${articleType}

iMedPub Journals
http://www.imedpub.com/

Journal of Animal Sciences and Livestock Production
ISSN 2577-0594

2017
Vol.1 No.2:06

DOI: 10.21767/2577-0594.100006

Development of an Objective Feet and Leg Conformation Evaluation Method Using Digital Imagery in Swine

JD Stock[1], JA Calderón Díaz[2,3], CE Abell[1], TJ Baas[1], MF Rothschild[1], BE Mote[4] and KJ Stalder[1*]

[1]Department of Animal Science, Iowa State University, Ames, IA, USA

[2]Teagasc Moorepark Grassland Research and Innovation Centre, Pig Development, Fermoy, Co. Cork, Ireland

[3]Polish Academy of Sciences, Institute of Genetics and Animal Breeding, Department of Animal Behaviour and Welfare, Jastrzebiec, Magdalenka, Poland

[4]Department of Animal Science, University of Nebraska-Lincoln, Lincoln, NE, USA

[*]**Corresponding author:** Stalder KJ, Department of Animal Science, Iowa State University, Ames, IA, USA, Tel: + 1515-294-4683; Fax: + 1 515-294-5698; E-mail: stalder@iastate.edu

Received Date: April 10, 2017; **Accepted Date:** April 24, 2017; **Published Date:** May 02, 2017

Citation: Stock JD, Calderón Díaz JA, Abell CE, et al. Development of an Objective Feet and Leg Conformation Evaluation Method Using Digital Imagery in Swine. J Anim Sci Livest Prod 2017, 1:2.

Abstract

Background: The objectives of this study were to create an objective measurement method of joint angles for knee, hock, front and rear pasterns and a rear stance position in swine using digital imaging technology and to assess the repeatability of the objective measurement process.

Methods and Findings: Forty-five multiparous sows (average parity 6.7 ± 2.5; parity range 5 to 14) from two commercial farms (n=21 farm 1 and n=24 farm 2) were used. Sows were moved to a pen where digital images of the profile and rear stance were captured. On average, 5.2 (± 2.6) profile and 2.6 (± 1.0) rear stance high quality images were used per sow. A joint angle measuring system was devised to collect angle measurements on the four feet and leg joints previously mentioned and the rear stance. Joint measurements were analyzed using repeated measure mixed model methods, including farm and parity (as 5, 6, and 7+) as fixed effects. Intraclass correlation coefficients were calculated to evaluate process repeatability. Joint angle measurement repeatability ranged from 0.63 to 0.82. Lowest and highest repeatabilities were observed for the front pastern and hock angle measurements, respectively. No significant farm or parity differences were observed for joint angles measured except for the knee angle between farms ($P<0.05$) and the hock angle between sows' parities 5 and 6 and parity 7+ ($P<0.05$).

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

Keywords: Swine; Digital imagery; Trait; Knee and hock

Introduction

Several methods [1-4] that are widely used in the pig industry have been developed to visually score feet and leg conformation in candidate replacement gilts and sows using a numerical scale. However, several studies have reported that the reliability for subjective observational methods depends on the observers' training and experience [5]. Furthermore, leg problems are reported as the second most important reason for involuntary sow culling in breeding herds before the 4th parity [6-8]. A more objective method to evaluate feet and leg conformation in replacement females could help to reduce premature culling due to feet and leg problems; thereby improving sow longevity, farm productivity and farm profitability. Digitally measuring joint angles could provide a more repeatable approach for evaluating feet and leg conformation traits in pigs. However, there have been only a few studies investigating digital imagery use for measuring joint angulation in any livestock industry with some examples in dairy cattle [9] and horses [10]. In pigs, to our knowledge, there is only one previous study regarding measurements of joint angles using digital images [11]; however, that study focused only on the rear leg joints.

Furthermore, genetic parameter studies [12-15] have reported feet and leg conformation traits to be lowly to moderately heritable (with most based on a categorical scale system). An objective scoring system could enhance the heritability estimates and produce greater accuracy and repeatability associated with them by creating a more consistent joint score regardless of evaluator. However, this yet remains to be tested. Considering that conformation traits are moderately heritable and linked to longevity, which is an important welfare and economic parameter [16-19], it could be possible to include these traits in selection programs to improve sow longevity and increase herd potentials, such as increasing sow longevity, farm productivity and farm profitability.

