hoof condition as a result of a change in nutrition (Bryant et al., 1985; Misir and Blair, 1986; Fjeldaas et al., 2006; Smith, 2007), but these studies infrequently target the hoof, foot or lameness as a primary outcome. The majority of the nutrition studies use a preventative versus a treatment approach. Physical interventions of the hoof, such as trimming, are commonplace in dairy cattl (Wentz et al., 1991) but are not routine practices in sows.

This systematic review analyzes the available literature as it relates to any intervention treatment targeted at improvements in the prevalence of lameness in sows.

Objectives:

Overall Objective

To determine the relationship between hoof abnormalities and breeding herd female longevity when housed in gestation and farrowing stalls.

Specific Objectives

- I. To assess the effects of over grown, uneven toes or cracked hooves on the ***reproductive, performance*** and ***behavior*** of parity matched sows during gestation and farrowing.
- II. To collect ***pictures and illustrations of hoof abnormalities to be used as a future*** training tool for pork producers to visually score overgrown hind hooves, uneven toes and cracked hooves in parity matched sows.
- III. To produce a ***systematic, evidence based, review*** of the effectiveness of treatment options for the lesions identified in this study. This comprehensive study would summarize effective treatment recommendations for the lesions identified as impacting performance in the study and identify gaps in the treatment knowledge base to efficiently guide further investigation.

Materials & Methods:

Objective I

Animals, Housing, and Husbandry

Farms. The project was approved by the Iowa State University Animal Use and Care Committee (IACUC #6-06-6159-S).These studies were conducted on two, 4200-hd sow farms within the same Midwestern system. Two experiments were conducted because lactation feed delivery was different in each of the farms and thus required different behavior observation periods. However, the building structures and management objectives were similar at both farms. The buildings utilized flush manure system and tunnel ventilation.

Gestation. Sows were housed in gestation stalls (Modern Hog Concepts, Iowa Falls, IA; 58 cm width x 244 cm length x 109 cm height). The stalls had solid concrete floors in the front half and slatted concrete floors in the rear half. At 0700 h each day, gestating sows were provided a commercially available corn-soybean based meal ration formulated to meet or exceed the sows' nutrient requirements (NRC, 1998). The feed ration was provided in a water/feed combination trough with the top of the trough level with the floor (Farm A, 13 cm depth x 31 cm width) or raised above the floor (Farm B, same dimensions). Sows were provided water 3 times/d from November to April and 4 times/d from May to October. A drip cooling system was utilized when temperature exceeded 25.6°C. Sows were moved in gestation stalls after they were confirmed pregnant from approximately d 30 of gestation and were moved into farrowing stalls at 112 d of gestation (range 109 to 113 d). Just prior to being placed into farrowing stalls, sows were washed using soap and water. Caretakers obverted all animals twice daily (0700 and 1500 h).

Lactation. Ten farrowing rooms were used on Farm A and 2 farrowing rooms were used on Farm B. Within each farrowing room there were 39 farrowing stalls (3 rows of 13 farrowing stalls in each row; Modern Hog Concepts, Iowa Falls, IA; 51 cm width x 214 cm length x 102 cm height with finger bars extending downwards on each side of the stall). Sows were provided water through nipple water drinkers approximately 84 cm from the floor and 36 cm from the front of the stall. The farrowing stalls had wire mesh flooring. Lactating sows were provided a commercially available corn-soybean based meal ration formulated to meet or exceed their nutrient requirements (NRC, 1998) during this phase of production. Feed was provided in a metal feeder at the front of each farrowing stall. Prostaglandin F2α (Lutalyse, Pfizer Animal Health, New York, NY) was injected following manufacturer's recommendations on approximately d 115 of gestation if the sow did not show imminent parturition signs. High and low ambient temperatures (°C; 30.8 and 19.7°C, respectively) were monitored and controlled for each farrowing room during lactation using the 6-stage ventilation system control (Airstream TC5 controller, Automated Production System, Assumption IL) located outside of the farrowing room. The temperature sensor was located in the center of each farrowing room, approximately 1.4 m above the floor.

Treatment descriptions. Sows were classified into three treatment groups and one control group by the same trained observer while sows were standing in gestation stalls approximately 1 d before sows were placed in farrowing stalls. The treatment groups were 1) presence of cracks in the outer hoof wall [CK], 2) length differences between the medial and lateral toe of the hoof [TS], and 3) excessive toe growth [OG] (Table 1.1).

Table 1.1. Hoof lesion[1] classification methods used in the evaluation of behavior and performance for commercial sows at a Midwestern U.S. swine integrator.

Control Sows [C]	
0	Absence of hoof cracks, less than 6.4 cm in length, and less than 1.3 cm difference between the outer and inner toe
Cracked hooves [CK]	
1	Presence of crack in hoof less than 1.3 cm in length
2	Crack in hoof of 1.4 to 2.5 cm in length
3	Crack in hoof greater than 2.6 cm or multiple cracks
Lateral and medial toe size differences [TS][2]	
1	Toe length difference between 1.3 and 1.9 cm
2	Toe length difference between 2.0 and 2.5 cm
3	Toe length difference greater than 2.6 cm
Overgrown toe [OG][3]	
1	One toe of a hoof must be within 6.4 and 8.3 cm in length
2	One toe of a hoof must be within 8.4 to 10.2 cm in length
3	One toe of a hoof must be greater than 10.3 cm in length

[1]The number, length, location, and lesion severity of hoof cracks were recorded for each toe and for all sows in all treatment groups.

[2]The length difference between the medial and lateral toe were obtained by using a standard ruler (measured at 0.32 cm increments) placed on the floor of the gestation stall between both toes and parallel to the long axis of the sow and leg.

[3]Toes were measured beginning at the coronary band and extending to the leading edge of the overgrown toe.

Some sows had both toe size differences and cracks in the outer hoof wall (n = 23). Hoof abnormalities were categorized into 3 scores based on the severity of the lesion, and those categories are shown in Table 1.1. The number, length, location, and lesion severity was recorded for each toe and for all sows in all treatment groups. The length difference between the medial and lateral toe were obtained using a ruler (3.5 cm width x

30.5 cm length, measured at 0.32 cm increments) placed on the floor of the gestation stall between both toes and parallel to the long axis of the sow and leg. Sow toes classified as OG were measured using the same ruler, placed parallel to the long axis of the sow and leg, but each toe was measured beginning at the coronary band and extending to the leading edge of the overgrown toe

For each treatment sow, a case-control sow [C] was identified that matched body condition score and parity as her treatment counterpart. Because of the difficulty finding both ideal treatment and control sows within the same parity within the same farrowing group, treatment and control sows were paired and considered a match using the following parity categories: 1, 2, 3 to 5, and 6 or greater parities. Within a farrowing room, treatment and control sows were placed in 2 rows of farrowing stalls extending the length of the room. Sows were placed in farrowing stalls in a pre-determined order so that an experimental and control sow were housed next to each other; however, treatments were alternated throughout the allotted spaces in the farrowing room. The case-control sows were alternated in the farrowing stalls to remove microclimate effects in the farrowing rooms on any particular treatment group.

Performance and behavioral parameters for both experiments

Sow and litter lactation performance. After parturition, the date, total number of piglets born, number of piglets born alive, number of stillborn piglets, and mummified fetuses were recorded for each sow before cross-fostering. Piglets that farrowed on a given day had the opportunity to be cross-fostered, within 24 h post farrowing, to other sows regardless of treatment or trial status in an attempt to equalize the number of piglets within a litter (approximately 11 piglets/litter). After the litter was established and within 24 h of farrowing, body weights were obtained for each litter. Additionally, the number and weight of pigs cross-fostered (added to or removed from the litter) were recorded. Piglet mortality was recorded including the day of death and piglet weight using a hand-held digital scale (Berkley FS-50, Spirit Lake, IA; maximum weight capacity = 23 kg). Weaning weights were measured using an analog scale attached to a wheeled, metal weigh crate (WayPig Litter scale, Raytec Manufacturing, Ephrata, PA; maximum weight capacity = 90 kg) 1 to 2 d prior to weaning. Piglet age at weaning averaged 19 d. Lactation length was then calculated as the number of days from the date that the litter was weighed (1 to 2 d post-farrowing) to the day weaning weights were obtained.

Total weight produced per sow during lactation was calculated using the following formula:

Adjusted weight produced in lactation = litter wean weight + piglet mortality weight + weight of pigs removed – weight of pigs added – weight of cross-fostered litter at birth.

Sow Behavior. Behavior was filmed using one 12 V closed circuit color television camera (Model WV-CP484, Panasonic Matsushita Co. Ltd, Kadoma, Japan) per parity matched treatment-control group and information was recorded onto a digital video recorder (RECO-204, Darim Vision, Pleasanton, CA) at 10 frames/s. Sows were recorded when the lactation length averaged 10 d. Prior to independently scoring sow behavior, two trained observers practiced scoring the same video using the Observer software (The Observer, Ver. 5.0.25 Noldus Information Technology, Wageningen, The Netherlands). Behavior times scored by each observer were compared and agreement (all behaviors and postures were correctly identified and times were ± 15 s of each observer) was achieved before any video was scored. Observers were blind to treatment during behavioral scoring.

The behavioral ethogram contained 4 postures (standing, sitting, kneeling, and lying down) and a maximum of 4 behaviors within each posture. Behaviors and postures were modified from the Encyclopedia of Farm Animal Behavior (2009). Standing was sub categorized into 4 behaviors: eating, drinking, defecating/urinating, and just standing. Sitting was sub categorized into 3 behaviors: eating, drinking, and just sitting. Eating was defined as the sow appearing to actively consume food by placing their head inside the feed trough, or alternatively, the observers were able to visually identify sows that appeared to be chewing food. Drinking was defined as the sow placing her mouth or nose on the nipple water which gave the appearance that the sow was ingesting water. Defecating and urinating were scored when a sow was observed in a crouching position, remaining stationary, and excreting feces or urine from the body. Lying down was categorized as lying sternal or as lying lateral on their left or right side. Lateral recumbency was defined as full lateral contact of the body with the legs fully extended. A lying down event was defined as the sow transitioning from a standing to kneeling then to a lying down position. Sows could remain in a kneeling posture for any length of time before lying down. The number of completed lying down events (sows that went from standing to kneeling to lying in one sequence) and the total number of lying down events attempted (the number of completed lying down events + the number of lying down events where sows transitioned from a standing to a kneeling posture and then back to a standing posture) were recorded per observation.

Experiment 1. Performance and 105 min sow behavior observation. Experiment 1 was conducted on Farm A using a total of 188 sows (Supermom, Newsham Genetics, Des Moines, IA) sows. The distribution of sows by treatment is shown in Table 1.2

Table 1.2. Distribution of sows categorized as having overgrown hooves [OG], differences in claw length [TS], hoof cracks [CK], or normal hooves [C] by parity and body condition score, conducted at a Midwestern U.S. swine integrator.

