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Hoof lesions and lameness in sows in three Greek swine herds

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Summary

Objectives: To characterize foot lesions, estimate their frequency and severity, and investigate their association with parity and lameness in three Greek farrow-to-finish swine herds.

Materials and methods: The studied sows, which had been individually stalled during previous gestations, were examined for foot lesions upon entry into the lactation facilities. Lesions scored included heel hyperkeratinization, erosions or cracks, and toe and dew claw overgrowths. When exiting the farrowing facilities, the sows were observed while walking along an alley and their degree of lameness was scored.

Results: The proportion of sows with at least one lesion on any foot was very high and similar among herds, with 121 of 125 (96.8%), 123 of 125 (98.4%), and 377 of 386 (97.7%) sows affected in herds A, B, and C, respectively. The most frequent lesions were those located on the heel, and overgrown toes and dew claws. For these sites, lesion severity increased with sow parity. The concurrent presence of lesions on more than one foot site, on the same or different feet or both, had a multiplicative effect on the likelihood of lameness.

Implications: Under the conditions in the herds participating in this study, sow foot lesions are extremely common, with older sows more likely than younger sows to have lesions on the heel and overgrown toes and dew claws. The degree of lameness may be affected by a causal interface among foot lesions.

Keywords: swine, hoof lesions, lameness

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Resumen - Lesiones de pezuña y cojera en hembras en tres hatos porcinos de Grecia

Objetivos: Caracterizar las lesiones de pata, estimar su frecuencia y severidad, e investigar su asociación con paridad y cojera en tres hatos porcinos de ciclo completo en Grecia.

Materiales y métodos: Las hembras estudiadas permanecieron en jaulas individuales en gestaciones previas y fueron examinadas en busca de lesiones al entrar a las instalaciones de maternidad. Las lesiones calificadas, incluyeron erosiones hiperqueratinizadas o grietas de talón, y el crecimiento excesivo en las uñas traseras o delanteras. Al salir de las instalaciones de maternidad, las hembras fueron observadas al caminar por el pasillo y se calificó su grado de cojera.

Resultados: La proporción de hembras con al menos una lesión en cualquier pata fue muy alta y similar entre los hatos, con 121 de 125 (96.8%), 123 de 125 (98.4%), y 377 de 386 (97.7%) hembras afectadas en los hatos A, B, y C, respectivamente. Las lesiones más frecuentes fueron aquellas localizadas en el talón, y las uñas delanteras o traseras con crecimiento excesivo. Para estos sitios, la severidad de la lesión se incrementó con la paridad de la hembra. La presencia simultánea de lesiones en más de un área de la pata, en la misma pata o en pata diferente o en ambas, tuvo un efecto multiplicativo en la probabilidad de cojera.

Implicaciones: Bajo las condiciones de los hatos participantes en este estudio, las lesiones de pata de las hembras son extremadamente comunes, teniendo las hembras más viejas mayor probabilidad que las hembras más jóvenes de tener lesiones en el talón y crecimiento excesivo de uñas. El grado de cojera puede ser afectado por una interrelación causal entre las lesiones de pata.

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Résumé - Lésions aux sabots et boiterie chez des truies dans trois troupeaux porcins en Grèce

Objectifs: Caractériser les lésions aux pieds, estimer leur fréquence et sévérité, et évaluer leur association avec la parité et les boiteries dans trois troupeaux porcins de type naisseur-finisseur en Grèce.

Matériels et méthodes: Les truies à l'étude, qui étaient logées individuellement lors des gestations antérieures, furent examinées pour la présence de lésions aux pieds lors de leur entrée dans les installations d'allaitement. Les lésions notées incluaient l'hyperkératinization du talon, les érosions ou les fendillements, et la croissance exagérée des onglons des orteils et des ergots. Lors du départ des installations de mise-bas, les truies étaient observées lorsqu'elles marchaient dans l'allée et leur degré de boiterie notée.