The objectives of this study were to create an objective measurement method of joint angles for knee, hock, front and rear pasterns and a rear stance position in swine using digital imaging technology and to assess the repeatability of the objective measurement process.

Materials and Methods

Care and use of animals

This study was approved by the Iowa State University Institution of Animal Care and Use Committee (protocol number 2117083-S). Additionally, this study was conducted in accordance with the Guide for the Care and Use of Agricultural Animals in Research and Teaching as issued by the American Federation of Animal Science Societies [20].

Animals: Only sows having produced 5 or more litters were used in this study under the hypothesis that sows that remain in the breeding herd for longer time periods would have feet and leg conformation traits that are conducive to improved longevity compared to sows culled in earlier parities. Forty-five crossbred, multiparous sows, parity 5 and older (hereafter referred to as older sows) were evaluated on two separate breed-to-wean farms for this study. Twenty-one sows (average parity=5.2 ± 0.4, range 5 to 6) were housed in gestation stalls in North Carolina. At the time of data collection this farm had a 6th parity forced culling practice in place, which limited the maximum parity from this operation. The other 24 sows (average parity=8.0 ± 2.8, range 6 to 14) were housed in gestation stalls located in Iowa. Due to limited number of sows from parity 7 or greater from this farm (only 1 to 2 per parity), all sows from parity 7 and older were placed into a single group labeled 7+. In total three parity groups were observed (P5=17, P6=16, P7 (+)=12).

Image Collection: Digital images (i.e. pictures) of the sows' left profile, right profile and rear stance were taken using a Samsung PL20 digital camera (Samsung Electronics Co., Ltd. Yongin-City, Gyeonggi-Do, South Korea). In order to maintain image consistency for analysis, all images were captured using camera default settings portrait mode with no zoom. Sows were moved to a gestation pen and feed was provided (approx. 0.5 kg/sow) on opposite sides of the solid flooring to assist with sow positioning to obtain "ideal" photos. When necessary, the sow was guided using a sort board to place her body parallel with the edge of the solid flooring, where the flooring met the slatted portion of the flooring and where profile image capturing occurred. The camera was held in position by the observers, under the hypothesis that under normal production practices a handheld device would be used instead of a stationary camera setting. Considering animals were not restrained, it was necessary to be able to remove the photographing devices to avoid damage. Positive results from this study would indicate an acceptable method, which could be improved further under more idealistic settings. Two separate observers recorded the images for the two separate farms using the same technique as described below. Profile images were obtained from the opposite side of the gestation pen. The camera was held approximately 2.4 m from the sow and 1.0 m from the floor **(Figure 1a)**.

The sow was repositioned in the opposite direction for the other body side profile images. Rear stance images were collected from behind the sow. The camera was held approximately 1.2 m from the rear of the sow and 1.0 m from the floor **(Figure 1b)**. To increase measurement accuracy, a minimum of four images were captured for the left and right profile each and the rear stance from each animal. Images were reviewed for quality and position, first at the time of collection on the cameras preview screen, and subsequently on a computer monitor. Images were discarded from further analysis if the sow was not standing squarely on all four legs, if the image was completely distorted, or the complete joint was not visible in the image. On average, 5.2 (± 2.6) profile and 2.6 (± 1.0) rear stance images were used for measurement per sow, yielding 398 images that were used to evaluate the objective scoring methods applied to various joint angles.

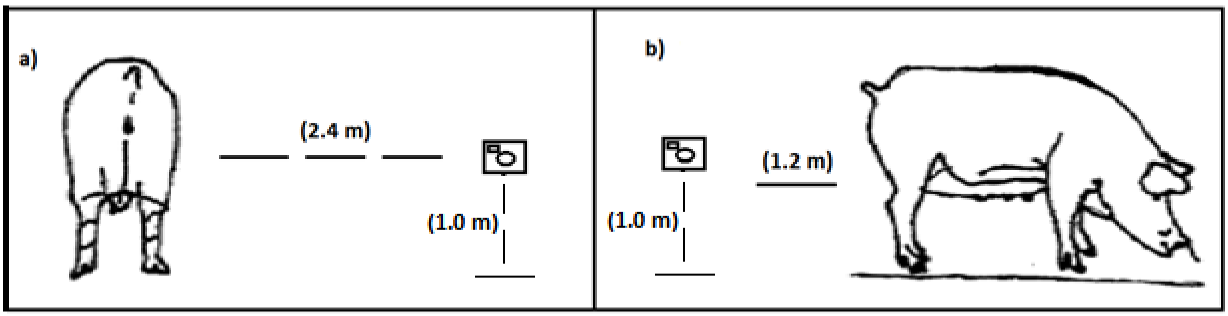

Figure 1 Digital image collection: sow and camera position for **a)** the profile image of the sow and **b)** the rear stance image of the sow, with approximate distance specified by their respective line.