		Parity[1]				Lesion Severity Score[2]				Farm[3]		Behavior Data: Exp. 1		Behavior Data: Exp. 2	
	N	1	2	3-5	6-8	0	1	2	3	A	B	N[4]	Obs[5]	N	Obs
Totals[6]		26	36	122	39	79	68	59	17	188	35	150	236	10	10
Treatment Group[7]															
C	79	11	11	42	15	79	-	-	-	68	11	53	86	5	5
CK	61	5	10	35	11	-	19	32	10	54	7	46	74	-	-
TS	84	5	12	52	15	-	44	32	8	73	11	56	89	2	2
OG	22	5	5	8	4	-	13	7	2	15	7	13	18	3	3
Treatment Score															
0	79	11	11	42	15	-	-	-	-	11	15	53	86	5	5
1	68	5	11	46	6	-	-	-	-	21	15	48	75	-	-
2	59	7	11	26	15	-	-	-	-	117	5	42	65	3	3
3	17	3	3	8	3	-	-	-	-	39	0	7	10	2	2

[1]Because of the difficulty finding both ideal treatment and control sows within the same parity within the same farrowing group, treatment and control sows were paired and considered a match using the following parity structure: 1, 2, 3 to 5, and 6 or greater parities

[2]Sows were also given a score that was positively correlated with the severity of the lesion. Sows classified as score 0 served as the control group; whereas sows of score 1, 2, or 3 were found to have some severity of hoof lesion.

[3]This study was conducted over two experiments. Experiment 1 was conducted on Farm A where feed intake data were recorded. Experiment 2 was conducted on Farm B where no feed intake data were available.

[4]The number of unique sows for which behavior was measured.

[5]Behavior data were recorded twice (on 10 and 11 d of lactation) for 86 of the 150 sows in Experiment 1.

[6]Sow totals represent the total number of unique sows measured in each category.

[7]A total of 23 sows had both TS and CK lesions. Therefore, the number of sows listed under treatment groups is greater than the number of unique sows by 23.

Farrowing rooms were equipped with individual feed drop boxes (Automated Production Systems, Assumption, IL) connected to a delivery system that automatically placed the food in the sows' feeders and subsequently refilled the containers 4 times/d every 6 h at 0245, 0845, 1445, and 2045 h. Mid-experiment, Farm A initiated a change in the time that feed was dropped from the feed boxes and the new feed times were 0215, 0815, 1415, and 2015 h. Farm employees adjusted the quantity of feed allotted to each sow at the same time each day during lactation. Described by the farm standard operating procedure (*personal communication, Iowa Select Farms*), sows were provided 1.8 kg of feed on the days just prior to farrowing. The day after farrowing, feed provided to lactating sows was increased 0.9 kg/d until each sow reached their maximum daily intake as measured by a function of disappearance and determined by the caretaker.

Feed intake data was collected for 139 sows and lactation performance was collected on 188 sows. Behavior was recorded on d 10 of lactation (± 3 d) at 0845 h for 64 sows and on d 10 and 11 of lactation at 0815 h for 86 sows. Thus, behavior data were collected for 150 sows at least once during lactation for a total of 236 observations. The days of lactation were chosen because sows were at mid-lactation and anticipated to be at or near maximum feed intake. Each sow observation was recorded for 45 min prior to feed delivery and 1 h after feed was available (a total of 105 min / observation) and this provided 24,780 minutes or 413 h. Two investigators entered the farrowing room immediately after feed was dropped and made each sow stand by placing a hand on the sow's back. The investigators verified that each sow was standing before leaving the room, and sows were not disturbed by caretakers until the behavioral recording ended.

Experiment 2. Performance and 24 h behavior observation. A total of 35 sows (Line 23 and 29, Pig Improvement Company, Hendersonville, TN) sows were categorized into treatment and control sows on Farm B and performance data were collected (distribution of sows by treatment in Table 1.2). Genetic line of each sow was not available on an individual basis at this farm. Data collection procedures were similar to Experiment 1 except for the following: after d 4 of lactation, sows were provided *ad libitum* access to feed. Thus, sow feed intake data was not available for this experiment. Behavior data were collected as previously described, for 10 sows (5 control, 3 OG, and 2 TS sows). Since there was not a defined time point for feeding the sows, behavioral observation occurred continuously for 24 h beginning at 0900 h on d 10 (± 3 d) of lactation and ending at the same time on d 11. The total amount of time collected was 2,400 min or 240 h.

Data analysis. Sows were blocked within room and farm. Between 2 and 8 sows were included in a block, depending on the similarity of parity and location within the farrowing room. Sows from different rooms were not included in the same block. Thus, sow block accounted for differences between farms as well as differences between rooms within a farm.

Sow performance variables collected during lactation (piglet mortality, adjusted litter BW at weaning, feed intake, number of piglets born alive, number of stillborn piglets, and mummified fetuses) were combined from both experiments. Lesions as well as the severity of each lesion (0 to 3) were included in a multiple linear regression model using the MIXED procedure (SAS Institute, Inc., Cary, NC).

The number of piglets in the litter after cross-fostering was tested for significance as a linear covariate for litter BW after cross-fostering, piglet mortality, the number of piglets weaned, and litter BW at weaning. Lactation length, the number of piglets weaned, and litter BW after cross-fostering were used as linear covariates for litter BW at weaning. Piglet mortality data was analyzed using generalized linear mixed models (GLIMMIX, SAS) fitting a Poisson distribution to the data. Treatment means for piglet mortality were back-transformed into the original unit of measure using the ILINK function. For all covariate effects, the covariate mean was used when estimating treatment effect means at each lesion severity score.

Behavior data were evaluated by experiment and were transformed using the logit function. The total time budget for some treatment groups do not sum to 100 % because a logit transformation was used before analyses. This transformation is non-linear; in that, the back-transformed means do not linearly equal the original values. The sow served as the experimental unit. In Experiment 1, lesions and their severity were evaluated using multiple regression of each behavior, similar to the analysis conducted for performance data. Block was included in the model as a fixed effect. Sow within block was used as a random effect to account for correlations between the day of observation (10 and 11 d of lactation) for sows that had repeated measurements. An environmental impediment during several lying down events was observed for one sow in Experiment 1. This caused her to stand nearly the entire time after feeding and was not a result of her lesion score. Therefore, this sow was removed from behavior analyses. The percent of time spent standing before feeding was used as a linear covariate for the percent time spent standing after feed delivery. Odds ratios were calculated and presented in the text as one unit increases represents either a percent increase or decrease in time spent in the specific behavior or posture.

For performance and behavior data, multiple linear regressions were estimated for each treatment group severity score (0 to 3). Thus, sows designated as control were included in the models as a severity score zero. The partial regression coefficients derived from the models estimate the associated increase or decrease in performance or behavior trait when the severity score is increased by one unit. For all variables listed in tables and figures, the control group is the starting value for associations with each severity score increase. No significance tests were calculated to compare regression coefficients between treatment groups.

In Experiment 2, behavior data were collected for 10 sows. Each of the treatment sows (2 TS and 3 OG sows, listed as abnormal in had lesion scores greater or equal to 2. Behavior video for CK sows was discarded because video was lost for 2 h during feeding on the morning of d 11 of lactation. Therefore, behaviors were compared for the 5 treatment sows versus the 5 control sows. Thus, the binary variable, with or without lesions, was used as a fixed effect in the model. No random variables were used in Experiment 2 because the sows were housed within the same area of 1 room (within a 4 stall radius) and were all of parity 1 sows. Sitting and feeding was removed from behavioral analysis because only 2 sows were observed to sit and eat before or after feeding in Experiment 1 and no sows were observed in this position from Experiment 2.

Objective II

Normal and abnormal hoof pictures were collected throughout the study. These pictures illustrate the range in severity of hoof cracks, overgrown toes, and toe size differences in two Midwest sow herds. Further, the pictures will be used in future classification of these specific lesions in an attempt to standardize the lesion identification and scoring process. The scoring system developed for the previous study as well a sample of pictures is listed in Table 2.1.

Table 2.1. Hoof lesion classification methods used in the evaluation of behavior and performance for commercial sows at a Midwestern U.S. swine integrator.

Control Sows [C]	
0	Absence of hoof cracks, less than 6.4 cm in length, and less than 1.3 cm difference between the outer and inner toe
Cracked hooves [CK][1]	
1	Presence of crack in hoof less than 1.3 cm in length
2	Crack in hoof of 1.4 to 2.5 cm in length
3	Crack in hoof greater than 2.6 cm or multiple cracks
Lateral and medial toe size differences [TS][2]	
1	Toe length difference between 1.3 and 1.9 cm
2	Toe length difference between 2.0 and 2.5 cm
3	Toe length difference greater than 2.6 cm
Overgrown toe [OG][3]	
1	One toe of a hoof must be within 6.4 and 8.3 cm in length
2	One toe of a hoof must be within 8.4 to 10.2 cm in length
3	One toe of a hoof must be greater than 10.3 cm in length

[1]The number, length, location, and severity of hoof cracks were recorded for each toe and for all sows in all treatment groups.

[2]The length difference between the medial and lateral toe were obtained by using a standard ruler (measured at 0.32 cm increments) placed on the floor of the gestation stall between both toes and parallel to the long axis of the sow and leg.

[3]Toes were measured beginning at the coronary band and extending to the leading edge of the overgrown toe.

Objective III

A systematic review to evaluate the effectiveness of the treatment of lameness in sows was conducted. The established steps for conducting a systematic review were followed. 1) A specific three part question was developed. 2) A comprehensive literature search was conducted. 3) All unique articles were reviewed for relevance to the research question. 4) The relevant articles were submitted to a quality screening. 5) The surviving articles had data extracted and were summarized.

The targeted, three point question was formulated to include the population of interest, the condition of interest, and the intervention of interest. The population of interest consisted of adult swine. Adult boars used for reproductive purposes were included in the population as they would be subjected to the same environments as the sows. Gilts in the acclimation phase or not yet selected for admission to the breeding herd were excluded. The condition of interest was prevalent, documented lameness in at least one foot of the sow. Quantification or qualification of foot/hoof lesions were not included unless the lesions were correlated directly with documented lameness observed during movement. The intervention of interest was any treatment applied to cause a change in the severity, prevalence, or duration of the lameness condition. An intervention was considered as a treatment compared between two groups of animals with one of those treatments serving as a control. The treatment could include physical, nutritional or surgical procedures. Interventions applied to mixed populations of lame and non-lame animals were excluded unless the subpopulations were reported separately. The final research question investigated by this systematic review was: "What is the effectiveness of treatment of lameness in sows".

A comprehensive search string, listed in Table 3.1., was created to capture all combinations of each aspect of the targeted question. Searches of seven electronic indices which included agricultural and veterinary based journals were conducted. No timeframe or language restrictions were placed on the original search. The electronic databases searched included: PubMed (1965-2009), CAB Abstracts (1910-2009), AGRIS (1975-2009), AGRICOLA (1970-2009), BioSis Previews (1980-2009), Biological and Agricultural Index (1983-2009) and Medline (1950-2009). Many of the indices included the same journals or proceedings papers but all had unique inclusions. This allowed for a more comprehensive list of any available data. A manual search was conducted of the 2006 Swine Information CD compiled by the American Association of Swine Veterinarians organization including proceedings from swine focused meetings and the Journal of Swine Health and Production covering the time frame of 1999-2006.

