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Lameness: a principle problem to sow longevity in breeding herds

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Keywords

Lameness, longevity, productive lifetime, sow

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Lameness: a principle problem to sow longevity in breeding herds (a review)

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Abstract

The objective of this article is to review causes of lameness lesions, lameness detection methods, factors affecting lameness, association between lameness and other economically important swine production traits, and treatment for lameness in swine breeding herds. Lameness in sows is an important welfare and economic challenge to pig producers. It has been reported to be the second most common reason for involuntary culling of sows which directly impacts sow longevity / sow productive lifetime. Factors affecting the prevalence and severity of gilt and sow lameness breeding herd are housing type, flooring type, toes / dewclaws management, genetic effect for feet and leg conformation, and nutrition especially mineral supplements. Sow preference and behavioral response to flooring type may be likewise be affected by lameness onset, duration, severity and location. To avoid unnecessary distress and associated financial losses, early treatment of lameness observed among the females in the gilt development unit and in the breeding herd is necessary. The key factors listed previously are the foundation to a proper prevalence strategy. However, this review shows that additional research is still needed, especially studies to accurately evaluate lameness lesions, examine nutrient requirements for optimum foot health, investigate genetic effects on feet and leg conformation, clearly define the supplemental vitamin or / and mineral levels and duration for usage. All of these factors may influence breeding herd lameness and may contribute to more consistent and comparable results from sow herd.

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Introduction

Over recent decades, genetic improvement of pigs has focused on production (growth, lean and meat quality; [1]) and reproductive traits (age at puberty and litter size; [2-3]). The economic relevance for functional traits, such as sow longevity, has increased during recent years as well [4], given its close relationship with culling / replacement costs. A sow remaining in the breeding herd for fewer parities is likely to produce fewer pigs in her lifetime, compared to a sow remaining in the breeding herd for a longer period time [5]. Sow longevity has been the subject of intensive research [6-7]. Sow longevity can be viewed as a critical indicator of animal welfare [8-9], but has likewise been shown to be related with both production traits [10-11] and some morphological traits, such as leg conformation [7]. Data from 2011 to 2016 indicated that the total annual culling and death rate was 45.7 to 47.4 % for sows and 8.3 to 13 % for gilts, respectively [12-13]. Locomotor problems are a major reason for culling in swine herds [5, 14-15] with a reported culling rate of 15.2% in US swine herds [16], 16.9% in England [17], 9.7% in Belgium [18], 15.5% in Southern Mexico [19] , 9 to 15% in Sweden, Finland and Denmark [9, 20-21], 22.5% in southern of People's Republic of China [22] and 37.4% in Thailand [23]. Because females with feet and leg problems are normally culled from the breeding herd in the early parities, many sows do not remain in the herd long enough to be sufficiently productive "to pay for themselves". The average parity at removal from breeding herds due to locomotion / feet and leg problems was 2.6 parities [24]. Consequentially, breeding herds usually have high proportions of low-parity females [25]. This problem usually results in a mean parity between 3 and 4 at removal [24-25].

Sow culled because of lameness are removed at a younger age when compared to sows removed for other reasons. Early removal of sows from the herd results in lower mean litter size, number of litter per sow per year, and number of pigs weaned per sow per year, thus increasing the cost per weaned pig [19, 24]. Economic loss estimates, calculated in 2011, due to lameness in the United States was over $23 million per year [25]. A better understanding the risk factors effects, effective lameness detection and improved lameness treatments would augment efforts to minimize lameness and associated costs in order to increase sow's productive lifespan and improve the profitability for swine operations. The objective of this article is to review causes of lameness lesions, lameness detection methods, factors affecting lameness, association between lameness and other economically important swine production traits, and treatment for lameness in swine breeding herds.

Causes of sow's lameness

Lameness is both a welfare issue of great concern and a major source of economic loss in pig production [26-28]. Additionally, lameness is likely associated with pain and distress in the animal [28]. Lameness can be caused by several factors, ranging between limb malformation, toe lesions, trauma, different manifestations of osteochondrosis, arthritis and infected skin lesions [29-31]. Among these reasons, osteochondrosis is a major factor contributing to leg weakness in pigs [20, 32-33]. Osteochondrosis is almost ubiquitin pigs and is a clinically important joint disorder that results from a failure of the articular cartilage and the growth plate to properly ossify. There is likely to causes the articular surface to become deformed, which then leads to abnormal conformation and locomotion traits [32-33]. Ytrehus and coworkers [33] stated that the most commonly cited etiologic factors for osteochondrosis are heredity, rapid growth, anatomic conformation, trauma, and dietary imbalances. Moreover, biomechanical pressure within the joints may be involved in osteochondrosis development [34].