Résultats: La proportion de truies avec au moins une lésion à un des pieds était très élevée et semblable parmi les troupeaux avec 121 des 125 (96,8%), 123 de 125 (98,4%), et 377 de 386 (97,7%) des truies affectées dans les troupeaux A, B, et C, respectivement. Les lésions les plus fréquemment observées étaient celles localisées au talon, et la croissance exagérée des orteils et des ergots. Pour ces sites, la sévérité des lésions augmentait avec le nombre de parité de la truie. La présence simultanée de lésions à plus d'un site, sur le même pied, sur des pieds différents, ou les deux, avait un effet multiplicateur sur la probabilité de boiterie.

Implications: Dans les conditions de la présente étude, les lésions aux pieds des truies sont extrêmement fréquentes, les truies plus âgées plus enclin que les plus jeunes à avoir des lésions sur les talons et a une croissance exagérée des orteils et des ergots. Le degré de boiterie peut être affecté par l'interaction entre les lésions aux pieds.

Hoof lesions, an important underlying cause of locomotor disorders in pigs,[1] have been associated with lameness and culling or euthanasia.[2-4] Lameness is an animal-based welfare indicator.[5] From an economic point of view, lameness reduces the productivity of a pig unit by reducing sow longevity and the number of pigs produced per sow per year due to increased involuntary culling rate of sows, increased expenses as a result of sow replacement costs, increased work load and treatment expenses, and fewer finisher pigs reaching the slaughterhouse.[6-8]

In studies conducted in modern herds in the United States and Belgium, almost every sow had at least one foot lesion.[9,10] However, not all of these sows were lame. Approximately 5% to 20% of lameness cases in sows were attributable to foot lesions.[1,11] Location[9,12] and severity[10,13] of the lesions might determine whether a sow shows overt lameness or not. Furthermore, hoof injuries may serve as possible ports of entry for infections which may ascend and spread through the body, affecting joints and other tissues, causing stress and pain. Hence, infected hoof lesions can cause severe lameness that reduces the sow's appetite and increases her susceptibility to other diseases, through alteration of the immunological response.[14]

One of the major causes of injuries to the foot at the time of mixing in pens is fighting on concrete or slatted flooring or on combinations of concrete and slatted flooring. Even after the dominance hierarchy is established, grouped sows will continue to fight if they are overstocked, have to compete for access to feed, or are stressed by a perpetual feeling of hunger.[15,16] Previously, fighting was controlled by the use of individual stalls for pregnant sows. However, the European Union (EU) Directive 2001/88/EC, implemented since January 2013 in all 25 member states, requires that sows and gilts be kept in groups during a period starting 4 weeks after service and until 1 week before the expected time of farrowing. Without managerial adjustments, it is reasonable to expect that the importance of foot lesions and associated lameness to longevity and productivity of grouped sows will increase.[9,17] In this study, conducted in three Greek swine herds during the first 6 months of 2013, sow foot lesions were characterized, their frequency and severity were estimated, and their associations with parity and lameness were investigated. The results depict the baseline prevalence and severity of foot lesions before implementation of the directive for group housing in these herds.

Materials and methods

This study was conducted in farms that complied with the current laws concerning the protection of animals kept for farming in the European Union.[18] Approval of the study protocol by an animal care committee was not required because taking part in the study was in no way painful or invasive for the animals.

Study population

The studied herds were indoor, farrow-to-finish herds with 330 (Herd A), 160 (Herd B), and 800 sows (Herd C), respectively, with Danbred (herds A and B) and Hermitage (Herd C) genotypes. Before finalizing the necessary reconstruction of the dry-sow units to meet the requirements of the EU Directive 2001/88/EC, all herds kept pregnant sows in individual stalls. Herd C finalized the reconstruction at the end of 2012 and was inspected and granted compliance with the directive by the veterinary authorities in January 2013, whereas herds A and B finalized the reconstructions in the spring and were granted compliance in June 2013.

In the reconstructed units, the animals were loose housed in groups of eight to 12 on combinations of concrete and slatted flooring, as described in the directive. All herds operated on weekly farrowing schedules. Transition to group housing was accomplished gradually, within 4 months after compliance was granted, by grouping the pregnant sows that had been inseminated a month before. Therefore, all sows in the study population had been individually housed during their previous gestations. For participation in the study, the only criterion was the owners' written consent. Neither the health status of the sows' feet nor the frequency of locomotor disorders was considered for herd selection.