Trait Evaluation Procedures: Feet and leg conformation traits such as knee, pasterns, hock, and rear stance were evaluated in this study. All digital images measurements were evaluated manually using the angle measurement tool in ImageJ (ImageJ, National Institute of Health, Bethesda, MD, USA) using modified methodology of the scoring method developed by The Norwegian Pig Breeders' Association [21]. Two individual joint angles are extracted per joint.

The knee (**Figure 2**, angles a and b) was measured, the joint between the radius/ulna and carpals, with the anterior contour top of the radius and posterior contour tip of the olecranon (dorsal) and the anterior and posterior positions of the carpal/metacarpal joint (ventral) acting as anchor points (i.e. a common position on the joint for all animals that is easily referenced and used for measurement purposes). Front pastern (**Figure 2**, angles c and d) was measured in reference to the slatted portion of the floor. The anterior and posterior joint positions between the carpals and metacarpals are the anchor points for the front pastern measurement that places a line down the top and bottom of the hoof to a straight edge that traces a line back creating the angle measurements for the front pastern angle.

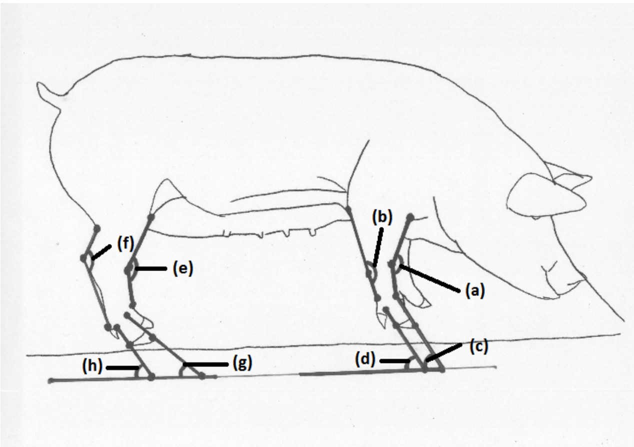

Figure 2 Topographical representation for locations of the joint angles measured in a study using digital imagery to evaluate feet and leg soundness in multiparous sows. **(a)** and **(b)** knee measured running on the front and back of the joint between the radius/ulna and carpals, with the contour sides of that joint acting as the anchor. **(c)** and **(d)** front pastern measured in reference to the floor, where the contour of the joint between the carpals and metacarpals is the reference point for the front pastern measurement that runs a line down the top and bottom of the hoof to a straight edge that traces a line back. **(e)** and **(f)** hock measured running on the front and back of the joint between the fibula/tibia and tarsals, with the contour sides of the joint acting as the anchor. **(g)** and **(h)** rear pastern measured in reference to the floor, where the contour of the joint between the tarsals and metatarsals is the reference point for the rear pastern measurement that runs a line down the top and bottom of the hoof to a straight edge that traces a line back.

Hock (**Figure 2**, angles e and f) was measured, the joint between the fibula/tibia and tarsals, with the anterior and posterior positions acting as the anchor. Rear pastern (**Figure 2**, angles g and h) was measured in reference to the floor. The anterior and posterior joint positions between the tarsals and metatarsals are the anchor points for the rear pastern measurement that places a line down the top and bottom of the hoof to a straight edge that traces a line back creating the angle measurements for the rear pastern.

Rear stance pattern (**Figure 3**, angles a and b) included two measurements from between the hooves and to the back of the hock from the same leg and across to the back of the hock from the opposite leg. This was replicated on the opposite leg and the two-measurement average was calculated to use as an individual angle value for rear stance (rear stance=(4a+4b)/2).