Table 3.1: Search Terms for Literature Review to evaluate Treatment of Lameness in Sows

POPULATION
hog or hogs or swine or swines or pig or pigs or sow or sows or gilt or gilts or porcine or

porcines or boar or boars NOT guinea

BIOLOGICAL CONDITION

lameness or lamenesses or hoof or hooves or foot or feet or “dew claw” or “dew claws”) NOT (foot-and-mouth disease)

INTERVENTION

treatment or treatments or “holistic medicine” or intervention or interventions or "management practice" or "management practices" or immunoprophylaxis

All articles produced by the searches were catalogued with a reference software database (Endnote® X, Thomson ResearchSoft). Duplicate articles were removed from the database using the find duplicates function in Endnote®. The compiled database was then manually searched and additional articles were removed based on authorship and manuscript title comparison. The titles and abstracts of all unique articles were evaluated by two reviewers for relevance to the research question. The relevance criteria posed four questions of each abstract:

1.) Does this abstract describe original research versus a narrative review, clinical case report or an annual summary of activity?

2.) Does the abstract directly reference lameness and/or foot or hoof care?

3.) Does the abstract describe a therapeutic treatment intervention versus a preventive application?

4.) Does the abstract describe research performed on adult sows/boars versus non-mature aged swine? (Table 3.2.)

Table 3.2: Relevance Criteria for Collected Publications to be considered for analysis in systematic review process

EBM Checklist for relevance in *Effective Treatment of Lameness in Sows* Systematic Review

Need all four boxes checked to accept

1. ☐ Does this abstract describe primary research as opposed to a review
2. ☐ Directly references lameness **AND/OR** foot/hoof care
3. ☐ Reports treatment option (therapeutic) **NOT** prevention
4. ☐ Study done with sows/boars **NOT** growing pigs (suckling pigs, nursery, feeder, finishing) **NOT** guinea pigs or other species as models

Full articles were obtained for those results lacking an abstract or whose title and/or abstract were not able to fully answer each relevance question. The relevance criteria allowed for the maximum number of applicable articles to pass to the quality screening without introduction of bias. Foreign language articles were translated sufficiently to analyze the abstract for relevance. Online translation resources (Altavista Babelfish, http://babelfish.yahoo.com/) were utilized for Romance languages. A blinded native speaker was used for translation of Dutch papers. No resources were available to accurately translate and evaluate any remaining languages. The articles that were unable to be translated sufficiently for relevance review were removed from further analysis. Articles moved to quality screening if they received a favorable evaluation by either reviewer on all four relevance questions.

The complete text of all relevant studies was obtained prior to evaluation by the quality criteria listed in Table 3.1. Affirmative (YES) answers to all questions were required to meet the quality evaluation and acceptance for the data extraction phase. The same two reviewers in the relevance stage evaluated the articles for quality. Any foreign language papers which passed relevance screening were fully translated with online resources and then validated by a native speaker. Those articles which met the relevance and quality screens were subjected to data extraction (Table 3.3.) The sample size, treatment and control populations, interventions and outcomes were all catalogued in a spreadsheet and reported in tabular format. No further statistical calculations were performed on the final results. Conclusions were drawn based on the extracted data.

Table 3.3.: Validity Criteria for collected publications to be considered for inclusion for data extraction and summary

Systematic Review Validity Checklist: Effectiveness of the Treatment of Lameness in Sows			
	Quality Item	**Coding**	**Score**
1	**Was the study an intervention trial?**	YES NO	1 0
2	**Was the study population (population at risk) clearly identified?**	YES NO	1 0
3	**Were the study subjects randomly selected with randomization method identified?**	YES NO	1 0
4	**Was the housing representative of field conditions?**	YES NO	1 0
5	**Were the pen/group size justified?**	YES	1

		NO	0
6	**Was the control group appropriately identified?**	YES NO	1 0
7	**Were the treatment groups clearly identified?**	YES NO	1 0
8	**Were the treatments and outcomes blinded?**	YES NO	1 0
9	**Was adequate time given between observations to measure outcomes?**	YES NO Unclear	1 0 0
10	**At what level were the observations recorded?**	Hoof Sow Unclear	2 1 0
11	**At what level were the observations analyzed?**	Hoof Sow Unclear	2 1 0
12	**Were the outcomes tested statistically?**	YES NO	1 0
13	**Were results reported appropriately?**	YES NO Unclear	1 0 0
14	**Was the handling of the study withdrawals clarified?**	YES NO	1 0
	A score of 7 or greater is required for acceptance of the document		
	"YES" answers are required to questions 1, 4, 6, 7		

Results:

Objective I

General lesion description. Sows from several different parities were evaluated in this study because hoof abnormalities are not limited to a particular parity. The parity distribution of sows at both farms by treatment is shown in Table 2.1. Sows included in this project on Farms A and B had an average parity of 4.1 and 1.7, respectively. Prior to initiating this experiment, Farm B was primarily used as a gilt development unit, and thus a younger average parity was observed for sows on that farm. The greatest number of hoof abnormalities was found in parity 3 to 5 sows, followed by sows in parity 6 to 8, parity 2, and finally parity 1.

Of the 223 sows from both experiments, 79 sows were considered the control population and the remaining 144 sows were found to have hoof lesions which varied in their degree of severity. Sows were also given a score that was positively correlated with the severity of the lesion. Averaging only those sows with at least one hoof lesion, Farm A and B averaged severity scores of 1.5 and 2.0, respectively. Only 11.8 % of sows with a hoof lesion were assigned the most severe score of 3, whereas 47.2 and 41.0 % of the 144 sows were assigned scores of 1 and 2, respectively. Sows denoted as a score of 0 were control sows. Six of 61 sows classified in the TS group and 1 of the 22 OG sows had toe length differences greater than 1.3 cm in the front hooves, and 4 of the 6 six sows had only toe length differences in the front hooves. Six sows had cracks in the front hooves. No sows were classified in the OG group because of overgrown front toes.

Sow and piglet performance during lactation for Experiments 1 and 2

Number of piglets born alive. Piglet weights from 223 litters were collected over the 2 experiments and were combined for analyses. Data were combined because the same protocol was used for both experiments and blocking of the treatment and control sows allowed comparisons within blocks, which accounted for farm and room level effects. The number of piglets born alive was not linearly associated with severity lesion score for any treatment group ($P > 0.15$); that is, all lesion scores over all treatment groups averaged the same number of piglets born alive as control sows.

Number of piglets and litter weight after cross-fostering. Piglets were cross-fostered to other sows within the same room for sows that farrowed on the same day and were equalized to 11 piglets / sow. Treatment severity score partial regression coefficients for both litter weight and litter size at cross-fostering were not significantly different than zero ($P > 0.15$, Table 1.3.). Therefore, there was strong evidence that sows within each treatment group began the experiment with equal litter sizes and litter weights.

Pre-weaning mortality. Increased piglet mortality during lactation was associated ($P = 0.02$) with an increase in CK and TS severity score (Table 1.3). Although the slope was positive, there was no evidence to suggest that piglet mortality increase with OG severity score. Piglet mortality increased with the number of piglets in the litter after cross-fostering (P = 0.02). A significant, negative partial regression coefficient was found for piglets weaned per litter for sows in the CK and TS groups; that is, as lesion severity increased, the number of piglets weaned per litter decreased. All severity scores for each treatment group averaged fewer piglets weaned per litter than control sows.

Piglets weaned per litter. A trend (P = 0.10) was observed that sows in the CK group weaned 0.21 fewer piglets per litter than control sows. Fewer piglets were weaned per litter for TS sows (P = 0.02).

Adjusted litter weaning weight. An increase in lesion severity score was associated with lighter adjusted litter wean weights for all treatment groups; however, only the slope for sows in the OG group was significantly (P = 0.03) different from zero. An associative trend (P = 0.07) was observed for sows in the CK group to wean lighter litters as lesion score increased. Litter BW at cross-fostering, lactation length, and piglets weaned were all positively associated (P = 0.01) with litter wean weight (Table 1.3.).

Feed disappearance during lactation for sows. A positive linear relationship (P < 0.01) was found between lactation length and the total feed disappearance during lactation. However, there was no significant association between feed disappearance during lactation and lesion scores.

Table 1.3. Lactation performance[1] of 223 sows categorized as having normal hooves [C] or as having hoof cracks [CK], differences in toe length [TS], or overgrown toes [OG], conducted at a Midwestern U.S. swine integrator.

	Number of Piglets Born Alive[2], N			Number of piglets after cross-fostering[3], N			Litter BW after cross-fostering, kg		
Item	Estimate	SE	*P*	Estimate	SE	*P*	Estimate	SE	*P*
Treatment Group									
Control [C]	10.90	0.34		10.88	0.13		17.24	0.27	
Cracked Hooves, *b*[4]	0.05	0.30	*0.86*	0.04	0.11	*0.72*	-0.14	0.24	*0.57*
CK 1	10.95	0.34		10.92	0.13		17.10	0.27	
CK 2	11.00	0.54		10.96	0.21		16.97	0.43	
CK 3	11.05	0.81		11.01	0.31		16.83	0.64	
Toe Length Differences, *b*	-0.10	0.33	*0.76*	-0.06	0.13	*0.66*	-0.32	0.27	*0.23*
TS 1	10.79	0.33		10.83	0.13		16.92	0.26	
TS 2	10.69	0.56		10.77	0.22		16.60	0.45	
TS 3	10.59	0.87		10.71	0.34		16.28	0.69	
Overgrown Toes, *b*	0.03	0.58	*0.96*	-0.02	0.22	*0.93*	0.32	0.46	*0.48*
OG 1	10.92	0.56		10.86	0.22		17.56	0.44	
OG 2	10.95	1.09		10.84	0.42		17.88	0.86	
OG 3	10.98	1.65		10.82	0.63		18.20	1.30	
Block Effect,[5] *P*			*0.24*			*0.57*			*0.15*
Covariance Effects									
Number of piglets in litter	-	-	-	-	-	-	1.18	0.17	*<0.001*

after cross-fostering

[1]Lactation and litter performance data were combined over two experiments. Sow genetics used in Experiment 1 and 2 were from Newsham Genetics (Supermom; Des Moines, IA) and Pig Improvement Company (Line 23 and 29; Hendersonville, TN).

[2]Farrowing data was missing from the farm database for 1 sow.

[3]Piglets were cross-fostered within 24 hr between sows that farrowed on the same day. Litter size was targeted at 11 piglets/sow.

[4]*b* = beta for partial regression coefficient of treatment group.

[5]Between 2 to 8 sows were blocked in remove effects due to parity, room, farm, and genetics. Treatment and control sows were paired and considered a match using the following parity structure: 1, 2, 3 to 5, and 6 or greater parities.