Several studies have reported correlations between osteochondrosis, conformation and locomotion traits including gait characteristics [20, 32, 35]. Research has focused on results obtained from post-mortem examination for several leading causes of lameness, which better allow the differentiation among these various causes [36]. In breeding-age sows, differential diagnosis of lameness includes toe lesions, trauma, and manifestations of osteochondrosis, osteomalacia, fractures, skin lesions and arthritis [17, 21, 29, 36-37].

In addition, numerous pig-related risk factors have been identified as contributing to the development of shoulder lesions, including lameness [38]. Anil and coworkers [39] studied 162 sows from four the United States farms and reported that shoulder lesion development had associated with lameness ($P<0.05$). Rioja and coworkers [38] reviews that inflammatory of shoulder lesions may be linked to increased lateral decumbency, are more common in lame sows [40].

General approaches for lameness detection

Lameness assessment can be based on gait analyses, postural behavior or weight distribution [41-42]. Gait and locomotion evaluation for gilts and sows is measured by visual appraisal, as a subjective method, and electronic or automatic detection systems, as an objective method. Locomotor scoring was assessed using the gait and standing postures [44]. Lameness scoring is distinguished from non-lame sows to focus mainly on clearly identifiable lameness (Table 1).

Table 1 Lameness scoring system used to assess lameness in sows

Year	Country	N[1]	Score	Clinical sign	Reference
1993	USA	50[b]	0 to 9	None (0), stiff gait (mild (1), moderate (2), and severe (3)), lame (mild (4), moderate (5), and severe (6)), requires assistance to stand and then can walk (7), can stand with assistance but then falls (8), and cannot stand with assistance (9)	[36]
2004	Denmark	352[a]	1 to 4	None (1), stepping frequently while standing (2), attempt to relieve limb (3), and reluctance to bear weight on limb (4)	[21]
2009	UK	24[b]	0 to 1	None (0), and lame, difficulties walking but using all legs, stride may be shortened or / and there may be swagger of the caudal part of the body when walking (1)	[45-46]
2000	USA and UK	29[b]	0 to 5	None (0), stiff (1), lameness detection (2), minimum weight bearing on affected limb (3), affecting limb on the floor while moving (4), severe or does not move (5)	[44]
		85[a]			[47]
		36[a]			[48]
		128[a]			[49]
2016	Germany	212[a]	0 to 2	None (0 or 1), and clearly visible lameness (2)	[31]
2017	Finland	13[b]	0 to 4	None (0), minimal (1), slight (2), moderate (3), and severe (4)	[50]

[1]N=Number of animal in the studies, a=both non-lame and lame sows, and b=only lame sows

Subjective visual scoring has the advantage to be low cost and routinely easy to implement on farm, but has high variability in repeatability, depending on observer training and experience [44, 51]. Therefore, research has been conducted to develop more objective methods for studying locomotor problems in pigs [52-54]. The researchers used video of sow behavior and posture, such as foraging, drinking, standing, sitting, lying sternal, lying lateral on both sides and across different times to record several these measurements. Recorded measurements for each video were analyzed, considering the front and rear limbs separately, by software program (Mesurim Pro 3.3 or Equine-Tec ™). Grègoire and coworkers [52] and van Der Tol and coworkers [55] applied kinetics and kinematics for locomotor measurements. These studies have largely used horses and cows in their experience. Kinetics aims to relate body motions of bodies to its causes and takes into account dynamic forces and acceleration and it is often studied using force plates or pressure mats to measure weight distribution on feet / toes and limbs [55]. Kinematics consists of analyzing movements without considering its causes [56]. Both of these methods have been used in pigs to evaluate gait [57]. The 3-dimensional coordinate data of utilizing reflective skin markers (kinematics) to identify pigs with abnormalities which had not previously been apparent by visual inspection [46]. Other methods have been reported [54], which utilized footprint analysis that were determined using a high-resolution floor mat to record foot pressure for gait in pigs. These objective methods provide precise information on gait, but they are quite time-consuming and technically complex [52]. Mohling and coworkers [56] and McNeil and coworkers [58] used embedded force plates as objective assessment tool to detect lameness and an automatic lameness detection system has been used in group-housed gestation sows where a sensor was placed in the sow's ear in order to capture both position and acceleration. They suggested the use of ear sensors as an objective and easy-to-use method to detect changes in the sow's activity pattern and its utilization is not limited to experimental farms [56]. McNeil and coworker [58] suggested that recorded data for 1 min could be used as the minimum time required to accurately assess lameness for each individual animal. This research can be used to efficiently improve the embedded micro-computer-based force plate for lameness evaluation.