Study design

Three farm employees examined the sows' feet for lesions when they entered the lactation facilities. Sow lameness was evaluated upon exit of the animals from the lactation facilities, when managers decided whether a weaned sow would be re-bred or culled, considering reproductive performance, age, and locomotor soundness. Two of the authors (LL and ML) trained the employees to recognize, characterize, and score foot lesions and lameness. An initial training session was held at the clinics of the School of Veterinary Medicine, University of Thessaly (Karditsa, Greece), where the different anatomical sites of the foot were identified, and representative foot lesions in feet collected at slaughter were characterized and scored. Lameness identification and scoring were demonstrated in a video of sows with normal or abnormal gait and posture. Training was repeated on each farm, and employees were provided with a collection of photographs and the video of the training material. Each sow's data was recorded on especially developed paper data-capture forms. The primary author visited all farms once a month, collected the completed data-capture forms, and cross-checked the data by re-examining a random sample of 20% of the sows with the responsible farm employee. The medial and lateral toes of each foot were individually examined for lesions and scored both when sows were lying down (the ventral surface) and standing up (the dorsal surface) in the farrowing crate before farrowing. Lesions included heel hyperkeratinization, erosions or cracks, and toe and dew claw overgrowth. Specifically, five hoof anatomical sites were examined: the heel (soft keratinized epidermis on the ventral surface of the hoof towards the caudal end); the sole (hard keratinized epidermis cranial to the heel on the ventral surface of the hoof, including the junction between heel and sole); the white line (junction between sole and wall); the wall (hard keratinized epidermis on the dorsal surface of the hoof); and the coronary band. The scoring system applied (Table 1) was based on "Zeugenklauwencheck," a scoring system developed in the Netherlands,[10] and the Zinpro Foot First method,[19] with some modifications. Epidermal lesions and length of toes and dew claws were scored on a severity scale ranging from 0 to 2, with the exception of the coronary band lesion, where the score was 0 when healthy and 1 when any lesion was observed. On exiting the farrowing facilities, sows were observed from the front and rear while walking down an alley, and their difficulty in bearing weight on one or more feet was scored. Sows exhibiting normal gait were assigned lameness score 0 (non lame); those with alteration or shortening of stride, without serious locomotion impairment or reluctance to move, showing partial inability to bear weight on one or more feet, were assigned score 1; and those with serious locomotion impairment and reluctance to move, showing complete inability to bear weight on one or more feet, were assigned score 2.

Statistical analysis

All statistical analyses were performed using Stata 13.1 (Stata Statistical Software, College Station, Texas). The total score for the four feet for each anatomical site was obtained by adding the respective scores of hooves, toes, and dew claws. Therefore, for each anatomical site except the coronary band, the total score for the four feet could range from 0 to 16; for the coronary band, the total score could range from 0 to 8. The total score for each foot was obtained by adding the scores for each anatomical site considered. Therefore, the total score for each foot could range from 0 to 13.

Subsequently, descriptive statistics of the data were calculated. The Wilcoxon signed-rank test was used to compare the medians of total scores of lesions in each anatomical site between front and rear feet, in each herd. McNemar's χ^2 test for symmetry was used to compare the proportion of sows with at least one lesion in front and rear feet. Pearson's χ^2 test was used to compare the proportion of sows with lesions on each site scored among the three herds, whereas the medians of scores for each site were compared among herds with the Kruskal-Wallis test. Multiple comparisons were interpreted at Bonferroni-adjusted *P* values.