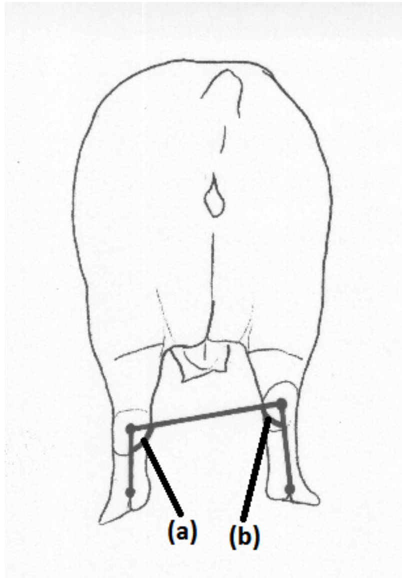

Figure 3 Topographical representation for locations of the joint angles measured in the rear stance in a study using digital imagery to evaluate feet and leg soundness in multiparous sows. **(a)** and **(b)** Rear stance included two measurements that ran from in between the hooves and to the back of the hock of the same leg and across to the back of the other hock.

Data analysis: Each sow was considered an experimental unit. To compare the measurement method, each joint angle for the knee, front pastern, hock and rear pastern was recorded as the anterior joint angle (**Figure 3**, angles a, c, e and g for knee, front pastern, hock and rear pastern, respectively) and also as the mean of the anterior and posterior joint angles for the same joints (**Figure 3**, (a+b) / 2, (c+d) / 2, (e+f) / 2, and (g+h) / 2, for knee, front pastern, hock and rear pastern, respectively). Rear stance position was only evaluated as the mean of the two measurements, as this was for leg position rather than joint angulation. Each joint angle measurement was analyzed using repeated measure mixed model equation methods (PROC MIXED, SAS v9.3; SAS Inst. Inc., Cary, NC). Repeated measure models included farm and parity as fixed effects. An interaction term between farm and parity was not included in the model, as it was not shown to be significant for any of the joints measured.

Measure was included as the repeated variable, with subject of ID and compound symmetry fit as the covariance structure. Statistical differences were reported when individual model main effects were a significant source of variation $P \leq 0.05$. Further, when an individual model main effect was a significant source of variation, main effect levels were separated using the PDIFF option, which displays the P values for differences for pairwise comparisons between all levels within a given class variable. Results for fixed effects are reported as least squares means ± standard error (LS Means (± SE)).

Repeatability for the measurements was defined by the intraclass correlation coefficient (ICC), which measures the repeatability for the joint value measurements controlling for unordered observations. For this study, the individual animal's measurements within each joint were considered unordered as any individual measurement within a joint within an animal could be ordered one through n. ICC was calculated using the following formula:

$$A = \pi r^2$$

where σ_{α}^{2}=variance between measurements and σ_{ϵ}^{2}=total model error variance. These values are obtained using the mixed model previously mentioned and are given as the covariance parameter estimates with σ_{α}^{2}=CS estimate and σ_{ϵ}^{2}=residual estimate.

Results

Repeatability

Intraclass correlation coefficients (± SE) are displayed in **Table 1.** Most values across joint angle measures are numerically similar, except for the values for the knee. The single anterior joint angle for the knee was 0.17 higher than the mean joint value for the anterior and posterior joint angles. The intraclass correlation coefficients show that the single anterior joint angle measurement method is repeatable as their values ranged from 0.63 to 0.82. Similarly, the intraclass correlation coefficients show that the mean joint measurement method is also repeatable as the values ranged from 0.49 to 0.83; however, the knee measurement is improved by only using the anterior joint angle measurement.

Table 1 Intra class correlation coefficients (± SE) for the repeatability of measuring the single anterior joint angle and mean of the anterior and posterior joint angulation of five feet and leg conformation traits from 45 multiparous gestating sows

	Anterior Joint Measurement 1		**Mean Joint Measurement 2**	
Joint	ICC[3]	SE[4]	ICC[3]	SE[4]
Knee	0.66	0.09	0.49	0.11
Front Pastern	0.63	0.09	0.67	0.09
Rear Pastern	0.72	0.08	0.71	0.08
Hock	0.82	0.05	0.83	0.05
Rear Stance5			0.71	0.08

1. Anterior angle of each joint measurement
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

2. Mean of the anterior and posterior angles of each joint measurement
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

3. Calculated as 111111111, where 22= variance between measurements

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

and 333= total model error variance

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
4. Calculated as 44444

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

5. Rear stance is a position value based on two measurements and does not have a single anterior angle

Joint measurements

Accounting for the measurement methods having intraclass correlation coefficients numerically similar to one another, and the single anterior joint angle having a higher intraclass correlation coefficient in the knee, the single anterior joint angle was used for further analysis. The similarities between the two intraclass correlation scores and the required measurements necessary, one versus two angle measurements per joint, makes the data collection process less time constrained and more labor friendly. Two measurements are still required for the rear stance position.