Although still in the early stages of research and development, genomic marker research for lameness in ruminant animals and poultry can provide a comprehensive insight into pathophysiological processes as well as more precise predictors of disease outcome not previously attainable with protein or biochemical biomarkers [59]. This work should be extended to other species including swine. In livestock, a molecular diagnostic assay (peripheral blood mononuclear cells; PBMCs) using clinically accessible tissue, such as blood, could greatly assist with detecting painful inflammatory lameness in dairy cows [60]. Researchers [61] collected blood samples from six healthy Holstein cows and six cows with clinical signs of lameness to assess differences in protein and cytokine blood parameters. They reported that cows affected by lameness had pronounced greater lactate, interleukin (IL)-6, serum amyloid A (SAA), and lipopolysaccharide-binding protein (LBP) concentrations in the serum when compared to healthy cows. A bead-based affinity matrix (ProteoMiner™) containing a library of hexapeptides was used to deplete high abundant proteins and enrich the less abundant proteins in order to compare between the sera from six week-old normal chicks with chicks that had a common lameness problem called tibial dyschondroplasia [62]. Skiöldebrand and coworkers [63] have analyzed cartilage oligomeric matrix protein (COMP) neoepitope concentrations using a custom-developed inhibition enzyme-linked immunosorbent assay (ELISA) between 15 normal and 17 lame horses. They stated that this method has the potential to be a unique candidate biomarker for the early molecular changes in articular cartilage associated with acute lameness. Utilizing biomarkers for lameness detection in other livestock species are beneficial concepts that might be applied to pork production in order to accurately detect lameness in the future.

Economic loss of lameness

Economic losses due to lameness increases labor (time to move, monitor and treat lame sows), higher veterinary costs, negative impacts on reproduction, premature removal from the breeding herd [64-65], loss salvage value due to on-farm euthanasia, and greater slaughter condemnation [66-67]. In addition to the impaired welfare, lameness is related to financial loss estimated at $180 per lame sow in the United State [68] and €20-37 per lame sow in Germany and the Netherlands [67, 69]. The authors [70] calculated economic losses that were found when sows were culled because of lameness / leg weakness, averaging about €83 per culled sow.

A high culling rate has been associated with a greater potential for health and welfare problems in the sow herd [15, 42]. It also adds to financial losses, because involuntary culling results in the immediate need to replace culled sows with new replacement gilts and the loss of income that would have been realized through slaughter [14, 42]. Dijhuizen and coworker [70] have reported that sows removed from the herd due to lameness were younger than sows removed due to other reasons. Further, it has been estimated least 3 litters are required from a sow before the producer gets a positive net present value for the gilt investment [65]. This suggests that many sows leave the breeding herd before they have “paid for themselves”.

Factors affecting of lameness

Factors as a housing system, a flooring type, toes or dewclaws management, genetic, nutrition, and body condition score (BCS) are focused on the principle effects for sow's lameness. These factors for sow's lameness and avoidance from scientific literature can be classified and showed in Table 2.

Table 2 Factors affecting sow's lameness and avoidance

Factor	Main topics	Avoidance	Reference
Housing system	Housing type	Conventional indoor housing, and individual stall	[77-84, 91-92]
Floor type	Dirty floor Space allowance Slatted floors	Cleanness, slipperiness, optimum space allowance, and suitable floor of group size Rubber mat might be applied.	[49, 83, 95-100]
Toes or dewclaws management	Overgrown toes or dewclaws	Functional trimming	[42, 54, 102-104]
Genetics	Heritability estimates: leg conformation (0.02 to 0.20) and osteochodrosis scores (0.06 to 0.31)	Monitoring genetic potentials for leg conformation and locomotor traits in a herd	[28, 32, 106, 110-111]
Nutrition	Lack of some minerals (Ca, P, Zn, CU, and Mg)	Consideration for optimum nutritional requirements for bone development, and joint and toe health	[116-118]

a. Housing system

The well-being of sows under human care has gained importance among producers in recent years because of public demand to ensure humane treatment and the need for producers to remain viable and competitive in the market [71]. Type of housing system is the most of the challenges to sow well-being in the breeding herd [18, 71-75]. There are mainly two types of gestation housing systems for swine utilized by swine producers in the United States: conventional gestation stalls as individual or group-housed pens. Another type of housing systems such as hoops and outdoor systems is also utilized, but represent a smaller percentage the total breeding herd females housed when compared to the levels of the previously mention systems throughout the United States [71].