Three ordered logistic regression models were fitted to estimate the association between parity and the total score on all feet, one for each of the three most frequently recorded lesions, which were heel lesions, overgrown toes, and overgrown dew claws. In each model, parity was the dependent variable, while the total lesion score was the explanatory variable. Parity was characterized in one of three categories (parity groups) (PGs) comprising parities 1 or 2 (PG1), 3 to 5 (PG2), and ≥ 6 (PG3). A dummy variable coding for "herd" was forced in all models because it controlled for variation in the outcome due to different herd-parity distribution and unmeasured factors associated with it, as well as different sampling frequency. The assumption of proportionality in the odds did not hold for herd in the models associating parity with heel lesions and dew-claw length, and for toe length in the model associating parity with this lesion. Thus, partial proportional odds models were fitted using the gologit2 command. These models are less restrictive than

Table 1: Scoring system applied for evaluation of lesions on seven foot sites of 636 sows in three Greek farrow-to-finish herds*

Foot site	Score 0†	Score 1‡	Score 2§
Sole	No lesions or very small superficial cracks in the epidermis	Serious lesions in the epidermis not extending into the corium, heel-sole separation, or both	One or more deep cracks extending into the corium, severe heel-sole separation, or both
Heel	No lesions or very small superficial cracks in the epidermis	Hyperkeratinization and erosions in the epidermis not extending into the corium	Hyperkeratinization, deep cracks extending into the corium, and often necrosis
White line	No lesions or very small superficial cracks in the epidermis	Wall-sole separation not extending into the corium	Wall-sole separation extending into the corium
Wall	No lesions or very small superficial cracks in the epidermis	Cracks not extending into the corium, often accompanied by bruising	Cracks extending into the corium, separation of the keratin, or both
Coronary band	No lesions or very small superficial cracks in the epidermis	Edema with purulent exudate, hemorrhage and necrosis, or both	NA
Toe	Normal length	Overgrown toes	Overgrown and twisted or cracked toes
Dew claw	Normal length	Overgrown dew claws, touching the floor when the animal is standing	Overgrown and twisted or crushed dew claws

* Based on a Dutch scoring system (Zeugenklauwencheck)[10] and the Foot First Method[19] with some modifications.

† Corresponding to "score 1 or 2" in the Dutch scoring system or "mild" in the Foot First system.

‡ Corresponding to "score 3" in the Dutch system or "moderate" in the Foot First system. For the coronary band, the score applied in this study corresponds to "score 3 or 4" in the Dutch system.

§ Corresponding to "score 4" in the Dutch scoring system or "severe" in the Foot First system.

NA = not applicable; for the coronary band, lesion score was 0 when healthy and 1 when any lesion was observed.

the parallel-lines models, but more parsimonious and interpretable than those fitted by a non-ordinal method, such as multinomial logistic regression.[20]

In herds A and B, the recorded frequency of lame sows was very low, and therefore their data was not considered in the analysis of the association between lameness and severity of foot lesions. Scoring of lesions at the seven foot sites considered resulted in 56 variables for each sow examined. The major problem to be dealt with in analyzing this data set was multicollinearity, ie, predictor variables were closely related to each other (highly correlated) because they referred to the same animal or foot, or even to the same claw. The available techniques to deal with multicollinearity include either exclusion of highly correlated variables after screening for associations among the independent variables, or creation of indices or scores which combine data from multiple factors into a single variable, or creation of a smaller set of independent variables through use of multivariable techniques such as principal components or factor analysis.[21] We opted to conduct factor analysis to consolidate the information contained in all the original variables into a new smaller set of uncorrelated variables (factors). In factor analysis, the original variables are assumed to be a linear combination of the factors with weights (factor loadings) plus an error term.[21]

Extraction of the factors was accomplished by using the method of principal components.[22] The suitability of individual variables for use in the factor analysis was evaluated by using the Kaiser-Meyer-Olkin measure of sampling adequacy. Determination of the number of factors to keep for interpretation was a compromise between parsimony, interpretability, and the total amount of variation in the original variables that was explained by the factors in the model.[22] Kaiser's criterion (initial eigenvalue ≥ 1), a scree-test plot, and the number of factors that are required to account for a given proportion of the variance observed in the original variables[23] were considered in the analysis to determine which factors to retain for interpretation. Orthogonal and oblique factor rotations were both evaluated, but ultimately an orthogonal rotation (varimax option) was selected for the final analysis because it resulted in a relatively simple and interpretable structure while maintaining factor independence.[22] Factor loadings > 0.40 were used in the interpretation of rotated factors. Sixteen factors had an eigenvalue ≥ 1, suggesting that they should be kept for interpretation according to Kaiser's criterion, while use of the scree method suggested that 15 or 16 factors should be retained. After consideration of the amount of variance explained, we retained 16 factors, cumulatively accounting for almost 70% of the variance in the original variables. Then, for these 16 factors, the regression method was used to produce standardized factor scores.[22]

