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Abstract
Sixty Duroc pigs, representing offspring of three lines from the fifth generation of divergent selection for leg weakness, were examined to determine correlated responses in joint angularity. The lines were low, control, and high, with the latter having superior front leg structure. At approximately 100 kg, 10 pigs of each sex and line were scored for front and rear leg structure and movement. The shoulder, elbow, carpal and hock joints were measured for resting angles and range of motion. The model to analyze the data included the effects of line, sire, sex and side and a covariable for weight. High-line pigs had significantly smaller ($P < .05$) resting angles of the elbow joint than did control- or low-line pigs. The low-line pigs, however, had significantly smaller resting angles at the carpal joint ($P < .01$) and greater resting angles at the hock joint ($P < .05$) than did control- or high-line pigs. The low-line pigs had fewer degrees extension at the elbow joint and fewer degrees flexion at the carpal joint than did control- or high-line pigs. High-line pigs had fewer degrees of flexion of the elbow joint than did control-or low-line pigs. Resting angles and range of motion for the elbow and carpal joints were less on the left side than on the right side. Males had greater degrees of extension and total degrees of movement at the elbow joint than did females. Selection for different degrees of leg weakness resulted in accompanying alterations in angularity of joints.

Keywords
Pigs, Leg Weakness, Joints (Animal)

Disciplines
Agriculture | Animal Sciences | Veterinary Anatomy

Comments
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EFFECTS OF DIVERGENT SELECTION FOR LEG WEAKNESS ON ANGULARITY OF JOINTS IN DUROC SWINE[1,2]

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ABSTRACT

Sixty Duroc pigs, representing offspring of three lines from the fifth generation of divergent selection for leg weakness, were examined to determine correlated responses in joint angularity. The lines were low, control, and high, with the latter having superior front leg structure. At approximately 100 kg, 10 pigs of each sex and line were scored for front and rear leg structure and movement. The shoulder, elbow, carpal and hock joints were measured for resting angles and range of motion. The model to analyze the data included the effects of line, sire, sex and side and a covariable for weight. High-line pigs had significantly smaller ($P < .05$) resting angles of the elbow joint than did control- or low-line pigs. The low-line pigs, however, had significantly smaller resting angles at the carpal joint ($P < .01$) and greater resting angles at the hock joint ($P < .05$) than did control- or high-line pigs. The low-line pigs had fewer degrees extension at the elbow joint and fewer degrees flexion at the carpal joint than did control- or high-line pigs. High-line pigs had fewer degrees of flexion of the elbow joint than did control-or low-line pigs. Resting angles and range of motion for the elbow and carpal joints were less on the left side than on the right side. Males had greater degrees of extension and total degrees of movement at the elbow joint than did females. Selection for different degrees of leg weakness resulted in accompanying alterations in angularity of joints.

(Key Words: Pigs, Leg Weakness, Joints (Animal).)

Introduction

Leg weakness continues to be one of the major problems in the swine industry. It is characterized by various degrees of lameness and may involve specific regions of the leg or the entire leg. Economic loss caused by leg weakness in the commercial swine industry is variable; however, culling in breeding stock, especially boars, ranges from 10% to 40% (Grondalen, 1974b; Reiland et al., 1978; Bereskin, 1979; Drewry, 1979; Wilson, 1980; Hagenow, 1984). Determining the cause of leg weakness and methods to prevent this abnormality could have major impacts on the swine industry.

Factors that could be involved in leg weakness include bone and joint diseases (Grondalen, 1974b; Goedegebuure et al., 1980a,b; van der Valk et al., 1980; Wilson, 1980; van der Wal et al., 1982), microbial infections (Christensen, 1953; Duthie and Lancaster, 1964; Grondalen, 1974a; Lawrisuk et al., 1987) and nutritional imbalances or deficiencies (Nielsen, 1973; Grondalen, 1974a,c; Reiland et al., 1978). Additionally, there is strong support for a hereditary component to leg weakness (Reiland et al., 1978; Bereskin, 1979; Drewry, 1979; Wilson, 1980; Webb et al., 1983; Rothschild and Christian, 1988). A five-generation divergent selection experiment for leg weakness has developed lines of pigs that differ genetical-

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ly in their expression of leg weakness (Rothschild et al., 1985; Rothschild and Christian, 1988). These lines of pigs offer a unique opportunity to study characteristics of joint angularity and movement that may produce abnormal stresses on the skeletal support systems of the legs. The specific purpose was to determine if there were differences in the resting angles and range of motion of selected joints in the front and hind legs in three lines of Duroc swine selected for different degrees of leg weakness.