Cox and Bilkei [76] has reported that 19% of conventional and 26% of outdoor sows were culled in response to locomotive disorders in Croatian herds. Other studies have reported higher occurrence levels for locomotive disorders in conventional and outdoor-housed sows than the previous study [77], with 25% of culling in indoor systems and 39% of culling in outdoor systems being attributable to lameness. Further, other studies have reported significantly lower percentage of sows were culled in indoor herds as a result of locomotive problems when compared to culling level of sows housed in outdoor herds ($P<0.05$) [78]. The researchers suggested that free-range housing increased the risk of acquiring osteochondrosis in the elbow and hock joints of fattening Swedish pigs [79] and lameness in growing-finishing pigs in Denmark [80]. These studies are in disagreement with other research [81] that examined differences in the prevalence of sow lameness between outdoor organic and indoor conventional herds in Denmark. The organic sows had a decreased risk of lameness when compared with indoor conventional sows (odd ratio=0.28, $P<0.001$). It has been reported that sows cannot walk and turn around in conventional indoor system using gestation crates [71]. The spatial restriction observed increases as the size of the sow increases during pregnancy and gestation crate systems have been criticized for being non-conducive to the well-being because sows that are housed in gestation stalls lack freedom of movement and environment stimuli [82-84]. Using the gestation stall housing system for sow's entire gestation period has become a cause of concern for animal welfare activists.

An alternative to gestation stall housing systems is to house pregnant sows in groups. This sow housing system has been mandated in all European Union member states since 2013 [83]. In the United States, the progress to ban confinement stall use to house sows during pregnancy is presently under intense debate. The state of Florida had voted against the using of gestation stalls [85]. However, group housing may present welfare issues, including injuries caused by post-mixing aggression and a higher lameness prevalence [86-88]. Most lameness cases during group housing develop shortly after the sows are introduced into the group [27, 88-91]. It has been reported that the lameness incidence is 10% within the first month after mixing [90]. Group housing has additional disadvantages such as losing individual sow feed intake control and aggression between sows, both of which may affect sows' well-being. Efforts have been made to modify group housing systems, mainly by providing individual feeding facilities such as electronic sow feeders (ESFs), which are expensive for producers [71]. Group housing that utilize ESFs may improve sow well-being by providing increased freedom of movement and space when compared with gestation stalls [71]. However, sows group-housed using ESFs have been shown to have increased aggression, injuries and other leg disorders [30, 71, 91-92]. These finding are in disagreement with research [93] that reported that when sows were housed in groups using ESFs, they performed similar to sows housed in gestation stalls, and sustained fewer skin lesions prior to farrowing.

b. Flooring type

Lameness is influenced by additional housing conditions, including floor space allowance, group size and flooring [35, 86, 92, 94]. The impact of space allowance on the development of lameness in group-housed sows from previous studies are inconsistent. A recent study reported that an increase in space allowance from $1.7m^2$ to $3.0\ m^2$ (P=0.03) of herd size from 144 to 750 sows per herd and group size less than 30 sows had significantly decreased the risk developing lameness among the sows housed in this system (P<0.02) [95]. The effect of space allowance on lameness development may be dependent on group size, as demonstrated for finishing pigs [96]. However, stocking density was not affected in gilts because gilts were less aggressive than boars [97]. Bare slatted concrete floors, which are predominantly used for group sow housing, have been associated with lameness development [17, 37, 83]. These studies are in agreement with previous findings [30], that identified that slatted concrete floors were a major risk factor for heel and dewclaw lesions as well as lameness when compared with straw among sows' housed in these systems. Other researchers have reported that toe health deteriorated when sows / gilts were housed on slatted steel when compared to sows housed on cast iron flooring [44].

Slipperiness, abrasiveness, hardness, surface profile, void ratio and cleanliness are the main characteristics contributing to the injury potential for the flooring where sows are housed [30, 98-100]. These authors [49, 100] recognized that comfortable flooring may impact many aspects for an animal's state of well-being, including an animal's lying behavior and its ability to change postures, as well as the incidence of lameness and lesions. Elmore and coworkers [49] used rubber mats (measuring 1.83m x 0.61m x 1.27m) in the sow's feeding stalls. The rubber mat covered half of the pens and were rotated in the opposite direction for pens in each replication. Sows housed in pens where rubber mats were utilized had a lower total lesion score at the end of the experiment when compared to sows housed in pens with concrete floors (P<0.05). However, the environmental temperature needed to be considered when providing rubber mats to cover a portion of the flooring, as higher temperatures might limit their use and thus potential benefits to the sow [49]. The results from study were in agreement with previous research [53] that high frequencies of sow's behaviors (lying lateral, lying sternal, sitting and standing) and low sow's lesion score on mat when compared to other flooring locations (alley and concrete) were reported.