Subsequently, the produced standardized factor scores were evaluated as predictors of lameness score in an ordinal logistic regression model. Adjustment for the likely parity effect was accomplished by forcing parity into the model.[24] Because the assumption of proportionality did not hold for all predictors examined, we fitted partial proportional odds models.[20] To identify partial proportional odds models that fitted our data best, we used the autofit option, which is a built-in option of gologit2. When this option is specified, gologit2 goes through an iterative process. Initially it fits a totally unconstrained model and then performs a series of Wald tests on each variable to determine whether its coefficients differ across equations, eg, whether the variable meets the parallel-lines assumption. If the test is significant for one or more variables, the variable with the least significant value is constrained to have equal effects across equations. The model is then refitted with constraints, and the process is repeated until there are no more variables that meet the parallel-lines assumption. Finally, a global Wald test is done, which compares the final model with constraints to the original unconstrained model and, if the Wald test is statistically insignificant, the final model does not violate the parallel-lines assumption.[20]

For factor score selection for the final regression model, we initially fitted bivariable models, including each factor score and parity. Factor scores significant at $P < .25$ were candidates for the final model.[25] The initial full model fitted included parity and all standardized factor scores previously identified as significant. It was then reduced by backward elimination of factor scores with $P \geq .05$.[26] When only those with $P < .05$ remained, factor scores previously eliminated were offered one at a time to the model. This ensured that factor scores excluded earlier, during backward elimination, but adding significantly to the final model, were not missed. Lastly, all possible two-way interactions between factor scores in the model were created and tested for significance one by one. The fit of the final model to the data was assessed by comparing the observed to model-predicted probabilities of occurrence of each lameness score.[27]

Results

Foot lesions

A total of 636 sows were scored, of which 125 were in Herd A, 125 in Herd B, and 386 in Herd C (Table 2). The proportion of sows with at least one lesion on any foot was very high and similar among herds with 121 of 125 (96.8%), 123 of 125 (98.4%), and 377 of 386 (97.7%) affected sows in herds A, B, and C, respectively. In Herd C, the proportion of sows with at least one lesion on the front feet (338 of 386; 87.6%) was lower ($P < .001$) than the proportion of sows with at least one lesion on the rear feet (378 of 386; 97.9%). However, these proportions did not differ in Herd A or Herd B.

The most frequent and severe foot lesions observed in each herd separately are shown in Table 2. There was among-herd variation in the frequency and severity of these lesions. Heel lesions were less frequent ($P < .001$) in Herd A than in Herd B or Herd C. Frequency of heel lesions did not differ ($P = .10$) between Herd B and Herd C. The total score of heel lesions differed ($P < .001$) among the three herds, being lowest in Herd A and highest in Herd C. Both the frequency and severity of overgrown toes differed among the herds ($P \leq .001$ in each comparison), being more frequent and severe in Herd A and least frequent and severe in Herd C. Similarly, the frequency and severity of overgrown dew claws differed among the three herds ($P < .001$ in each comparison), being more frequent in Herd A and more severe in Herd C, and least frequent and severe in Herd B. In general, within herds, the median scores of the heel lesions, toe, and dew-claw length were higher ($P < .02$ in each comparison) for the rear than for the front feet, with the exception of the toe length in Herd A sows, which did not differ between front and rear feet ($P = .29$).

Association of lesions with parity

For heel lesions and for overgrown toes and dew claws, which were the most common lesions, there were associations of parity with the total score (Table 3). These associations were adjusted for the herd effect, which was included in the models as a confounder. For each unit increase in the total score of heel lesions and dew-claw length, a sow was 1.10 times ($P < .001$) and 1.20 times ($P < .001$) more likely, respectively, to belong to PG2 or PG3 than to PG1. Additionally, for each unit increase in the total score of toe length, a sow was 1.15 and 1.26 times more likely ($P < .001$) to belong to PG2 or PG3 than to PG1 and to PG3 than to PG2 or PG1, respectively.