Table 1.3. (Continued)

	Piglet Mortality during Lactation[6], N			Piglets weaned per litter, N			Adjusted Litter Wean BW[7], kg		
Item	Estimate	SE	*P*	Estimate	SE	*P*	Estimate	SE	*P*
Treatment Group									
Control [C]	0.02	1.60		9.15	0.15		44.61	0.63	
Cracked Hooves, *b*[4]	0.25	0.11	*0.02*	-0.21	0.12	*0.10*	-0.93	0.51	*0.07*
CK 1	0.02	-		8.95	0.15		43.68	0.61	
CK 2	0.03	-		8.74	0.23		42.74	0.94	
CK 3	0.03	-		8.53	0.34		41.81	1.39	
Toe Length Differences, *b*	0.30	0.12	*0.02*	-0.35	0.14	*0.02*	-0.52	0.59	*0.39*
TS 1	0.02	-		8.80	0.14		44.09	0.57	
TS 2	0.03	-		8.45	0.24		43.58	0.98	
TS 3	0.04	-		8.11	0.36		43.06	1.52	
Overgrown Toes, *b*	0.16	0.19	*0.40*	-0.13	0.24	*0.60*	-2.16	0.98	*0.03*
OG 1	0.02	-		9.02	0.24		42.46	0.97	
OG 2	0.02	-		8.90	0.45		40.30	1.85	
OG 3	0.03	-		8.77	0.68		38.14	2.80	
Block Effect,[5] *P*			*0.88*			*< 0.01*			*< 0.01*
Covariance Effects									
Number of piglets in litter after cross-fostering	1.25	1.09	*0.02*	0.05	0.09	*0.61*	-	-	-
Litter BW at cross-fostering, kg	-	-	-	-	-	-	0.45	0.16	*0.01*
Lactation Length, d	-	-	-	-0.03	0.10	*0.74*	1.78	0.40	*< 0 .0001*
Piglets weaned per litter, N	-	-	-	-	-	-	4.05	0.35	*< 0 .0001*

[4]*b* = beta for partial regression coefficient of treatment group.

[5]Between 2 to 8 sows were blocked in remove effects due to parity, room, farm, and genetics. Treatment and control sows were paired and considered a match using the following parity structure: 1, 2, 3 to 5, and 6 or greater parities.

[6]Piglet mortality during lactation were analyzed using a Poisson distribution. The beta estimates and their standard errors are listed on the log scale. Least Square Means were back-transformed using the ILINK function of SAS.

[7]Adjusted weight produced in lactation = litter wean weight + piglet morality weight + weight of pigs removed – weight of pigs added – weight of cross-fostered litter at birth.

Table 1.3. (Continued)

Item	Sow feed Disappearance during Lactation[8], kg			Adjusted Litter Wean BW per kilogram feed intake, kg/kg		
	Estimate	SE	*P*	Estimate	SE	*P*
Treatment Group						
Control [C]	125.84	2.23		0.41	0.01	
Cracked Hooves, *b*[4]	1.98	1.96	*0.32*	-0.02	0.01	*0.02*
CK 1	127.82	2.37		0.39	0.01	
CK 2	129.80	3.74		0.37	0.02	
CK 3	131.79	5.48		0.35	0.02	
Toe Length Differences, *b*	3.04	2.46	*0.22*	-0.02	0.01	*0.07*
TS 1	128.88	2.44		0.39	0.01	
TS 2	131.92	4.37		0.37	0.02	
TS 3	134.96	6.66		0.36	0.03	
Overgrown Toes, *b*	-10.79	6.99	*0.13*	0.004	0.03	*0.90*
OG 1	115.04	6.62		0.41	0.03	
OG 2	-	-		-	-	
OG 3	-	-		-	-	
Block Effect,[5] *P*			*<0.01*			*0.04*
Covariance Effects						
Litter BW at cross-fostering, kg	-	-	-	0.01	0.00	*0.03*
Lactation Length, d	5.03	1.52	*< 0.01*	-0.01	0.01	*0.16*
Piglets weaned per litter, N	-	-	-	0.03	0.01	*< 0.001*

[4]*b* = beta for partial regression coefficient of treatment group.

[5]Between 2 to 8 sows were blocked in remove effects due to parity, room, farm, and genetics. Treatment and control sows were paired and considered a match using the following parity structure: 1, 2, 3 to 5, and 6 or greater parities.

[8]Feed intake data were recorded for 135 sows. No data were available for sows in the OG 2 and 3 severity scores.

Experiment 2. 24 hr behavior observation

General time budget. Averaging over the 10 sows, the greatest portion of time was spent in lateral recumbency (88.7 ± 3.26 %, mean ± SD), splitting the time nearly equally between the left (40.0 ± 14.5 %) and right (35.9 ± 17.8 %) side. However, left to right side ratios ranged from 0.3 to 6.6 (time spent lying laterally on the left side divided by the times spent on the right side), suggesting that some sows had a preference for lying lateral on their right or left side for no apparent reason. The closest ratio to equal time on both sides was 1.3. Sows averaged 12.9 ± 5.0 % of the 24 hr period lying sternal. Sows spent a very small percentage of their time kneeling (0.1 %). Sows averaged 35 % of the time in a sitting posture drinking from the nipple waters. For the remainder of time spent in a sitting posture (65 %), sows were observed to watch other activity in the room, perform biting, and interacted with her piglets. Sows in this experiment were observed standing between 5.6 and 10.9 % of the observation period, and of the variables recorded, eating was the primary activity performed while standing (range 3.3 to 9.1 %). Only 2 additional attempts to complete a lying down event (for 101 completed events) were observed. Sows averaged 10.1 lying down events during the observation period.

Treatment comparisons. There was no evidence to suggest that sows in treatment groups were associated with less time standing, kneeling, or lying down compared to control sows (Table 1.4). However, sows with hoof lesions were observed to spend 1.5 % more time (*P* < 0.01) sitting than control sows.

Table 1.4. Standing, sitting, kneeling, and lying down posture[1] least squares means (± SE) over a 24-h time period for 10 sows classified as having hoof lesions (abnormal) or normal hooves in an evaluation of the effects of toe abnormalities on lactating sow performance from a Midwestern U.S. swine integrator.

	Standing									
	Eating		Drinking		Defecate / Urinate		Other[2]		Total time standing	
Item	Total	SE	Total	SE	Total	SE	Total	SE	Mean	SE
Treatment Groups[3], *P*	*0.47*		*0.82*		*0.45*		*0.47*		*0.95*	
Abnormal[4]	6.3%	0.5	0.1%	0.6	0.2%	0.6	1.3%	0.6	7.9%	0.5
Control	5.6%	0.5	0.1%	0.6	0.2%	0.6	1.6%	0.5	8.0%	0.5
Block Effect, *P*	*0.17*		*0.33*		*0.46*		*0.10*		*0.24*	

[1]Sows in Experiment 2 were observed for a continuous 24 h period beginning at 9 AM on d 10 of lactation and ending at the same time on d 11. Sow genetics used in this experiment were Pig Improvement Company (Line 23 and 29; Hendersonville, TN).

[2]Other behaviors include all behaviors not specifically recorded. Most frequently, sows were just sitting or standing and watching other activity in the room, bar biting, or interacting with her piglets.

[3]Differences between treatment groups for all behaviors were *P* > 0.05.

[4]Sows classified in the abnormal category had overgrown toes (N = 3) or toe length differences (N = 2).

Table 1. 4. (Continued)

	Sitting					
	Drinking		Other		Total	
Item	Total	SE	Total	SE	Mean	SE
Treatment Groups, *P*	*0.18*		*0.01*		< *0.01*	
Abnormal	1.4%	0.6	2.4%	0.5	3.9%	0.5
Control	0.6%	0.6	1.5%	0.5	2.4%	0.5
Block Effect, *P*	*0.11*		*0.02*		< *0.01*	

Table 1.4. (Continued)

	Kneeling		Lying Down							
			Sternal		Lateral, Left		Lateral, Right		Total	
Item	Total	SE	Total	SE	Total	SE	Total	SE	Mean	SE
Treatment Groups, *P*	*0.69*		*0.45*		*0.39*		*0.44*		*0.15*	
Abnormal	0.1%	0.6	13.9%	0.6	44.9%	0.6	27.2%	0.6	87.7%	0.5
Control	0.1%	0.6	11.1%	0.5	35.2%	0.6	37.6%	0.6	89.4%	0.5
Block Effect, *P*	*0.27*		*0.36*		*0.40*		*0.37*		*0.02*	

Experiment 1. 105 min sow behavioral observation

Overall time budget for sows. A time budget for 3 postures (standing, sitting, and lying down) by treatment group is shown in Figure 1. Sows in the control group spent 18.9 % (19.9 min) of the 105 min observation period standing (Figure 1.4.), 1.3 % (1.4 min) sitting, 0.3 % (0.3 min) kneeling, and 76.1 % (79.9 min) of the time lying lateral or sternal. Each score increase in CK lesions was associated with a 1.2 odds ratio for standing (P = 0.02). However, each increase in OG lesion score was associated sows spending 54 % less time standing (P = 0.01). No significant associations were observed for the total amount of time spent sitting for any treatment groups compared to control sows. As a result of the time budget adding to near 100% and significant associations were observed for standing times, the opposite associations were observed for times spent lying; that is, as CK sows spent more time standing, those same sows inherently spent less time lying down. Odds ratios for times spent lying down were 0.8, 1.0, and 1.3 for each score increase in CK, TS, and OG lesions, respectively. Each posture will be discussed further on the basis of before and after feeding.

Standing Postures. Control sows spent 12.7 % (13.3 min) of the total time standing and eating. Before feeding, control sows spent 1.2 % of time standing and eating (Figure 1.2). However after feed delivery, sows increased time spent standing and eating to 10.7 %. Sows were provided feed 4 times / d, and some sows did not consume the entire amount of the provided ration immediately after feed delivery. Therefore, the amount of time spent standing and eating before feed presentation was negatively associated with time spent eating after feeding (b = -0.24, P < 0.01); that is, for each percent increase in time spent eating prior to feeding was associated with a 79 % decrease in time spent standing and eating post feeding. Standing and eating estimates for each lesion score were estimated using the average of time spent standing and eating prior to feeding (2.3 % of the 105 min observation period).

Before feed delivery, there was no evidence (P > 0.15) that sows of different treatment severity levels were associated with different amounts of time spent standing and eating compared to control sows. Post feeding, each OG lesion score increase was associated with a 40.0 % decrease in time spent standing and eating. This observation held true for total time spent standing and eating during the observation period [Odds Ratio (OR) = 0.45]. A positive odds ratio (1.19, P = 0.06) was observed for total time spent standing and eating for sows in the CK group. A negative association was observed between total time spent standing during the 105 min observation and increasing OG lesion score. Each increase in lesion score was associated with a 54 % decrease (P = 0.01) in time spent standing as compared to control sows. However, an odds ratio of 1.2 (P = 0.02) was observed for each lesion score increase on total time spent standing for CK sows. This result is unexpected, in that one may hypothesize that sows with severely cracked hooves, thus assuming some level of pain, would be less controlled when lying down. One plausible explanation for this result is that some hoof cracks may visually appear more severe or appear to cause more pain than what truly occurs. Some hoof cracks may only be superficial and not penetrate to more sensitive areas of the toe or foot. Because only the methods to determine true crack severity include radiographs or sacrificing the animal, the costs to do this were prohibitive in the current study.

Kneeling and Sitting Posture. There were no significant associations observed for time spent kneeling before feeding for any treatment group compared to control sows. Sows with OG toes spent 53 % less time kneeling after feeding (P = 0.01) and 50 % less time (P < 0.01) kneeling over the entire observation period for each incremental increase in lesion score (Figure 1.3.). Sows with CK and TS lesions had odds ratios near 1.0 (1.01 and 1.04 before feeding and 1.09 and 1.01 after feeding, respectively) for time spent kneeling and partial regression coefficients were not significantly different than zero (P > 0.15).