c. Toes or dewclaws management

Toe lesions are one of the leading causes for sow lameness, specifically caused by overgrown toes or dewclaws [54]. Functional trimming to correct toe horn overgrowth and reestablishing even weight distribution across the limb and has been utilized as management practice in some farms [101]. The functional trimming method originated from horse and cattle trimming techniques where five steps were originally developed in the Netherlands [102]. Toe trimming within the swine industry is not a standard practice when compared to the horse, cattle or dairy industries. Results from past sow studies revealed no improvement in longevity or any clear effect on toe lesion development [39]. Tinkle and coworkers [54] reported that functional toe trimming improves gait and locomotion in sows such as swing movement and stride duration, decreases break over time, stance ratio, and velocity ($P<0.05$). These study changes signify more forward movement and increased efficiency of gait following toe-trimming [54]. Sow with overgrown toes show abnormal lying-down behavior [21]. Overgrown toes may crack over time and become infected [103]. Dew claws and toes can become injured or even completely torn off on the slatted flooring when dew claws become torn off, the well-innervated corium will be exposed which can be considered extremely painful for sows [18]. Trimming overgrown toes is an alternative approach when attempting to treat pododermatitis [42] and laminitis [104]. More work examining, the effects of toe trimming on sow longevity / sow productive lifetime are needed. Further, identify the causes for toe overgrowth and implementing mitigation systems to prevent the overgrowth may be practical for pork producers when compared to wide-spread toe trimming.

d. Genetics

Lameness in sows is a painful condition and causes economic losses through decreased longevity, impaired reproductive performance, and involuntary culling [64-65]. Breed effect was studied by researchers [105], who reported that osteochondral lesions in Duroc was more affected with distal epiphyseal cartilage of ulna and condyles medialis femoris, and osteochondral lesions in Landrace was more affected in the condyles lateralis humeri regions. Swiss Landrace showed proportionally more osteochondral lesions at condyles medialis femoris but slightly less at radius and ulna proximal when compared with Large White dam and sire lines [106].

A few studies have reported a genetic effect on lameness trait in dairy cattle and sheep [107-109]. They reported heritability estimates for lameness in dairy cattle ranged from 0.07 to 0.22 [107-108] and 0.06 to 0.12 in sheep [109]. In swine, genetic effect for lameness was not found but some studies reported heritability estimates for feet and leg weakness, leg conformation, and osteochodrosis scores (Table 3). Le and coworkers [28] reported heritability estimates for leg conformation and locomotion traits were low to moderate and it was similar to findings previously reported for the Swedish Yorkshire pig population [32].

Heritability estimates for osteochondrosis scores of the medial and lateral condyles at the distal end of the humerus or the femur from the right and left leg by using information from computed tomography in Norway was reported to be in the moderate range [110]. The authors [111] estimated that heritability for leg structure traits in a commercial herd ranged from 0.07 to 0.31. Heritability estimates for osteochondral lesions at condylus medialis humeri, distal epiphyseal cartilage of ulna, and condyles lateralis femoris ranged from 0.16 to 0.18 in Swiss Landrace and Large White by using linear mixed animal models [106]. The large variation in heritability estimates could be a result of testing scheme, scale for scoring and evaluation subjectivity [27, 111].

Table 3 Heritability estimates (h^2) for leg conformation, locomotion traits and osteochondrosis scores

Traits	Country	System	Breed[2]	h^2	References[1]
Leg conformation	Norway	Scoring (1 to 3)	Y	0.02 to 0.20	[28]
Leg weakness	Sweden	Scoring (1 to 3)	LR, Y	0.11 to 0.14	[32]
Osteochondrosis scores	Norway	Scoring (0 to 4)	LR	0.06 to 0.21	[110]
Osteochondrosis scores	Switzerland	Scoring (1 to 5)	LW, LR	0.07 to 0.31	[111]
Osteochondrosis scores	Switzerland	Scoring (1 to 7)	LW, LR	0.16 to 0.18	[106]

[1] These studies used an animal model for analysis, and

[2]LW=Large White, LR= Landrace, and Y=Yorkshire

e. Nutrition

It is common practice to feed diets formulated for finisher pigs to replacement gilts from development until service or to switch from a finisher diet to a gestation sow diet at the end of the finishing period [99]. Finisher diets are formulated to maximize lean tissue growth and a gestation sow diet is formulated for an animal that has completed growth and its key requirements are maintenance of appropriate body composition and amino acid requirements [112]. Diets fed to gilts during the development period should be purposed to prepare animals for maximum lifetime performance by satisfying the nutritional requirements for reproductive performance, bone development, and joint and toe health [113-114]. Previous research findings [115] have confirmed that one the most critical factors identified for sow lameness is nutrition.