Association of lesions with lameness

In Herd C, the proportion of sows with locomotor disorders was 81 of 386 (21.0%). Specifically, 53 of 386 (13.7%) and 28 of 386 (7.3%) sows had lameness scores 1 and 2, respectively. In herds A and B, three of 125 and one of 125 sows, respectively, had lameness score 1, whereas none had lameness score 2.

All variables examined were suitable for inclusion in the factor analysis, since their Kaiser-Meyer-Olkin values were > 0.5, suggesting an acceptable fit with the structure of the other variables. Most variables loaded high on only a single factor, the exception being Factor 1. For this factor, three different groups of variables loaded: variables describing scores of white-line and sole lesions and of toe length of the rear foot. During final model building, five factor scores were found significant after backward elimination, and another during forward selection. None of the examined interactions were significant. Thus the final model included factor scores 1, 2, 5, 7, 11, and 13 as independent variables (Box 1).

According to the final model, lameness was associated with lesions on five foot sites. For all but one site, lameness severity increased with increasing lesion score, the exception being the wall of the front hoof, factor score 11 (Table 4). The likelihood of lameness score being ≥ 1 compared to 0 was almost three times higher ($P < .001$) per one unit increase in factor score 1, whereas it was almost two times higher ($P < .001$) for lameness score 2 compared to ≤ 1. For one unit increase in factor score 2, the odds were 1.90 times higher ($P = .004$) that lameness score would be 2 rather than ≤ 1. It was 1.70 times more likely ($P < .001$) that a sow would have a higher lameness score for a unit increase in

Table 2: Frequency of sows with at least one foot lesion and median (range) of the total score* for all feet by site and herd in a study conducted in three Greek farrow-to-finish herds

	Lesion frequency by site on the foot						
Herd	Sole (%)	Heel (%)	White line (%)	Wall (%)	Coronary band (%)	Toe length (%)	Dew-claw length (%)
A n = 125	55 (44.00)	65 (52.00)	58 (46.40)	67 (53.60)	21 (16.80)	115 (92.00)	114 (91.20)
B n = 125	70 (56.00)	112 (89.60)	24 (19.20)	84 (67.20)	12 (9.60)	96 (76.80)	83 (66.40)
C n = 386	207 (53.63)	362 (93.78)	148 (38.34)	212 (54.92)	63 (16.32)	162 (41.97)	322 (83.42)
	Median of total score (range)						
A	0 (0-13)	1 (0-12)	0 (0-8)	1 (0-11)	0 (0-8)	4 (0-14)	3 (0-15)
B	1 (0-7)	2 (0-10)	0 (0-6)	1 (0-4)	0 (0-3)	2 (0-7)	2 (0-9)
C	1 (0-12)	7 (0-10)	0 (0-11)	1 (0-10)	0 (0-5)	0 (0-10)	5 (0-16)

* Scores defined in Table 1. The total score for the four feet for each anatomical site was obtained by adding the respective scores of hooves, toes, and dew claws.

Table 3: Odds ratios (OR) and 95% confidence intervals (CI) for herd-adjusted associations between sow parity group (PG)* and total lesion score on heel, overgrown dew claws, and overgrown toes.

Foot site	PG ≥ 2 versus PG1 and PG3 versus PG ≤ 2	PG ≥ 2 versus PG1	PG3 versus PG ≤ 2
	OR (95% CI)	OR (95% CI)	OR (95% CI)
Heel†	1.10 (1.06-1.14)	NA	NA
Overgrown dew claws†	1.20 (1.19-1.26)	NA	NA
Overgrown toes‡	NA	1.15 (1.06-1.20)	1.26 (1.07-1.40)

* PG1, parity 1 or 2; PG2, parities 3-5; and PG3, parities ≥ 6.

† The assumption of proportionality in the odds is valid.

‡ The odds ratios are not constant across PGs because the assumption of proportionality in the odds is not valid.