Control sows spent 0.7 and 1.2 % of the sitting time before feeding performing drinking and other behaviors, respectively. After feeding, control sows spent 0.8 and 0.7 % of sitting time after feeding performing drinking and other behaviors, respectively. Compared to control sows, each lesion severity score increase for all treatment groups was not linearly associated with the time spent sitting before and after feeding as well as the total time spent sitting (P > 0.15).

Lying Down Posture. Sows categorized in the CK group spent less (P = 0.01) time for the total observation period lying down compared to their control counterparts (Figure 1.4.). As the severity of OG lesion increases, total time spent lying down increases (OR = 1.69, P = 0.02). In contrast, CK lesion scores were negatively associated with time spent lying down before (P = 0.06) and after (P < 0.01) feeding. Because time spent sitting was not linearly associated with lesion scores of any treatment group and kneeling only accounted for a relatively small percentage of the sows' time budget, generally the time spent standing was balanced by the time spent lying down. For example, CK sows spent the greatest portion of time standing and the least percentage of time lying down. The percentage of time lying down was not linearly associated with TS severity scores before or after feeding (P > 0.15).

Repeated Lying Down Events. Sows that show abnormal lying down (described by Bonde et al. (2004) as interruptions in the sequence by stopping the lying down behavior and resuming from an earlier stage such as standing, or described as slipping or uncontrolled movement) may increase piglet mortality though uncontrolled sudden movements. Sows averaged 1.9 completed lying down events during the 105 min observation. Including all attempted a lying down event an average of 2.3 times per observation period. Four sows (2 OG and 2 C sows) were removed from the treatment analysis of lying down events because those sows did not perform the defined lying down behavior. These sows lowered from a standing to a sitting position using their rear legs instead of the front legs instead of lowering to a kneeling posture on their front knees. In most cases, this was observed when sows were standing and drinking, lost traction with their rear hooves, and experienced severe slips and lowered to a sitting posture. The only OG sow (of 13 total sows classified as OG in experiment 1) that did not complete the lying down event on the first attempt required 13 times to successfully complete one lying down event. This sow had the appearance that she wanted to lie down, and failing to do so, caused her to have larger than normal standing time as well as time spent kneeling. Thus, this observation was removed from subsequent behavior analyses. The number of completed and attempted lying down events for sows by treatment group is listed in Figure 5. After removing those observations, sows in the C, CK, TS, OG, and TK groups completed 89.3, 80.9, 93.1, 100.0, and 77.4 % of the 525 attempted lying down events. With the OG sow removed, the number of attempts required when lying down above those that were defined as completed ranged from 0 to 6 per observation for all sows.

Figure 1.1. Time budget of sows for 45 min prior to and 1 h post feeding by treatment and lesion severity in an evaluation of the effects of toe abnormalities on lactating sow[1] performance from a Midwestern U.S. swine integrator.

[1]Sows (Newsham Supermom, Des Moines, IA) were categorized as having overgrown toes [OG], differences in toe length [TS], hoof cracks [CK], both hoof cracks and toe size differences, or normal hooves [C] and assigned a severity score of 0 to 3. No behavior data were collected for the OG 3 group because of the low prevalence of this severity on Farm A.

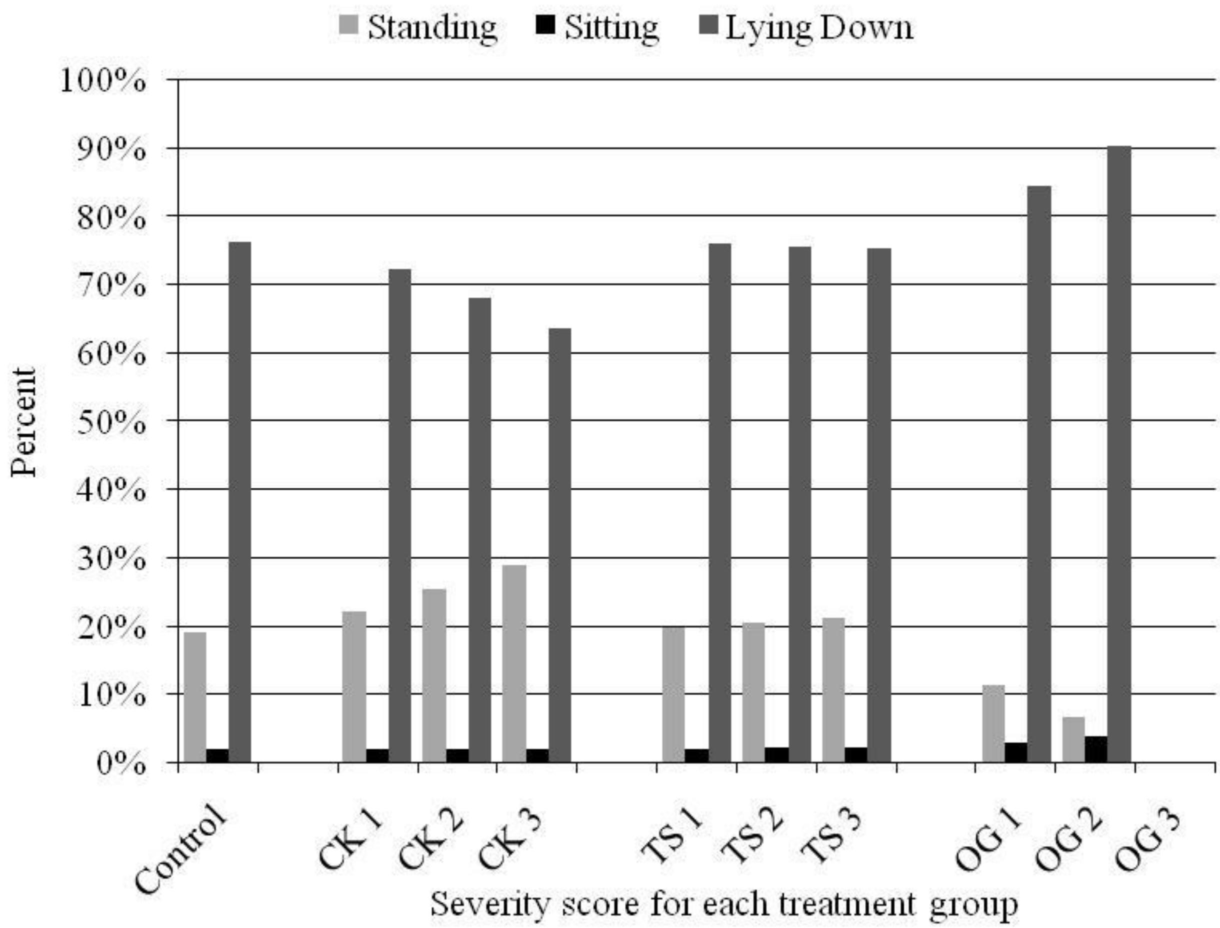

Standing
Sitting
Lying Down
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent
Control
CK 1
CK 2
CK 3
TS 1
TS 2
TS 3
OG 1
OG 2
OG 3
Severity score for each treatment group

Figure 1.2. Percent of time spent standing and eating before and after feeding during a 105 min observation period by treatment and lesion severity in an evaluation of the effects of toe abnormalities on lactating sow[1] performance from a Midwestern U.S. swine integrator.

[1]Sows (Newsham Supermom, Des Moines, IA) were categorized as having overgrown toes [OG], differences in toe length [TS], hoof cracks [CK], both hoof cracks and toe size differences, or normal hooves [C] and assigned a severity score of 0 to 3. No behavior data were collected for the OG 3 group because of the low prevalence of this severity on Farm A.

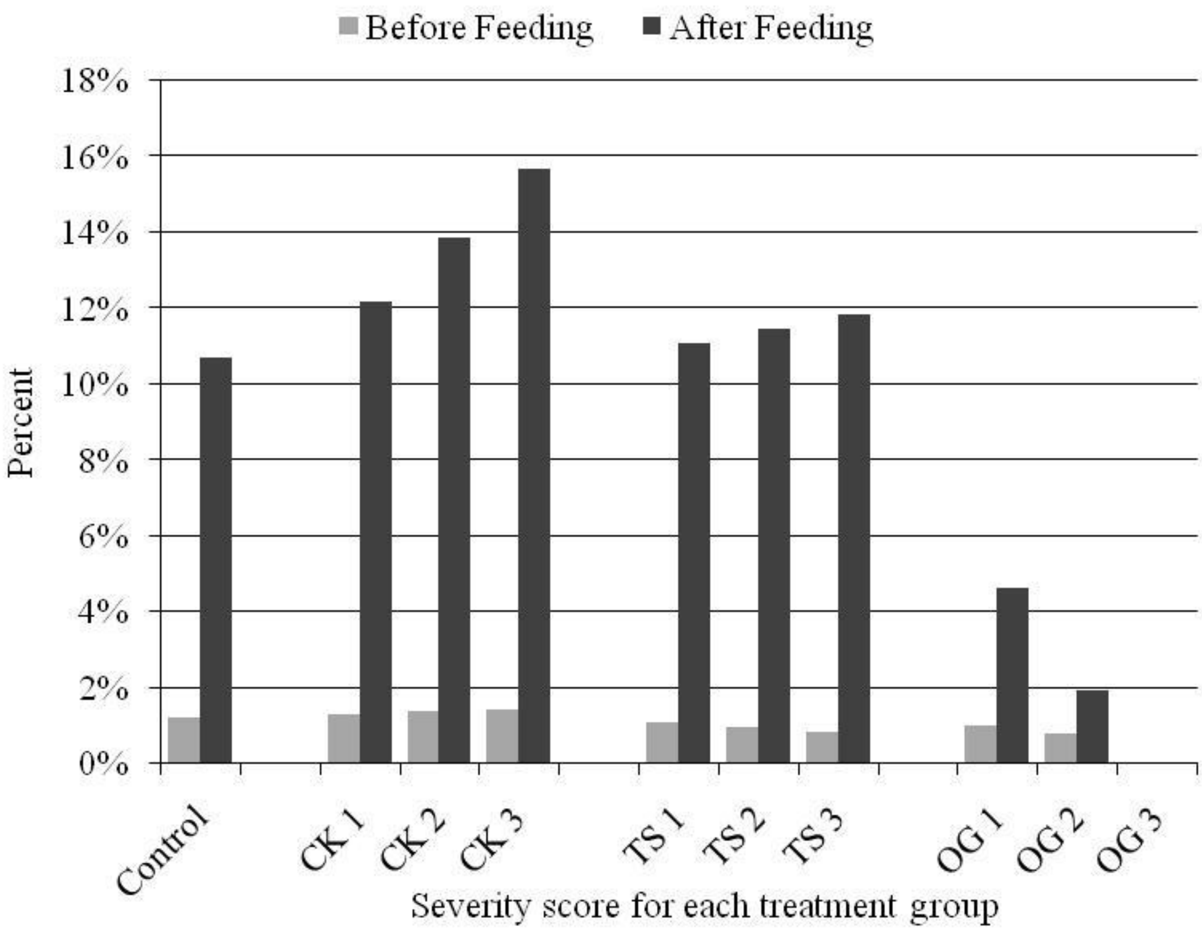


Figure 1.3. Percent of time spent kneeling after feeding and total time spent kneeling during a 105 min observation period[1] by treatment groups and severity lesion in an evaluation of the effects of toe abnormalities on lactating sow[2] performance from a Midwestern U.S. swine integrator.