A very high average daily gain (>485 g/day) from 96 kg to first service was associated with premature culling for lamenesss [8] while optimum dietary supplementation with Ca, P, Zn, Cu and Mg improved toe and leg health [116-118]. Only one study has examined the potential benefits of restricted diets to limb health and limb related culling in replacement gilts. They reported that a restricted access diet for replacement gilts (14 MJ of DE/kg, 0.75% lysine), fed respectively from 70 kg to until ~130 kg, then *ad libitum* until ~140 kg had significantly improved locomotor ability, and humeral condyle joint lesions compared with traditional diets [48].

f. Parity

Parity was employed to analyze the impact on sow culling. The highest proportion of culling for lameness occurred among sows in the first parity (20.6%) when compared with gilts and multiparous sows [22]. This study was in agreement with other reports [71] and [95] that reported the incidence for lameness in first parity sows more than other parities. Leg weakness was the most common removal reasons among sows from parity 2 to 5 [23] and researchers [47] identified that the sow's parity influenced particular toe lesions. Third parity sows were at greater risk for developing cracks in the toe wall compared to second parity sows. This result is in agreement with previous findings [18]. However, there was no difference between second and ≥4 parity sows because sows that survive in the herd until the fourth parity may have undergone indirect selection for good toe / foot health and it is possible that these sows with severe toe lesions may be culled from the herd [47].

g. Body condition score

Regarding body condition score (BCS), backfat thickness and body weight are the main factors contributing to a decreased score in lame sows [119]. Previous research [78] has reported that fat sows (BCS>3) had an increased risk of lameness in outdoor herds. They explained the association between BCS and lameness as feeding behavior in outdoor sow herds is a very competitive affair and it is also relevant that a heavy animal puts more weight on its legs [78]. The animals may have a risk factor related to lameness from walking on a hard (frozen) or slippery (wet or icy) surface or fighting other sows for feed. Heavier sows may have a tendency to develop osteochondral lesions opposed to optimal or lighter weight sows [108]. A significant difference for average backfat thickness between lame sows (15.3±3.7) and non-lame sows (14.6±3.7)

(P<0.05) has been reported [95]. The effect of lameness may be displayed through lower feed intake or / and different nutrient partitioning that results in proper sow body composition and condition score at the end of lactation [119]. However, other researchers [21] have reported that fat sows had an insignificantly increased risk of lameness because fat sows were less likely activity or possibilities for movement.

Lameness relating with economic traits

Associations between lifetime / longevity, growth, reproductive and carcass traits and lameness or leg weakness have been investigated and shown in Table 4. The association between feet and leg conformation traits and production traits has been reported in the scientific literature [106]. They reported low genetic correlations between osteochondral lesions at condylus medialis humeri, distal epiphyseal cartilage of ulna, and condyles lateralis femoris and exterior and production traits (-0.02 to 0.01). Genetic selection that favors leaner and faster growing pig does not seem to increase the genetic predisposition to exhibit osteochondral lesions considerably in Swiss breeds [109]. Associations between osteochondrosis lesions in 7 areas (head of humerus, condyles medialis humeri, condyles lateralis humeri, radius and ulna proximal, distal epiphyseal cartilage of ulna, head of femur, and condyles medialis femoris) and meat quality in a pig company in Switzerland were analyzed by [105]. They reported unfavorable genetic correlation with meat quality and feed conversion ratio. This inflammation, often accompanied by pain, is one of the most apparent consequences of lameness. It has the potential to impact feed consumption and thus may explain why lame sows are thin and exhibit poor body condition score [119].

There are limited studies that report the estimates for the associations between conformation / locomotion traits and reproduction performance in pigs [29, 120-121]. These studies have focused on the causal relationship between lameness or leg weakness due to osteochondrosis, and fertility. Sows with severe leg problems tend to have lower number of piglets born alive during their reproductive lifetime [11]. Previous work, [122-123] found a disparity in reproductive capacity between 3 lines selected for different front-leg structure. The "no leg-weakness" line had larger litter sizes and higher number of piglets born alive compared with the "intermediate or severe leg-weakness" lines. Nikkilä and coworkers [111] reported that sows with slightly outward turned front legs, less upright rear leg posture and intermediate rear leg foot size had an antagonistic effect on lifetime performance. This association is in agreement with other research findings [28], which reported that good structural conformation and locomotion are likely to have a favorable relationship with reproductive traits such as larger litter size, higher number piglets born alive, fewer stillborn piglets and shorter weaning to service interval. Sows with poor locomotion showed reduced reproductive performance due to extended age at puberty, conception or farrowing rate [114, 120]. The biological mechanism for how abnormal conformation and lameness reduce reproduction performance is that inferior leg conformation strength can cause pain to the animals [29]. Pain is a cause of stress, which has a negative influence on sow reproductive performance [121]. Moreover, inactive behavior such as spending more time sitting or lying can lead to an increase in microorganisms around the perineal region, resulting in higher risk of urogenital infections. These infections in the sow's reproductive tracts are expected to reduce the fertility capacity among affected animals [124].