Materials and Methods

Sixty Duroc pigs with differing degrees of leg weakness were used in this experiment. These animals represented the fifth generation of offspring from a long-term divergent selection experiment on leg weakness conducted at the Bilsland Memorial Swine Breeding Farm, Iowa State University, located near Madrid, Iowa. Complete details of the selection experiment are in Rothschild and Christian (1988). Six line-sex subclasses of animals were studied: 10 boars and 10 gilts from the high-line (superior front and hind leg structure), 10 boars and 10 gilts from the control-line (intermediate leg structure), and 10 boars and 10 gilts from the low-line (increased leg weakness). Because of the logistics of conducting the experimental procedures and the lack of differences in leg structure between replicates (Rothschild and Christian, 1988), only pigs from replicate one were studied. Pigs were sampled from the 18 sires represented and from 44 of 50 litters. A random sample of pigs from each sire was made in proportion to the number of pigs available within each sire progeny group.

All pigs were raised in an enclosed confinement building with concrete floors and a flush gutter. All pigs had free-choice access to water and to a 16% protein corn-soybean meal diet fortified with the recommended minerals and vitamins. At weekly intervals when the pigs reached 100 kg of live weight they were moved from the confinement building to large outdoor pens with concrete floors. Approximately 5 to 9 d after the pigs were moved into the outdoor facilities, each animal was scored for front and hind leg weakness by three observers working independently who had no knowledge of which line each pig belonged to. A scoring system of 1 to 9 was used, with 9 representing superior leg structure and 1 representing extreme leg weakness (Rothschild and Christian, 1988).

After each animal had been visually scored for degree of leg weakness or soundness, it was placed in a restraining apparatus that suspended the animal's body but did not restrict limb movement. The sternum, abdomen and pubis of the pig rested on a board, and a bar was placed along each lateral surface of the pig to prevent it from falling to either side. The resting angle and range of motion of the shoulder, elbow, carpal and hock joints were determined by use of a goniometer. Resting angle was defined as the angle assumed by a joint when it was not in movement and when the limb was placed in a normal standing position. Range of motion was the maximum degrees of flexion and extension of a joint about its center of rotation (Figure 1). Goniometric measurements were obtained by first palpating and then marking surface landmarks that were repeatable from animal to animal. For the shoulder joint, the center of the goniometer pivot was placed just dorsal to the lateral surface of the greater tubercle of the humerus. The proximal arm of the goniometer was aligned with the spinous tuber of the scapula, and the distal arm was aligned with the point of the lateral epicondyle of the humerus. For the elbow, the center pivot was placed over the point of the lateral epicondyle of the humerus, the proximal arm aligned with the previous point marked over the greater tubercle of the humerus, and the distal arm aligned with the lateral tuberosity of the distal extremity of the radius, the proximal arm aligned with the point of the epicondyle of the skin just ventral to the lateral tuberosity of the distal extremity of the radius, the proximal arm aligned with the point of the epicondyl of the humerus, and the distal arm aligned with an eminence on the lateral condyle of the fourth metacarpal bone. For the hock joint, the goniometer pivot was placed just ventral to the lateral malleolus of the fibula. The proximal arm was aligned with the center of the lateral condyle of the tibia, and the distal arm was aligned with the lateral tuberosity of the distal extremity of the fourth metatarsal bone.

For a given joint, the resting angle was determined first. Then, with the goniometer still in place, the joints were maximally flexed and extended (joint could no longer be moved), and the degrees of each were recorded. The degrees of flexion were calculated by subtracting the degrees of maximum flexion from the resting angle of a joint (Figure 1). Degrees