Joint measurement LS Means (± SE) by farm and parity are reported in **Table 2.** No differences were observed for the different joint angles measured between sows from the two farms, except for the knee measurement, where knee angle was 7 degrees greater for sows from farm 1 when compared to sows from farm 2 (P<0.05). Additionally, there was no difference between parities for any of the joints measured except for the

Journal of Animal Sciences and Livestock Production
ISSN 2577-0594
2017
Vol.1 No.2:06

hock angle, where hock angle was 9 degrees less for sows' parity 7+ when compared to sows' parity 5 and 6 (P<0.05).

Table 2 Feet and leg conformation trait joint angle LS Means (± SE) from 45 multiparous crossbred gestating sows from two different farms

Variable	Knee		Front Pastern		Rear Pastern		Hock		Rear Stance		Observations
	LS Means	SE	LS Means	SE	LS Means	SE	LS Means	SE	LS Means	SE	
Farm[1]											
1	161.9^a	1.8	53.8^a	2.5	51.2^a	2.9	148.5^a	2.2	88.9^a	1.9	21
2	154.6^b	1.3	54.2^a	1.7	56.5^a	1.9	148.2^a	1.5	88.3^a	1.4	24
Parity[2]											
5	157.7^a	1.9	53.9^a	2.6	55.6^a	2.9	151.5^a	2.3	89.9^a	1.9	17
6	159.4^a	1.4	53.9^a	1.9	54.9^a	2.2	151.3^a	1.6	88.1^a	1.5	16
7+	157.6^a	1.8	54.2^a	2.4	51.1^a	2.7	142.3^b	2.1	87.7^a	2	12

1. Commercial breed-to-wean farms. Farm 1 (n=21) sows are culled after parity 6. Farm 2 (n=24) allows sows to "cull itself" based on production
2. Parities ranged from 5th to 14th for all sows measured. Sows parity 7 and above were grouped into a single category "7+"
^{a,b}Within columns, values with different superscripts indicate significant differences between predictor variables; P<0.05

Discussion

Subjectively scoring feet and leg conformation traits has and continues to serve the swine industry commercial and breeding sectors when selecting replacement gilts with acceptable conformation. However, they depend on observers' training within the scoring system used and the observers' experience. Studies have shown that scores between two individuals can widely vary [5,22-23]. Advancing digital imagery technology could allow for the development of new and more accurate procedures to assist in gilt selection through an objective scoring process for the important feet and leg traits. The development of a repeatable, objective method to measure conformation could lead to better phenotypes to select replacement gilts with the most desirable structural soundness and could decrease the likelihood a gilt would be culled due to leg problems. This in return would likely increase profitability for commercial swine breeding herds as fewer replacement gilts will be needed. Additionally, retaining sows in the herd for multiple parities allows the sow to pay for herself and to spread the initial cost over a greater number of piglets produced [24].

Joints have a certain typical range of motion; however, those ranges have not been widely investigated in sows. One study [25] measured knee and hock angles in Duroc finishing pigs while standing, as part of a study on divergent selection for front leg weakness [13]. In the latter study, a low line (increased front leg weakness), a control line (intermediate front leg weakness), and a high line (no front leg weakness) were developed over five generations. This study [25] reported knee joint angles of 167.8 (low), 173.5 (control) and 174.5 (high) degrees and hock joint angles of 151.0 (low), 142.7 (control) and 144.5 (high) degrees. These results [25] are similar with the joint angle measurements found in this study. The results [25] also suggested that a seven-degree separation in either the knee or the hock is significant enough to be a potential risk indicator within the joint for leg weakness. However, while this seven-degree separation in those joints may be a risk factor, they should not be isolated from the remaining important joint measurements for leg conformation. For instance, the previous study [25] did not measure pasterns which have been reported to be strongly associated with sow longevity [3,26].