Lameness has been reported to be the second most common reason for early culling of sows [11]. Longevity / sow productive lifetime can be defined in terms of reproductive performance such as length of productive life (LPL), lifetime number of total piglets born, lifetime number of piglets born alive or lifetime number of litters. The majority of studies reported a favorable association between proper leg conformation and longevity, but correlations between them greatly varied among studies and breeds. A moderate genetic correlation between overall leg score and LPL in Landrace while the estimate in Large White was lower [11]. It has been reported [122] that a zero genetic correlation between leg score and stayability was observed in Large White, but a favorable genetic correlation (0.19 to 0.36) in Landrace, was found. This indicated that sows with better leg quality had a higher chance to remain in the herd for a longer period of time [125]. Other researchers [126] have reported an insignificant genetic correlation between leg conformation and longevity (0.08). The researchers [127-129] suggested that selection programs for sow longevity seemed feasible and indirect selection based on some leg conformation defects could also be applied.

Table 4 Relationship between leg score, osteochodrosis, and leg conformation with other traits

Traits	Country	Breed[2]	Method	Model	Genetic correlation	Reference
Leg score and length of productive life	Finland	LW, LR	REML	Sire	0.07 to 0.32	[11]
Front leg structure a lifetime production	USA	Commercial lines	REML	Animal	-0.06 to 0.48	[111]
Rear leg structure a lifetime production	USA	Commercial lines	REML	Animal	-0.30 to 0.51	[111]
Leg score and stayability	Germany	LW, LR	REML	Animal	0.002 to 0.36	[122]
Leg conformation and longevity	Poland	LW, LR	VCE	Animal	0.08	[126]
Osteochondrosis lesions and growth performance	Switzerland	LW, LR	VCE	Animal	0.01 to 0.11	[105]
Leg conformation and NBA[1]	USA	Y	REML	Animal	0.03 to 0.16	[28]
Leg weakness score and carcass traits	France	LR, Y	Henderson	-	-0.67 to -0.24	[32]
Osteochondrosis lesions and meat quality	Switzerland	LW, LR	VCE	Animal	-0.30 to -0.21	[105]

[1]NBA= number born alive

[2]LW=Large White, LR= Landrace, and Y=Yorkshire

Behavior changes associated with sow's lameness

Improving sow welfare begins with assessing individual sow's welfare and the many components of sow health and behavior that are related to welfare. Locomotor disorders have been reported to be a major sow health and welfare issue [52]. Naturally occurring lameness may result in wide variations of sow behavior response (i.e. the time spent lying or the number of times a sow changes their postures) based on the severity, location and injury type [53]. Studies in the scientific literature have reported that only 43% of non-lame sows, 18% of mildly lame, and 45% of lame sows stood up, but that sow reactivity to humans could be a potential confounding factor [52]. Lameness can be expected to cause behavior changes due to physically reduced locomotion ability, pain or general discomfort and sickness behavior [29]. Lame sows have been reported to show an increased incidence of uncontrolled lying-down behavior [21], a decreased frequency of standing and an increased frequency of lying postures [130] when compared to non-lame sows. Roca and coworkers [131] reported that lame sows transitioned through fewer postures and moved more quickly through the standing to lying transition on the most lame day when compared to sound and resolution days ($P<0.05$). Lame sows were more passive, they lay more and stood and explored pen fixtures less when compared to the control sows ($P<0.05$) [49]. This same study reported that lameness had reduced sow activity which affected their position in the pen. Parsons and coworkers [53] agreed with Elmore and coworkers [49] and stated that standing, lying and drinking frequencies seem to be promising sow behavioral tools when transitioning from sound to lame states. Several other studies have reported that the feeding and drinking behavior of lame sows was affected as well as the lame sow's social behavior when compared with non-lame sows [21, 50]. Changes in the feeding behavior pattern of lame sows could be used as a lameness indicator [132].

Lameness treatment

Lameness is not a single disease, but rather a presentation associated with a range of conditions. The majority of lameness cases are caused by four different diseases of the foot, namely, sole haemorrhage and ulceration, white line disease, digital dermatitis and interdigital necrobacillosis [133]. Several studies because the duration of confinement is positively correlated to the degree of joint damage in swine [134-135]. Fredeen and Sather [134] found that confinement housing may be the primary factor in the incidence and severity of structural weakness in swine. Conversely, exercise in swine has been shown to decrease the degree and to delay the onset of leg weakness [136]. In addition to decreasing leg weakness, consistent access to exercise has been shown to increase muscle weight, which may improve sow agility and possibly decrease piglet crushing [84]. However, other researchers [137] have reported that there was no benefit from sow's exercise by walking / running 122 min/d for 5 d/wk. Differences in bone density and quality, lying behavior, and piglet survivability may provide useful insight into alternative housing of sows to assist in decreasing leg weakness. Researchers [137] have recommended that the amount of exercise needed to improve the sow's musclo-skeletal system conditions and to decrease the occurrence and severity of lameness.