[1]Percent of time spent kneeling before feeding was not analyzed because low percentages of time were recorded for this period.

[2]Sows (Newsham Supermom, Des Moines, IA) were categorized as having overgrown toes [OG], differences in toe length [TS], hoof cracks [CK], both hoof cracks and toe size differences, or normal hooves [C] and assigned a severity score of 0 to 3. No behavior data were collected for the OG 3 group because of the low prevalence of this severity on Farm A.

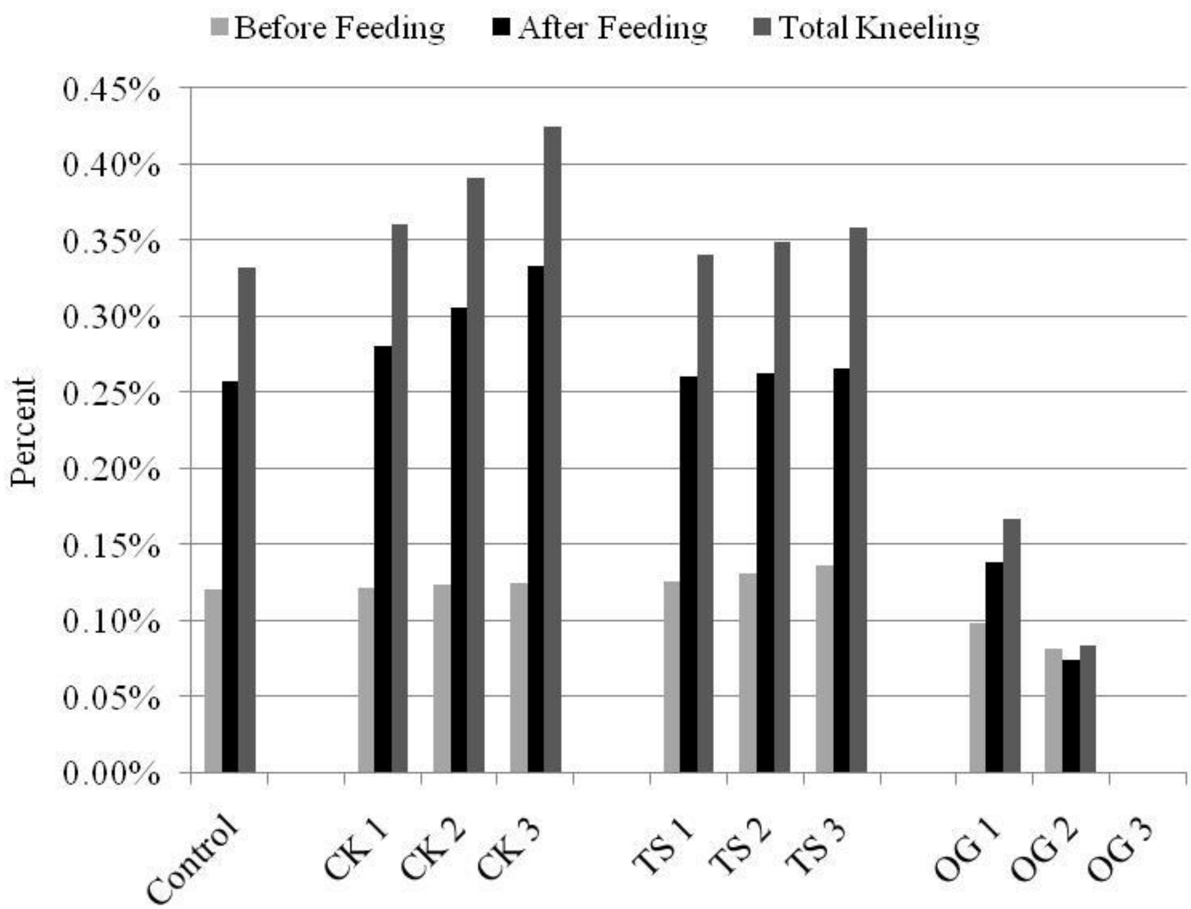


Figure 1.4. Percent of time spent lying down before and after feeding during a 105 min observation period by treatment groups and severity lesion in an evaluation of the effects of toe abnormalities on lactating sow[1] performance from a Midwestern U.S. swine integrator.

[1]Sows (Newsham Supermom, Des Moines, IA) were categorized as having overgrown toes [OG], differences in toe length [TS], hoof cracks [CK], both hoof cracks and toe size differences, or normal hooves [C] and assigned a severity score of 0 to 3. No behavior data were collected for the OG 3 group because of the low prevalence of this severity on Farm A.

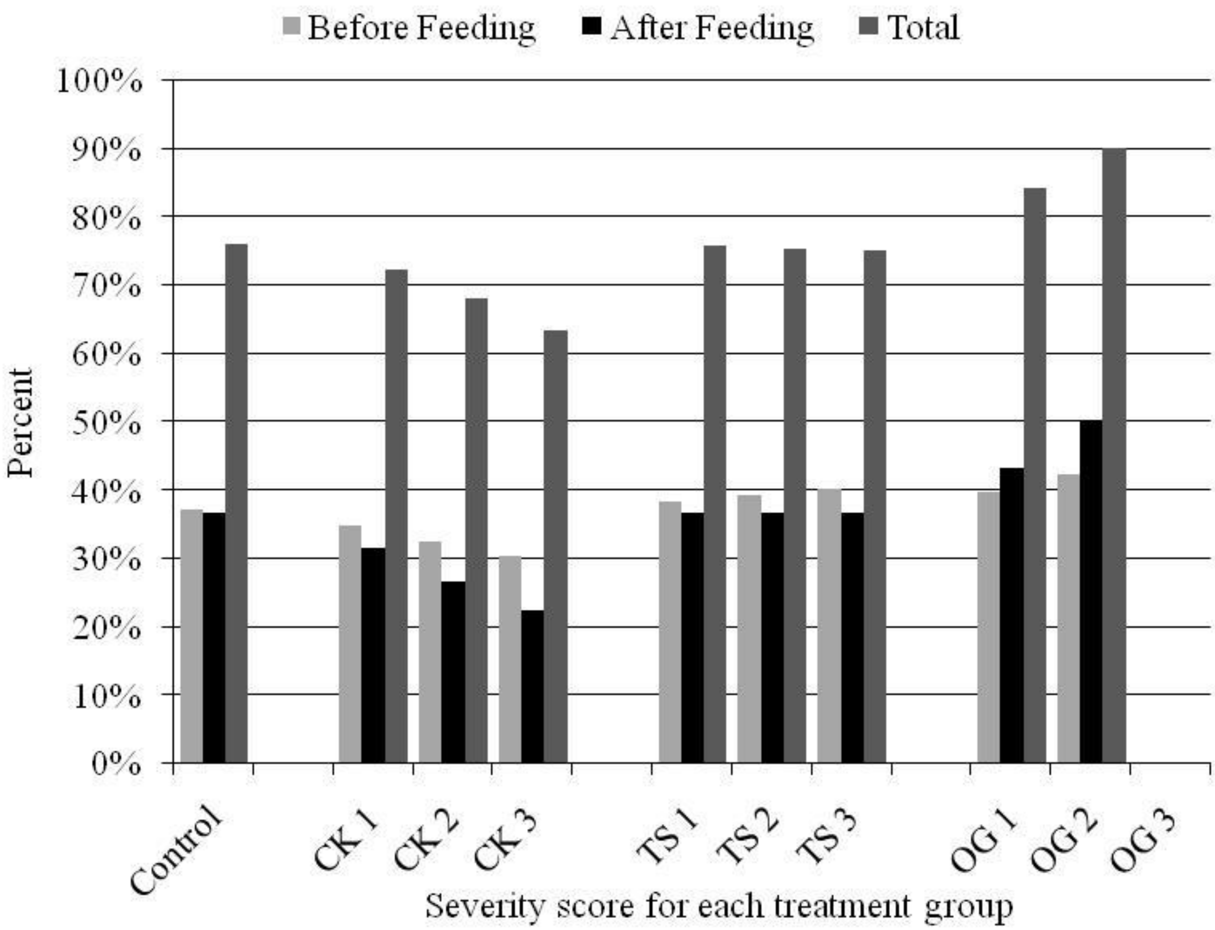
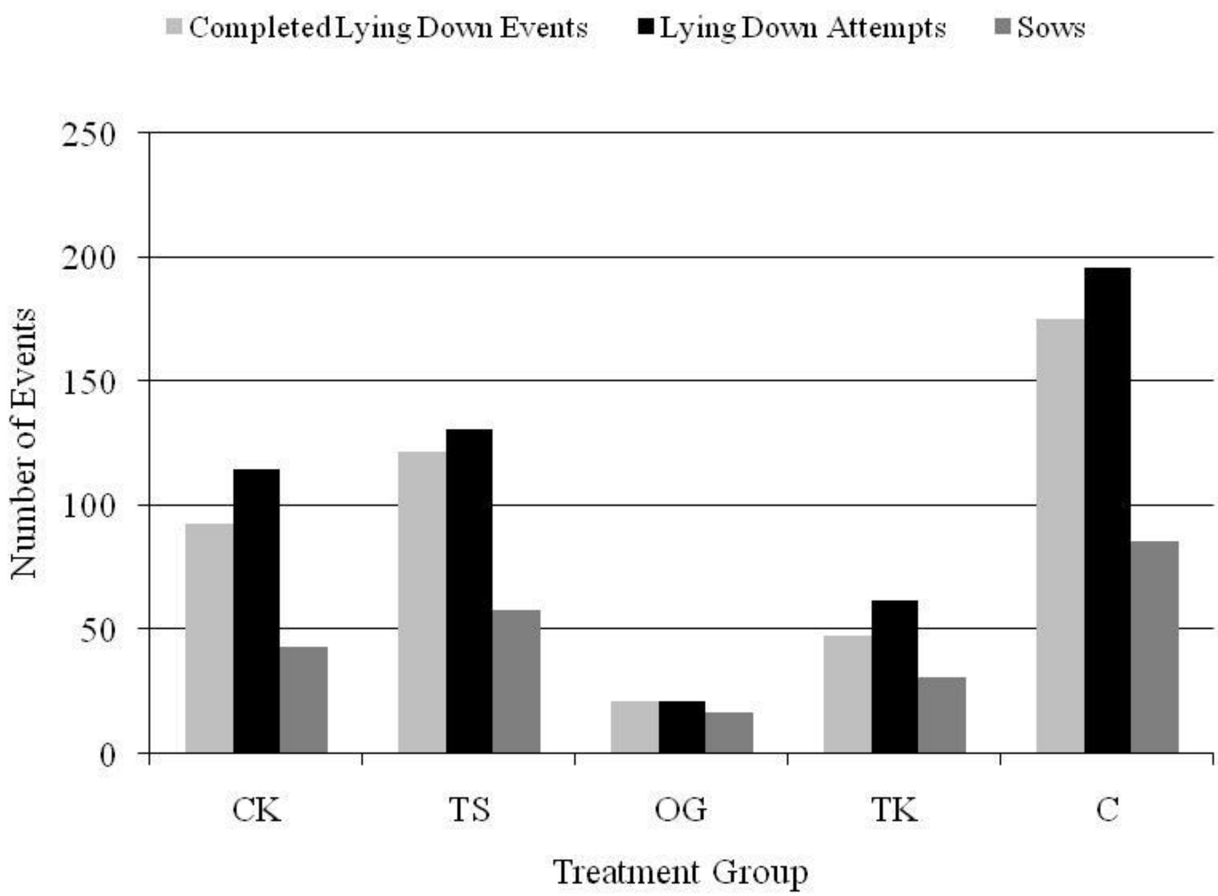


Figure 1.5. The number of completed and attempted lying down events during a 105 min observation period and the number of sows by treatment group in an evaluation of the effects of toe abnormalities on lactating sow[1] performance from a Midwestern U.S. swine integrator.