There is limited research regarding feet and leg conformation changes as parity number progresses and the few studies have focused on gilts and young parity sows (i.e. sows parity 1 to 2). de Sevilla et al. [27] reported in his study that in gilts, feet and leg conformation deteriorated from the end of finisher period to the first parity as well as from first parity to second parity. Additionally, the authors reported that the incidence rate for straight pastern position doubled between the end of finisher period and the first parity in the Large White population, but no further change was observed by the second parity. These results would suggest that feet and leg conformation could change as a sow ages although the implications for sow welfare and sow longevity are still unknown.

The objectives of this study were to create an objective measurement method of joint angles for knee, hock, front and rear pasterns and a rear stance position using digital imaging technology and to assess the repeatability for the objective measurement process. To achieve this objective, it is necessary to understand the typical joint value ranges that can be found in a sow herd. It has been suggested that sows that are involuntarily culled due to leg problems in early parities may have undergone an indirect selection process for good feet and leg conformation [28]. The animals chosen for this study therefore represented the oldest sows among the two farms to identify joint angles that potentially contributed to extended longevity. However, the full biological significance of the results from this study requires further investigation in replacement gilts and younger populations.

Based on the results from the ICC analyses, the objective method used to measure feet and leg conformation described in the present study is repeatable. As previously stated, the anterior single joint angle was numerically similar to the mean joint value of the anterior and posterior joint angles. Therefore, the measurement method using only one joint measurement instead of two is less time consuming and is more labor efficient than the anterior and posterior mean and is the recommended measure from this study. Hock repeatability had the largest ICC from the five joint measurements. This could be related to the anatomical function of the hock, as opposed to the other joints, where the hock can move anteriorly, but is restricted in moving posteriorly past the normal resting point, if at all, whereas the other joints have the capability to move either anteriorly or posteriorly from a centralized resting position to a varying degree. One previous study of Van Steenbergen [1] used a 9-point linear visual scoring system, which included half point measurements, to determine repeatability for various feet and leg joint angle measurements including the front leg side view, hock, pasterns, and rear leg views (similar to rear stance from the present study). Repeatabilties ranged from 0.40 for the rear pastern, 0.47 for the rear view of rear legs, 0.49 for both the hock and front leg side view, to 0.54 for the front pastern [1], which are lower than the repeatabilities achieved in the present study for the same joint measurement. Repeatability differences between studies are likely due to the different measuring methods used for both studies.

Conclusion

Objective feet and leg conformation trait measurement could be successfully implemented as an alternative to subjective method as it is repeatable and provides an accurate representation of the joint. Measuring joint angles using the method described in this work appears feasible as measurements were consistent across parities and farms, except for the knee and hock respectively, and were shown to be highly repeatable when compared to subjective repeatability scores. All levels within a genetic implementation program, from grandparent to maternal cross, could execute the measurement system described. Further investigation still remains regarding these measurements, specifically at the time of selection and over the first several parities of the female's life. These remaining answers would further validate the overall application of the measuring process described in this work.

Acknowledgements

This project was funded by the Iowa Attorney General's Office, which did not provide additional assistance beyond funding. We would also like to thank Smithfield Premium Genetics and Fast Genetics for their assistance with this project.