Lameness treatment in commercial swine breeding herds is for management to use their judgement on whether the animal can be treated, or needs to be culled or euthanized for the first step [66]. Two research groups [138-139] have suggested that lame sows may suffer from severe pain that needs treated with a non-sterodial anti-inflammatory drug (NSAID) typically through oral administration of ketoprofen at a dose of 2 mg/kg for 5 consecutive days or injecting sows with meloxicam at a dose of 0.4 mg/kg for 2 consecutive days. A survey conducted in the United Kingdom [140] in 2012 to 2013 found that all veterinarians used NSAID to treat pigs showing lameness symptoms, whereas one quarter of the farmers did not use any pain medication. Time and the practicality of treating lame animals with drugs, associated cost of products, producer attitudes towards lameness and treating lame animals, poor communication between farmers and veterinarians regarding the appropriate treatment of lame sows, and the general lack of producer knowledge in the sow lameness area were potential barriers to the increased use of pain relief medications in pigs [49]. The NSAID ketoprofen and meloxicam have been reported to be effective in treating non-infectious locomotor disorders commonly observed in sows and pigs [138-139].

Treatment of infected toe / foot lesions is most challenging because of the difficulty in ensuring adequate local treatment [42]. Infected lesions should be cleaned, debrided and sterilized, followed by an antibiotic such as penicillin or some other veterinary prescribed antibiotic [66, 83] and NSAID therapy [42]. Lincomycin has been advised by veterinarians in treatment of deep infections such as laminitis and arthritis [42]. Foot-rot is a problem that is typically observed as pedal sepsis with infection of soft tissue and occasionally bone that breaks through at the coronary band [103]. In non-responsive cases, amputation of the toe can be considered but not often utilized because of cost [103]. It has been described [123] that utilizing foot baths (5 to 10% of formalin solution) as a treatment strategy for foot-rot outbreaks due to infected false sand-cracks administered twice-weekly can be effective [141].

Conclusion

Lameness in sows housed in commercial breeding herds is a common welfare and animal health challenge resulting in high culling and replacement rates as well as economic losses and decreased sow longevity and lifetime productivity. Sow lameness, identifying lameness risk factors and proper treatments can aide in the prediction of sow lameness and identify mitigation strategies as well as how best to convey optimum animal health and welfare care and benefits, to pork producers so that the goal of improving sow lifetime productivity and optimizing sow farm labor can be achieved.

Lameness is one of the most important reasons for early culling gilts and sows from breeding herd and a main cause for euthanizing animals in the breeding herd. Sow's lameness can be caused by limb malformation, toe lesion, osteochondrosis, and shoulder lesion. Accurate measurement and well-defined lesion scoring systems as an objective method are necessary to ensure that results from future studies would be comparable to a subjective method. Biomarker method should continuously be developed and evaluated to determine their effectiveness to detect lameness in sows for proficient measurement methods. Strategies to control risk factors such as a housing system, a flooring type, overgrown toes / dewclaws management, genetic effect for leg conformations and nutrition (especially related to additional minerals and vitamins for optimum foot health) should be developed. Prevention of lameness from developing in group-housed sows is a major importance. Every housing system poses its unique set of challenges when managing the herd to reduce lameness. Slatted-floor systems which have inappropriate widths need to be eliminated. A flooring material as a rubber mat which is resilient to the activity of the sow and produce relieve mild strain on the sows would help to decrease lameness. The interaction between genetics and nutrition, relative to lameness, and osteochondrosis needed to be fully understood.

Genetic selection against lameness, while keeping production stable would help decrease this issue and increase sow lifetime production / longevity. Skeletal adaptation in pigs, indicating the best time or growth phase to prevent musculo-skeletal problems should be concerned in early development. Post-mortem investigation of culled and euthanized sows can yield additional diagnostic information. Foot baths may have potential as part of a preventive foot-rot outbreaks but utilization in grouped house sows needs further research.

Future research to reduce economic losses that occur results from sow lameness include, more accurate an objective method for locomotor measurement, optimum floor profile or floor type, stocking density in group housing of sows during gestation, additional mineral and vitamin supplementation (in both quality and quantity level and duration for using), effective sow management, optimum feeding program for gilt development, genetic components or breed effects for leg defects and genetic effects for feet and leg conformation are necessary and present opportunities for further refinement of all traits associated breeding herd lameness. Moreover, the associations between different feet and leg conformation traits and the frequency or duration of sitting and lying behavior, and with the clinical pathology of urogenital infections need to be conducted. The proposed future work will help reduce breeding herd sow culling / replacement that results from lameness. In turn, mortality / euthanasia that occurs in the breeding herd as a result of lameness should be reduced as well. Ultimately, reducing breeding herd sow lameness will improve sow longevity / productive lifetime, sow welfare, worker morale, and producer profit ability.

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