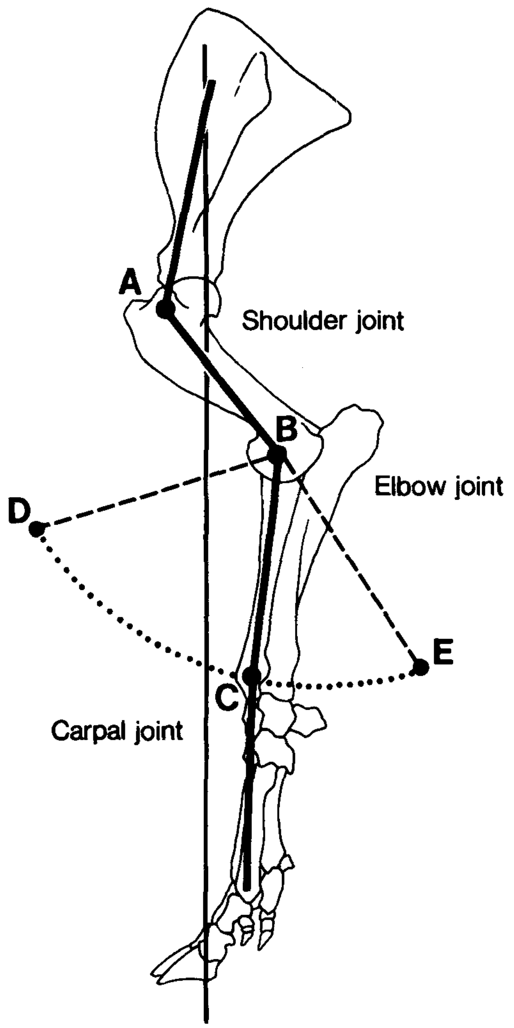

Figure 1. Resting angle and range of motion for the elbow joint (A-B-C, resting angle; A-B-D, maximum degrees flexion; A-B-E, maximum degrees extension; D-B-C, degrees flexion; C-B-E, degrees extension; D-B-E, total degrees of movement).

of extension were calculated by subtracting the resting angle of a joint from the maximum degrees of extension (Figure 1). The total degrees or range of motion of a joint was determined by summing the degrees of flexion and degrees of extension (Figure 1). Both right and left front leg joints were measured, whereas only the left hind jock joint was examined.

The distance from the olecranon tuberosity of the elbow to the distal end of the metacarpus was measured for both front legs. In the hind leg, the distance from the tuber calcanei to the distal end of the metatarsus was measured. The same individual made all the measurements on all the animals. These were made without knowledge of an animal's visual leg structure score or the group to which it belonged.

Data were analyzed using analysis of variance procedures with a mixed model that included the effects of line, sire within line (random), sex and side (front leg traits only), with weight as a covariate. Line effects were tested using sire within line as the error term. No attempt was made to account for genetic drift resulting from the divergent selection experiment. Interaction effects were tested originally but were discarded from the final model when none was found to approach significance ($P > .10$). For significant effects, all possible means were compared using Student's t-test.

Results

The visually assessed front leg soundness score values for the pigs used in this experiment averaged 3.01 ± .17 (worst), 5.67 ± .21 and 7.91 ± .21 (best) respectively, for the low-, control-, and high-lines ($P < .01$; Goedegebuure et al., 1988). Rear leg movement scores among lines also were significantly different, with low-line pigs worst (3.62 ± .18), control-line pigs intermediate (4.75 ± .22), and high-line pigs best (5.75 ± .21). These pigs were considered to be representative of the lines from which they were sampled.

Line differences were significant for resting angles in three of the four joints examined (Table 1). The resting angle of the shoulder was nearly the same for all three lines, each having a mean value of approximately 130°. The resting angle for the elbow joint of high-line pigs was less ($P < .05$) than that of the control- or low-line pigs. At the carpal joint, the low-line pigs had a smaller ($P <. 01$) resting angle than that of the control- or high-line pigs. In the rear limb, the low-line pigs had a greater ($P < .05$) resting angle of the hock joint than that of control- or high-line pigs.

Several right-left asymmetries were found for resting angles of the front leg joints (Table 2). The resting angles were less on the left side than on the right side; these values were different for the carpal ($P < .01$) and elbow ($P < .001$) joints. A similar, but nonsignificant, trend was present for the shoulder joint. There were no significant sex differences in resting angles for any of the joints.

TABLE 1. MEANS[a] OF RESTING ANGLES, DEGREES OF EXTENSION, DEGREES OF FLEXION AND TOTAL DEGREES OF MOVEMENT OF THE SHOULDER, ELBOW, CARPAL AND HOCK JOINTS IN THREE DIVERGENT LINES OF DUROC SWINE SELECTED FOR FRONT LEG SOUNDNESS