References

1. Van Steenbergen EJ (1989) Description and evaluation of a linear scoring system for exterior traits in pigs. Livest Prod Sci 23: 163-181.
2. Koning G (1996) Selection in breeding programs against leg problems. In: Danielsen V (editor) Proceedings of the Nordiska Jordbruksforskares Ferning Seminar 265-Longevity of Sows. Research Centre Foulum: Denmark, Pp: 85-87.
3. Grindflek E, Sehested E (1996) Conformation and longevity in Norwegian pigs. In: Danielsen V (Editor) Proceedings of the Nordiska Jordbruksforskares Ferning Seminar 265-Longevity of Sows. Research Centre Foulum: Denmark, Pp: 28-33.
4. National Swine Improvement Federation (NSIF) (2002) Guidelines for uniform swine improvement programs. Appendix D: Live Evaluation.
5. Main DC, Clegg J, Spatz A, Green LE (2000) Repeatability of a lameness scoring system for finishing pigs. Vet Record 147: 574-576.
6. D'Allaire S, Stein TE, Leman AD (1987) Culling patterns in selected Minnesota swine breeding herds. Canadian J Vet Res 51: 506.
7. Boyle L, Leonard FC, Lynch B, Brophy P (1998) Sow culling patterns and sow welfare. Irish Veterinary Journal, 51: 354-357.
8. Mote BE, Mabry JW, Stalder KJ, Rothschild MF (2009) Evaluation of current reasons for removal of sows from commercial farms. Profess Anim Scientist, 25: 1-7.
9. Qian D, Wang W, Huo X, Tang J (2008) Study on linear appraisal of dairy cow's conformation based on image processing. In: Li D (editor) Computer and Computing Technologies in Agriculture: Springer, US, 1: 303-311.
10. Thomas D, Gabdulkhakova A, Artner N, Brem G, Kropatsch WG (2014) The use of image data in the assessment of equine conformation-"limitations and solutions". In: Fisher RB, Hammal J, Boom B, Spampinato C (editors) Visual observation and analysis of Vertebrate and Insect Behavior. Springer.
11. Pluym LM, Maes D, Vangeyte J, Mertens K, Baert J, et al. (2013) Development of a system for automatic measurements of force and visual stance variables for objective lameness detection in sows: SowSIS. Biosys Engineering 116: 64-74.
12. Bereskin B (1979. Genetic aspects of feet and leg soundness in swine. J Anim Sci 48: 1322-1328.
13. Rothschild MF, Christian LL (1988) Genetic control of front-leg weakness in Duroc swine. I. Direct response to five generations of divergent selection. Livest Prod Sci 19: 459-471.
14. Serenius T, Sevón-Aimonen ML, Mäntysaari EA (2001) The genetics of leg weakness in Finnish Large White and Landrace populations. Livest Prod Sci 69: 101-111.
15. Fan B, Onteru SK, Mote BE, Serenius T, Stalder KJ, et al. (2009) Large-scale association study for structural soundness and leg locomotion traits in the pig. Genetics Selection Evol 41: 14.
16. Serenius T, Stalder KJ (2004) Genetics of length of productive life and lifetime prolificacy in the Finnish Landrace and Large White pig populations. J Anim Sci 82: 3111-3117.
17. Tiranti KI, Morrison WG (2006) Association between limb conformation and retention of sows through the second parity. Am J Vet Res, 67: 505-509.
18. Fernàndez de Sevilla X, Fàbrega E, Tibau J, Casellas J (2008) Effect of leg conformation on survivability of Duroc, Landrace, and Large White sows. J Anim Sci 86: 2392-2400.
19. Nikkilä MT, Stalder KJ, Mote BE, Rothschild MF (2013) Genetic associations for gilt growth, compositional, and structural soundness traits with sow longevity and lifetime reproductive performance. J Anim Sci 91: 1570-1579.

20. FASS (2010) Guide for the care and use of agricultural animals in teaching and research. 3rd ed. Federation of Animal Science Societies, Champaign, IL.

21. Norwegian Pig Breeders' Association. Exterior evaluation of Norsvin genetics manual, 39 p.

22. Van Nuffel A, Sprenger M, Tuyttens FAM, Maertens W (2009) Cow gait scores and kinematic gait data: can people see gait irregularities? Anim Welfare 18: 433-439.

23. D'Eath RB (2012) Repeated locomotion scoring of a sow herd to measure lameness: consistency over time, the effect of sow characteristics and inter-observer reliability. Anim Welfare 21: 219-231.

24. Stalder KJ, Lacy RC, Cross TL, Conaster GE, Darroch CS (2000) Net present value analysis of sow longevity and the economic sensitivity of net present value to changes in production, market price, feed cost, and replacement gilts costs in a farrow-to-finish operation. The Professional Animal Scientist 16: 33-40.

25. Draper DD, Rothschild MF, Christian LL, Goedegebuure SA (1988) Effects of divergent selection for leg weakness on angularity of joints in Duroc swine. J Anim Sci 66: 1636-1642.

26. Jorgensen B (1996) The influence of leg weakness in gilts on their longevity as sows, assesses by survival analysis. In: Danielsen V (editor) Proceedings of the Nordiska Jordbruksforskares Ferning Seminar 265-Longevity of Sows. Research Centre Foulum: Denmark.

27. de Sevilla FX, Fàbrega E, Tibau J, Casellas J (2009) Genetic background and phenotypic characterization over two farrowings of leg conformation defects in Landrace and Large White sows. J Anim Sci 87: 1606-1612.

28. Calderón Díaz, JA, Fahey AG, Boyle LA (2014) Effects of gestation housing system and floor type during lactation on locomotory ability; body, limb, and claw lesions; and lying-down behavior of lactating sows. J Anim Sci 92: 1675-1685.