[1]Sows (Newsham Supermom, Des Moines, IA) were categorized as having overgrown toes [OG], differences in toe length [TS], hoof cracks [CK], both hoof cracks and toe size differences [TK], or normal hooves [C] and assigned a severity score of 0 to 3. No behavior data were collected for the OG 3 group because of the low prevalence of this severity on Farm A.



Objective II

The two images listed below were representative of hooves described as normal (control) in the present study. At least two quality images were obtained for each severity score within each lesion.

Normal hooves

Objective III

The original literature search produced 1560 articles. A total of 414 duplicate articles were removed. Following removal of the duplicates, the 1146 unique articles were reviewed for relevance. The relevance screen eliminated all but five articles. A single non-English article, published in Portuguese, passed the relevance screening. The article was fully translated with online resources and the translation validated by a blinded native speaker. The native speaker was given the article in Portuguese only and was not given access to the translated version to control for bias.

The five relevant articles were subjected to the quality screening criteria. Two articles were removed due to not meeting the intervention criteria. Two articles were removed due to not randomizing treatments. A single article met all of the quality criteria. Wentz et al.[16], detailed the treatment and control populations, the prevalence and severity of lameness at the onset and completion of the trial, and utilized a field setting for this study.

Wentz et al. (1991) randomized penned groups of sows between two treatments. The intervention treatment utilized a 10% formalin footbath, two or three times a week, applied to the exterior anatomy of the hoof for a five week period. The control group received no footbath treatment. Results showed significant differences in the increased prevalence of sows without clinical lameness ($P < 0.05$) and a reduction of 'severe category' clinical lameness ($P < 0.05$).

Discussion:

Objective I

General lesion description. In this study, the rear hooves were the major location of all hoof cracks, toe size differences, and overgrown toes, and these results are supported by those previously reported studies (Gjein and Larssen, 1995; Stienezen, 1996). The minimum differences in toe length for sows to be categorized as TS 1, 2, and 3 were 1.3, 1.9, and 2.5 cm, respectively, and this difference occurred between the toes of the rear hooves. Penny et al. (1963) performed post-mortem examinations at a slaughter house on 31 mixed breed and gender pigs that had a lesion in the lateral foot and measured medial and lateral toe length. They observed a lateral to medial ratio of 1.11:1 for length and 1.13:1 ratio for width. They also reported a difference in shape, as the lateral toe tended to be more rounded and the medial pointed. Further, they observed that most lesions were localized to the lateral toe of the rear hooves.

The average lesion scores on Farm A and B were 1.5 and 2, respectively, and 11.8% of the lesions evaluated were in the most severe score. There were very few extreme lesions evaluated and this likely made it difficult to greater differences in performance or behavior. Boyle (1996) evaluated toe length for 133 mixed parity sows in a research herd and 3512 sows in commercial herds. Of the sows evaluated on commercial farms, Boyle reported that greater than 1 % and less than 0.5 % of the sows had severe overgrown lateral and medial toes, respectively. Larger percentages were recorded for mildly overgrown lateral (> 10 %) and medial (7 %) toes from that same study. Further, Boyle also reported that the greatest prevalence of sows' overgrown toes on the rear hooves occurred in parities 4 to 6 in the research herd were the investigation took place.

Most of the hoof cracks in the present study were localized to the rear hooves; however, crack length, severity, and type varied. One plausible reason for the greater prevalence in the rear hooves is that some of the sows were observed to place either the lateral or medial toe of the rear hooves between the concrete slat flooring. If sows placed a large amount of weight or had to move suddenly, this could result in an abnormal amount of weight on a part of the outer hoof wall that might not be accustomed to bearing that weight. Also, another hypothesized reason is the difference in microenvironment between the front and rear feet. The rear feet are in a microenvironment where percent moisture may be greater as well as the presence of manure. The longest recorded hoof crack was 5.1 cm long. Most of the sows assigned to the most severe hoof crack score had obvious separations (where a fingernail or larger could be placed in the crack) in the outer hoof wall. In these cases, cracks could allow bacteria and other pathogens to infect the hoof, potentially affecting other body organ systems and moreover impacting sow performance (e.g. lower milk production during lactation, lower feed intake, etc.). Similarly, Penny et al. (1963) observed hoof crack variation ranging from shallow, discolored indentations to, as described by Penny et al. "a deep fissure, with marked enlargement and deformity of the claw." In the present study, 7 of the 38 sows having cracked toes were classified in the most severe category. Further, length of hoof crack might not be the most accurate method to determine hoof crack severity, and future studies might consider more objective assessments that might be more correlated to pain or discomfort to assign sows to severity scores. In this study, inaccuracies in determining true hoof crack severity may explain the unexpected results for some behavior traits.

Performance. Partial regression coefficients for number born alive were not significantly different than zero for all treatment groups compared to the control. Similar observations were made for litter size and weight at cross-fostering for all treatment groups, suggesting that sows of all scores started the experiment with approximately the same litter size and weight.

During lactation, CK and TS sows were associated with increased piglet mortality compared to control sows, and subsequently, were associated with weaning fewer piglets per litter. As lesion scores increase for OG sows, sows were associated with spending less time kneeling when lying down. This observation coupled with no additional attempts needed when lying down suggests that these sows have the least controlled movements when lying down. Bonde et al. (2004) reported that sows with overgrown rear toes were 11.5 times more likely to show abnormal lying down behavior than sows with normal hooves. Thus, unexpectedly, lesion scores for sows in the OG group were not associated with an increase in piglet mortality.

Each lesion score increase for sows in the OG group was significantly associated with 2.1 kg less adjusted litter body weight at weaning. For the 22 OG sows in this study, this would equal 71.3 kg less piglet weight at weaning. Multiplying the partial regression coefficients for each treatment group times the number of sows within each severity score (an average of TS and CK coefficients was used for TK sows), 144 treatment sows weaned a total of 215 kg less piglet body weight compared to control sows. Commercial sow farms frequently record the number of piglets weaned per litter, piglet mortality during lactation, and other easily obtained measurements for sows during lactation and use that data for culling criteria. However, most farms do not weigh individual litters at weaning due to the expense associated with obtaining that data. Thus, the adjusted litter weaning weight might have the most unnoticed consequence of hoof lesions in many commercial swine production systems.

Sow Behaviors and Postures in Experiment 1. Sows classified in the OG group spent less time standing and eating as lesion severity increased when compared to control sows. This observation is concurrent with findings previously reported. Stienezen (1996) compared the behavior from stall-housed sows with overgrown rear toes (13 sows, 6.8 cm average length of rear toes) to a control population (11 sows, 4.8 cm average length of rear toes) during farrowing and lactation. Steinezen also reported that sows with overgrown rear toes spent less time feeding (8.2 vs. 14.5 min, respectively) and standing (4.2 vs. 11.4 min, respectively), slipped more with the rear hooves while standing (0.9 vs. 0.2 times / min), and needed more rising attempts (2.3 vs. 1.3) when raising from the lying down to the standing position when compared to control sows. In that study, sows with overgrown toes tended to produce smaller litters at birth compared to the control sows (10.5 vs. 12 piglets born alive, respectively). Further, in that study, a large range of behaviors was observed and that a great amount of individual variation existed. They suggested that lack of exercise was the major contributory factor to the development of overgrown toes, which is also supported by Vaughan (1969). However, the authors of the present study suggest that overgrown toes are often accompanied with overgrown dew claws. Dew claws do not typically touch the ground in an animal that is structurally correct (NHF, 2004). Hence, the lack of exercise contribution to overgrown toes or dew claws or both is not likely the cause for this condition. A study by Leonard et al. (1997) found that sows' feeding and standing time decreased and weight shifts and slipping increased among sows with overgrown rear toes. These findings indicate that sows with overgrown rear toes exhibited signs of discomfort and, thus, decreased the amount of time weight was distributed on the limb with the affected hoof or toe.

Sows categorized in the CK and TS groups averaged more time standing and eating when compared to control sows. One plausible explanation for this is there were an insufficient number of sows receiving the most severe lesion score, and the performance of these sows was diluted by sows with less severe hoof cracks or toe size differences in order to accurately estimate the effects. For TS sows, toe lengths have not yet reached the lengths required to be classified as OG. Therefore, with time and further growth of the toes, some of the sows might be classified as OG and thus the associated loss in performance may occur.

Sow Behaviors and Postures in Experiment 2. Sows spent between 3.3 and 9.1 % (mean = 5.7 %) of the 24-h day with her head in the feeding trough. In this group of 10 sows, eating occurred only while standing as opposed to eating that can take place when a sow is in the sitting position. Eating was the primary activity recorded while standing, ranging from 55 to 91 % of the time spent standing. Producers should identify sows standing for an excessive amount of time after feeding (2 standard deviations above the mean equals 29.4 min post feeding) and confirm that there are no environmental impediments such as inappropriately placed bars or sharp objects that prohibit sows from lying down. Sows appeared to have a preference for the side when lying laterally, after successfully lying down; however, averages of time spent lying laterally on each side over the 10 sows appeared relatively equal between both the right and left side.

In conclusion, this study indicates that litter weaning weight adjusted for on-test weight and number of piglets at cross-fostering was negatively associated with lesion score increases in OG (P = 0.03), CK (P = 0.07), and TS (P = 0.39) sows. There was no evidence that sows with hoof lesions produced fewer number born alive. Sows with overgrown toes were associated with standing less time after feeding, and this result is consistent with previously reported findings. Increased piglet mortality during lactation was associated with an increase in CK and TS severity score, and thus, sows from those treatment groups weaned fewer piglets per litter.

Objective II

Images obtained during the present study will be utilized in extension presentations and publications to educate swine producers on the type and severity of hoof lesions present in swine herds. Also, unique observations were made while photographing sow hooves. In some cases, the lateral claw was observed to be placed between concrete slats in the gestation stalls or between mesh flooring connections in the farrowing stalls. In these cases, sows may use these gaps as anchor points when slipping which may cause hoof cracks. The image library will be maintained at Iowa State University and image requests can be made through the National Pork Board.

Objective III

The literature search produced five articles which met the relevance criteria based on reporting lameness in the treatment population, but only the Wentz et al. (1991) article randomized the treatments and recorded the pre and post-intervention lameness prevalence. Two articles which passed the relevance screening failed to list that the subjects were randomly assigned to the treatments. The study design of the articles lent itself to randomization, but without the explicit description this can only be assumed. This critical point could be used to improve the reporting of results in many of the articles found by the literature search.

Four of the articles removed during relevance screening referenced foot lesions but did not associate this back to a clinical lameness condition. This lack of association can lead to an underrepresentation of the treatable condition.