Trait	Low line (n = 20)		Control line (n = 20)		High line (n = 20)	
	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
Resting angles, °						
Shoulder joint	129.4	1.4	131.8	1.7	129.2	1.6
Elbow joint	139.3^{b}	1.3	139.9^{b}	1.6	133.2^{c}	1.5
Carpal joint	167.8^{d}	1.0	173.5^{e}	1.2	174.5^{e}	1.2
Hock joint	151.0^{b}	1.8	142.7^{c}	2.1	144.5^{c}	2.1
Extension, °						
Shoulder joint	15.1	1.7	19.6	2.0	21.3	2.0
Elbow joint	18.6^{b}	1.5	21.2^{bc}	1.8	26.8^{c}	1.8
Carpal joint	8.1	0.8	6.7	1.0	7.5	1.0
Hock joint	21.3	1.9	25.0	2.3	24.9	2.3
Flexion, °						
Shoulder joint	18.9	1.4	20.1	1.8	16.1	1.7
Elbow joint	44.6^{bc}	2.2	46.3^{b}	2.7	38.2^{c}	2.7
Carpal joint	101.5	1.6	106.4	1.9	106.8	1.9
Hock joint	86.9	2.5	78.6	3.0	84.5	3.0
Total movement, °						
Shoulder joint	34.1	1.8	39.6	2.1	37.4	2.1
Elbow joint	63.2	2.4	67.6	2.8	65.0	2.8
Carpal joint	109.6	1.5	113.1	1.8	114.4	1.8
Hock joint	108.1	3.1	103.5	3.7	109.4	3.7

[a]Least squares estimates.

[b,c]Means within a row without a common superscript significantly differ ($P < .05$).

[d,e]Means within a row without a common superscript significantly differ ($P < .01$).

Several line differences in range of motion were found (Table 1). The degrees of flexion of the elbow were less ($P < .05$) for high-line pigs than for the control-line pigs. In turn, the degrees of extension of the elbow were greater ($P < .05$) for the high-line pigs than comparable degrees for control- or low-line pigs. The average degrees of maximum extension of the carpal joint were less ($P < .01$) for low-line pigs (175.92° ± .92) than for control- (180.24° ± 1.10) or high-line (182.08° ± 1.09) pigs. There also was a trend for the degrees of flexion of the carpal joint to be less in low-line pigs than in control- or high-line pigs. In the hind leg, the low-line pigs (172.2° ± 1.99) had greater maximum extension of the hock joint (sum of resting and extension angles) than did control- (167.8° ± 2.37) or high-line (169.4° ± 2.35) pigs ($P < .05$). Although not significant, the total degrees of movement for the shoulder, elbow, and carpal joints tended to be less in low-line pigs than in the other two lines (Table 1).

There were several significant asymmetries in range of motion for the elbow and carpal joints (Table 2). At the elbow joint, the left side had fewer degrees of maximum flexion ($P < .05$) and maximum extension ($P < .001$) than the right side. Similarly, the mean degrees of flexion for the carpal joint was less ($P < .001$) for the left side than for the right side. The left carpal joint also had fewer ($P < .05$) average degrees of maximum extension than did the right carpal joint. Additionally, the total degrees of movement of the carpal joint were less ($P < .01$) on the left than on the right side.

Sex differences were noted in range of motion of the elbow joint. Degrees of extension, maximum extension, and total degrees of movement of the elbow joint were all less ($P < .01$) in gilts (19.7° ± 1.33, 157.3° ± 1.27, 60.7° ± 2.08) than in boars (24.7° ± 1.31, 162.1° ± 1.25, 69.9° ± 2.04).

There were no significant line, side, or sex differences in the length of the front or hind legs.

TABLE 2. MEANS[a] OF RIGHT AND LEFT SIDES IN RANGE OF MOTION IN THREE DIVERGENT LINES OF MALE AND FEMALE DUROC SWINE SELECTED FOR DIFFERING DEGREES OF LEG SOUNDNESS

Trait	Right side (n = 30)		Left side (n = 30)	
	$\overline{X}$	SE	$\overline{X}$	SE
Resting angles, °				
Shoulder joint	131.6	1.2	128.8	1.2
Elbow joint	139.9[g]	1.1	135.1[f]	1.1
Carpal joint	173.7[d]	0.9	170.2[e]	0.9
Extension, °				
Shoulder joint	17.5	1.4	19.9	1.4
Elbow joint	23.2	1.3	21.3	1.3
Carpal joint	6.8	0.7	8.1	0.7
Flexion, °				
Shoulder joint	18.8	1.2	17.8	1.2
Elbow joint	42.8	1.9	43.3	1.9
Carpal joint	107.8[d]	1.4	102.0[e]	1.4
Total movement, °				
Shoulder joint	36.3	1.5	37.7	1.5
Elbow joint	65.9	2.0	64.6	2.0
Carpal joint	114.6[d]	1.3	110.1[e]	1.3
Maximum extension, °				
Shoulder joint	149.1	1.5	148.6	1.5
Elbow joint	163.0[g]	1.2	156.3[g]	1.2
Carpal joint	180.5[b]	0.8	178.3[c]	0.8
Maximum flexion, °				
Shoulder joint	112.8	1.4	110.9	1.4
Elbow joint	97.1[b]	1.8	91.7[c]	1.8
Carpal joint	65.9	1.2	68.2	1.2

[a]Least squares estimates.