NA = not applicable.

factor score 5. It was 1.40 times more likely ($P = .005$) that a sow would have a higher lameness score for a unit increase in factor score 7. It was 1.50 times more likely ($P = .001$) that a sow would have a higher lameness score for a unit increase in factor score 13. It was 0.60 times less likely ($P = .006$) for a sow to be lame for a unit increase in factor score 11.

Box 1: Factor scores* included in the final model for lameness, representing the lesion scores† for the foot sites examined in 386 sows in Herd C

Factor score 1, for toe length and white-line and sole lesions, rear hooves

Factor score 2, for dew-claw length, front hooves

Factor score 5, for dew-claw length, rear hooves

Factor score 7, for toe length, front hooves

Factor score 11, for wall lesions, front hooves

Factor score 13, for white-line lesions, front hooves

* Scoring of lesions at the seven foot sites considered (Table 1) resulted in 56 variables for each sow examined. From these multicollinear variables, a smaller set of independent variables (factors) were extracted using factor analysis. The regression method was used to produce factor scores for these factors.

Discussion

This study is part of a greater project aiming to characterize foot health and improve sow longevity in Greek swine herds with managerial and nutritional interventions. In the first part of the project, presented here, we estimated the frequency and severity of foot lesions and associated lameness in three herds with general management and housing typical of that in most Greek herds. We initially developed and documented a scoring system for lesions and lameness which was similar to those used in previous reports, with some modifications. Almost every sow examined in the three herds had at least one lesion, and the most frequent and severe were the heel lesions and the overgrown toes and dew claws. Likewise, other studies also recorded an extremely high frequency of foot lesions in sows.[9,10] Heel lesions and hoof wall cracks were the most common,[9,28-30] whereas the most severe lesions were detected on the heel and the dew claws.[10] We found a positive association between parity and severity of lesions. Older sows were more likely to have severe heel lesions and overgrown toes and dew claws. Hoof abnormalities occurred more frequently and were more severe in older sows,[1,10,17] although a reverse effect has also been reported,[9] probably due to the differential culling rate of affected sows. Since the heel bulb, mainly of the lateral digits, carries most of the sow's weight,[31] and high-parity sows, on average, weigh more than younger sows, the heel area is stressed more in older than younger sows. Furthermore, the mean rate of hoof horn growth in sows was recently estimated at approximately 6.3 mm and the mean wear rate at approximately 5.1 mm per month.[32] Therefore, toe overgrowth may occur simply as a function of age, especially when sows are not provided with enough space for exercise. Formation of hoof horn is a complex and structured process of cellular changes that transform living, highly functional epidermal cells into mechanically very stable horn cells. This process of horn formation is sensitive to nutritional influences, hormones, and environmental factors.[33,34]

In general, lameness is considered a multifactorial phenomenon with several physiological causes (infectious and non-infectious) affecting various tissues and anatomical structures.[35] There is evidence that some types of foot lesions cause lameness and poor reproductive performance.[10,17] The link between foot lesions and lameness is believed to be pain mediated.[36] Typically, the location[9] and severity of lesions[13] are important factors. However, several relevant studies have either failed to demonstrate a significant association[37] or identified few specific foot lesions (ie, white-line lesions, overgrown toes) associated with lameness.[9,38,39] In our attempt to associate foot lesions with lameness, we employed factor analysis, which handled the limitations and complications involved in the simultaneous evaluation of a large number of variables, many of which were correlated. We were able to identify a causal interface between various foot lesions and lameness scores. Some lesions affected lameness scores when they were combined (factor score 1), whereas others had a discerned effect according to their location. Lesions located on five sites of the foot, namely the white line, sole, wall, and overgrown toes and dew claws, were associated with lameness. Furthermore, the concurrent presence of lesions on more than one foot site, on the same or a different foot had a multiplicative effect on the likelihood of lameness. It is understandable that severe white-line and sole lesions can affect some gait parameters in sows.[30] Since the white line is the junction of wall and sole horn, injuries on that site may easily facilitate the invasion of bacteria into the corium, causing pain and inflammation. This can lead to locomotor disorders in sows[9] and in cows – white-line disease.[40] According to the experience obtained in this study, lesions on the white line of a hoof were frequently accompanied by lesions on the sole, since these two sites are adjoined. The prominent clinical sign of locomotion disorder associated with long toes was a gait abnormality that has been described as "goose-stepping of rear legs."[39] Severe overgrowth of toes and dew claws was associated with lameness[10,38] and was reported to be the most common foot lesion responsible for culling.[1] When sows are kept on fully or partially slatted floors, overgrown toes and dew claws may be caught between slats. When the animal attempts to move they may be cracked, and dew claws especially may be completely ripped off. Furthermore, overgrown dew claws may be concave and extend beneath the heel bulb, which is thereby traumatized. Thus, bacteria can enter the corium, causing infection and pain. These observations may explain why sows with long dew claws were more likely to be lame. Therefore, regular trimming of dew claws, which grow along with the toes but do not normally touch the ground to wear, may be a valuable measure to mitigate the risk of lameness.[41]