The relevance screening criteria used in this systematic review allowed for the maximum number of articles to be preserved for quality screening. The wording of the lameness condition would allow for an article that did not directly reference lameness but one that highlighted a specific foot care procedure to pass to quality screening. This article would fail at the quality screening level due to the lack of description of the lameness condition. This point could be included in either the relevance or the quality step, but inclusion of the foot care element allowed for all studies with application to a lameness treatment to receive the fullest consideration prior to elimination.

The systematic review process in this study revealed no blinded, randomized control trials relevant to the study question. The highest level study surviving the quality screening was an intervention study. Intervention studies are common in swine research with field settings and were accepted for analysis in this systematic review to increase the external validity of the final conclusion to modern producers even though they do not represent the highest level of evidentiary value. Caution must be taken when drawing conclusions with this type of study design as control of bias is not always included.

Additional quality criteria, not used to evaluate papers in this systematic review that would further strengthen the quality of the research include: blinding observers to the administration or analysis of treatment data, highlighting and balancing for known confounders, and justification of the sample size. Wentz et al. (1991) utilized a foot bath treatment without a negative control footbath which prevented blinding the personnel from treatment status. This could potentially introduce bias in the observers reporting the severity of the clinical lameness condition of the animals. Wentz et al. (1991) indicated that the animal housing pens were randomly selected for treatment assignment however, the method of randomization and any potential confounders were not highlighted. Wentz et al.[16] further did not highlight the frequency that the footbath solution was refreshed, any differences in the distance the animals traveled to reach the bath nor whether the order the animals entered the bath (within the pen) was randomized. As animals enter the footbath, fecal material can be introduced or the solution may be removed from the bath thereby making the volume and or concentration of the formalin solution variable for each group of animals. Both conditions could further under represent the impact of the treatment. The use of formalin in the footbaths represents a topical treatment to address the lameness in sows. The main component of 10% formalin (37% formaldehyde) is a known carcinogen and can present human safety hazards with routine use. It is also unknown if the compound can be absorbed into the tissues or blood stream of the sows over time thereby potentially creating a food safety concern. Improper handling or incorrect disposal of formalin can also pose adverse environmental impacts. The only article that passed the relevance and quality screens (Wentz et al. 1991) was published in Portuguese. While this article did utilize a field setting of undefined geographic origin, there may be substantial differences between the study settings and those in the United States. The authors of this systematic review aimed to provide maximum external validity of the summarized results to US producers, but this article may itself introduce bias based on the parameters of the referenced field setting. While a significant improvement in lameness was demonstrated in a single study; the frequency of use, the amount of animal movement required and footbath refreshment rate could be constraints on some farms due to limited labor resources or may also be cost prohibitive depending on the treatment. This systematic review showed that the use of a formalin footbath can improve lameness in sows. However, this conclusion only represents one study. The results of this systematic review highlighted the low number of articles that are available which can specifically address the question of the effectiveness of the treatment of lameness in sows. Only five articles met the stringent relevance standards set by this systematic review. Other articles found by the literature search addressed foot lesions without reference to the effects on lameness or without the details needed to accept the study in the quality screening analysis. This lends credence to the adoption of the systematic review process in veterinary and agricultural research studies to help determine what research has been conducted and to improve the overall quality of studies and articles in publication. Implications for producers include:

- Footbaths may be an option to improving overall foot health and clinical lameness prevalence, but they need to be used at a high frequency to assure maximum benefit.
- High evidentiary level studies (blinded, randomized control trials) evaluating the treatment of lameness are scarce
- The use of the systematic review process can help determine what evidence is available to guide future research on a given topic. This can then help with the refinement of study design to collect and report the highest quality data.

References

Anil SS, Anil L, Deen J. 2001. Evaluation of patterns of removal and associations among culling because of lameness and sow productivity traits in swine breeding herds. J Am Vet Med Assoc.226:956–961.

Anil, L., S. S. Anil, and J. Deen. 2001. Stall housing for pregnant sows: Size and injury levels. In: Allen D. Leman Swine Conference. pp 185-186.

Bonde, M., T. Rousing, J. H. Badsberg, and J. T. Sorensen. 2004. Associations between lying-down behaviour problems and body condition, limb disorders and skin lesions of lactating sows housed in farrowing crates un commercial sow herds. Live. Prod. Sci. 87:179-187.

Bryant KL, Kornegay ET, Knight JW, Veit HP, Notter DR: Supplemental biotin for swine. 3. Influence of supplementation to corn- and wheat-based diets on the incidence and severity of toe lesions, hair and skin characteristics and structural soundness of sows housed in confinement during four parities. Journal of Animal Science 1985; 60(1): 154-162.

Corr, S. A., C. C. McCorquodale, R. E. McGovern, M. J. Gentle, and D. Bennett. 2003. Evaluation of ground reaction forces produced by chickens walking on a force plate. Am J Vet Res 64: 76-82.

Davies, P. R., W. E. M. Morrow, D. C. Miller, and J. Deen. 1996. Epidemiological study of decubital ulcers in sows. J. Am. Vet. Med. Assoc. 210:1173-1157.

Fjeldaas T, Sogstad AM, Østera O. 2006. Claw trimming routines in relation to claw lesions, claw shape and lameness in Norwegian dairy herds housed in tie stalls and free stalls. Preventive Vet Med. 73:255–27.

Gjein, H., and R. B. Larssen. 1995a. Housing of pregnant sows in loose and confined systems--a field study. 2. Claw lesions: Morphology, prevalence, location and relation to age. Acta Vet Scand 36: 433-442.

Gjein, H., and R. B. Larssen. 1995b. Housing of pregnant sows in loose and confined systems--a field study. 3. The impact of housing factors on claw lesions. Acta Vet Scand 36: 443-450.

Knauer, M. 2006. Factors influencing sow longevity, Iowa State University, Ames. M.S. Thesis.

Knauer, M. Stalder KJ, Karriker L, , Baas TJ, Johnson C, Serenius T, Layman L, McKean JD. 2007a. A descriptive survey of lesions from cull sows harvested at two Midwestern U.S. facilities. Prev. Vet. Med. 14;82(3-4):198-212.

Knauer M, Karriker LA, Baas TJ, Johnson C, Stalder KJ. 2007b. Accuracy of sow culling classifications reported by lay personnel on commercial swine farms. Am Vet Med Assoc. 231:433–436.

Leonard, F. C., I. Stienezen, and P. B. Lynch. 1997. Behaviour of sows with overgrown hooves in the farrowing house. In: Agriculture Research Forum, Dublin

MAFF. 1981. Injuries caused by flooring: A survey in pig health scheme herds. Proc Pig Vet Soc 8: 119-125.

Main, D. C. J., J. Clegg, A. Spatz, and L. E. Green. 2000. Repeatability of a lameness scoring system for finishing pigs. Vet. Rec. 147: 574-576.

Misir R, Blair R. 1986. Effect of biotin supplementation of a barley-wheat diet on restoration of healthy feet, legs and skin of biotin deficient sows. Res Vet Sci. 40(2): 212-8.

Ritter, L. A., J. Xue, G. D. Dial, R. B. Morrison, and W. E. Marsh. 1999. Prevalence of lesions and body condition scores among female swine at slaughter. J Am Vet Med Assoc 214: 525-528.

Rountree, W., M. Morrow, and P. Davies. 1997. Observational studies of shoulder ulcers in sows. 261-264. Quebec City, Quebec, American Association for Swine Practitioners.

Smith. 2007. Effects of frequent functional foot trimming on the incidence of lameness in lactating dairy cattle. The Bovine Practitioner 41(2):138-145.

Smith, B. 1988. Lameness in pigs associated with foot and limb disorders. In Pract. 10: 113-117.

Stalder, K. J., M. Knauer, T. J. Baas, M. F. Rothschild, and J. W. Mabry. 2004. Sow longevity. Pig News Info. 25: 53N-74N.

Stalder, K. J., C. Lacy, T. L. Cross, and G. E. Conatser. 2003. Financial impact of average parity of culled females in a breed-to-wean swine operation using replacement gilt net present value analysis. J. Swine Health Prod. 11: 69-74.

Stienezen, I., and N. Leonard. 1996. Welfare of confined sows with overgrown hooves in the farrowing house. Unpublished work.

The Cochrane Collaboration. http://www.cochrane.org/index.htm Accessed April 24, 2009.

Stalder KJ, Knauer M, Baas TJ, Rothschild MF, Mabry JW. Sow Longevity. 2004. Pig News and Information ;25(2):53N – 74N.

Wells, G. A. H. 1984. Locomotor disorders of the pig. In Pract. 6: 45-53.

Wentz I, Sobestiansky J, Silveira PRSd, Munari JLP, Freitas ARd: Efeito de pediluvio com solucao de formalina associado a desgastamento do piso, sobre o quadros clinico de porcas com afeccoes podais. 1991. Effect of footbath treatment with formalin solution along with smoothing of the floor surface on the clinical picture of pigs with lameness. Brazilian Journal of Veterinary Research and Animal Science 28(2): 231-234.

Publications, presentations or abstracts from the project:

Meetings:

Johnson, A. K. 2007. Hosted the Japanese Ministry of Agriculture Fisheries and Food and National Pork Producers Council from Washington D.C. Spoke about the swine well-being research initiatives, teaching and extension activities as well. Students: Berry, Fitzgerald and Goldsmith presented, in addition Dr. K. Stalder presented the sow productive lifetime posters and the extension related activities. April 11th 2007.

Stalder, K. J., R. F. Fitzgerald, A. K. Johnson, L. A. Karriker, and D. Meisinger. 2007. A summary of the 13th Discover Conference on sow productive lifetime. National Swine Imprv. Fed. Conf. Annu. Mtg. Kansas City, MO, December. 2007.

Stalder, K. J., T. Serenius, R. Fitzgerald, L. Karriker, and A. Johnson. 2007. Evaluation of body condition and feet and leg soundness on sow productive lifetime. Sow Productive Lifetime. ADSA. September 10th – September 13th 2007. Brownsville, IN.

Stalder, K. J., R. F. Fitzgerald, A. K. Johnson, L. A. Karriker, and D. Meisinger. 2007. A summary of the 13th Discover Conference on sow productive lifetime. Record of 32nd Proc. National Swine Imprv. Fed. Conf. Annu. Mtg. Kansas City, MO, Dec. 6 – 7 2007.

Media:

Johnson, A. K., and R. F. Fitzgerald. 2009. Overall mouth health: How could this affect the sows productive lifetime? Farms.Com

PhD Thesis:

Fitzgerald, R. F. 2009. An evaluation of practices to improve sow productive lifetime
and producer profitability. Iowa State University, May 2009.

Peer review papers

Fitzgerald, R. F., K. J. Stalder, P. M. Dixon, A. K. Johnson, L. Karriker and G. F. Jones. 2009. The accuracy and repeatability of sow body condition scoring. Professional Animal Scientist 25:415-425.

Coming in 2010:

We anticipate in 2010 to 2011 having two peer review abstracts written on this work. We also plan on writing three Animal Industry Reports and one article for the National Hog Farmer. In addition Dr. Fitzgerald is completing a peer review paper for submission to the Journal of Animal Science; Fitzgerald, A. K. Johnson, L. Karriker, L. Sadler, and K. J. Stalder. 2009. Comparison of behavior and performance of sows with and without hoof abnormalities. Plan to submit to the Journal of Animal Science.