The results of our study are limited to the extent that recording and scoring of lesions and lameness were conducted by farm personnel. Although there were training sessions for lesion characterization and

Table 4: Odds ratios (OR) and 95% confidence intervals (CI) for parity-adjusted associations between factor scores and lameness for 386 sows in one Greek farrow-to-finish herd (Herd C)*

Factor scores	Lameness score ≥ 1 versus 0 and score 2 versus score ≤ 1	Lameness score ≥ 1 versus score 0	Lameness score 2 versus score ≤ 1
	OR (95% CI)	OR (95% CI)	OR (95% CI)
1†	NA	2.90 (2.10-4.00)	1.80 (1.30-2.40)
2†	NA	1.20 (0.90-1.60)	1.90 (1.02-3.00)
5‡	1.70 (1.30-2.30)	NA	NA
7‡	1.40 (1.10-1.70)	NA	NA
11‡	0.60 (0.40-0.80)	NA	NA
13‡	1.50 (1.20-1.90)	NA	NA

* Factor scores defined in Box 1. Lameness scored from 0 (non-lame) to 2 (complete inability to bear weight on one or more feet).

† The odds ratios are not constant across lameness scores because the assumption of proportionality in the odds is not valid.

‡ The assumption of proportionality in the odds is valid.

NA = not applicable.

lameness diagnosis by the personnel, and the validity of a subsample of the recordings was verified by one of us (ML), there were differences among herds. These differences were due not only to the unavoidable imperfect validity and repeatability of personnel scorings, but also to the existing variations in management, productivity, and genetic lines of sows. In two of the three herds (herds A and B), primarily managerial decisions for quick culling of sows with locomotor problems, and secondarily limited ability to detect lame sows, resulted in very low frequencies of lame sows. Using the data from the third herd, we identified significant associations between several foot lesions and lameness score. Our analytical approach was able to identify groups of closely related foot lesions among a larger set of 56 variables describing lesions on the feet of each sow, without losing any important information, and minimizing the possibility of finding associations "due to chance alone."[21] We showed that the degree of lameness was affected by a causal interface among various foot lesions. Although generalization of these results is risky, since the data originated from one herd, when combined with the results of other studies[10] they point out the need for general improvement in foot health. Though housing conditions and management on the farm are crucial as immediate causes for development of foot lesions,[37] trace-mineral nutrition should also be considered a predisposing factor, because it is vital in developing foot structure and integrity.[42] Proper nutrition with supplementation of proteinated trace mineral may improve the quality of the hoof horn tissue and reduce its susceptibility to chemical, physical, or microbial damage from the environment.[42] It should, therefore, very likely be part of managerial changes required for transition from individual to loose housing of pregnant sows.

Implications

- Under the conditions of this study in three Greek herds, sow foot lesions are extremely common.
- Older sows are more likely than younger sows to have heel lesions and overgrown toes and dew claws.
- The degree of lameness in sows may be affected by a causal interface among foot lesions.

Conflict of interest statement

There are no conflicts of interest professionally or financially with this manuscript, to the knowledge of the co-authors.

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