[b,c]Means within a row without a common superscript significantly differ ($P < .05$).

[d,e]Means within a row without a common superscript significantly differ ($P < .01$).

[f,g]Means within a row without a common superscript significantly differ ($P < .001$).

Discussion

Duroc pigs that differed genetically in their expression of leg weakness after five generations of selection also differed in several angularity measurements of joints. Selection of pigs for differing degrees of leg weakness has resulted in different resting angles of several major joints of the body. In the front limb, the elbow and carpal joints were affected more than other joints. In high-line pigs, the elbow joint had a smaller resting angle than it did in control- or low-line pigs. At the carpal joint, the resting angle in low-line pigs was less than in control- or high-line pigs. This arrangement resulted in an animal with straight legs at the elbow, but a collapsed or "bucked" carpal joint. This shifted the center of gravity forward, which altered the direction of forces on the bones of the thoracic limb. As a consequence, many animals with severe leg weakness subsequently may develop osteochondrosis. This relationship has been reported by several investigators (Grondalen, 1974a; Reiland et al., 1978; Goedegebuure et al., 1980b; van der Wal et al., 1983, 1987). Some animals with severe leg weakness attempted to walk on their carpuses, because it was either impossible or too painful for them to extend their carpal joints.

In the hind leg, the hock joint of low-line pigs had a greater resting angle than it did in control- or high-line pigs. Legs of low-line pigs appeared very straight with little flexion of the hock. This arrangement may stress the hock joint and lead to various joint lesions. The hock joint is a frequent site of articular cartilage damage in cases of leg weakness (Reiland, 1978; Nakano et al., 1979; Goedegebuure et al., 1980a.).

Several of the differences among lines for range of motion can be explained by their relationship to resting angles. High-line pigs, for example, had fewer degrees of flexion of the elbow joint, but greater degrees of extension of this joint than did pigs in the other two groups. These findings correspond to the smaller resting angle of the elbow joint. Because of the smaller resting angle, it follows that there would be a smaller arc of flexion (fewer degrees) and, correspondingly, a greater arc for extension. More important was the finding that low-line pigs cannot maximally extend their carpal joints as much as control- or high-line pigs. This may mean that genetic selection for leg weakness has resulted in structural changes in the front leg that prevent low-line pigs from extending the carpal joint as much as would a normal pig. This inability to extend the carpal joint in a normal manner may result in a lack of proper structural support and increase the potential for collapse.

The low-line pigs were able to extend maximally the hock joint farther than were control- or high-line pigs. The reason for this is unclear, but could relate to altered structural changes, particularly increased muscle mass in the rear legs. Because muscle mass was not determined, no definitive conclusion as to the cause of increased hock extension in low-line pigs can be made. The straighter the hock joint, however, the more likely the joint is to develop lesions or problems with movement (Rothschild and Christian, 1988).

The right-left asymmetry was unexpected but is considered of major importance. Resting angles of joints were smaller on the left than on the right side, regardless of group. Similarly, several range of motion values for elbow and carpal joints were less on the left side. Because animals were suspended so that both right and left limbs were of equal distance from the ground, it seems unlikely that the asymmetries were a result of positioning or measurement error. But the asymmetries could be an indication of handedness in the pig. It is known that given animals within a species can be either right- or left-handed. However, there is little evidence of handedness for any subhuman species (Warren, 1977; Corballis, 1983; Denenberg and Yutzey, 1985; Galaburda et al., 1985). Because no tests have been performed to determine handedness in swine, we only can infer that it exists in the pig.

The major sex difference observed was that boars have greater range of motion of the elbow joint than do gilts. The importance of this finding is unclear, but it may relate to the sexual behavioral activities of the boar. The boar is more likely to use his front legs in manipulative ways, especially in courtship behavior, than is the gilt. Boars frequently exhibit a pawing action with their front legs after exposure to female pheromones. This behavior requires considerable movement of the elbow joint. Similarly, for a boar to mount a female pig, it is necessary for the front legs to be extended. To accomplish this, the elbow first must be flexed. It is common for the boar to make several leg extensions before successfully mounting the female. Thus, it is plausible that the sex difference in the movement of the elbow joint is related to different behavioral activities of the boar. Additionally, sex differences exist in leg weakness and/(or) osteochondrosis (Nakano et al., 1979; van der Wal et al., 1983, 1987; Rothschild and Christian, 1988); these conditions are less severe in female than in male pigs.

Selection for different degrees of leg weakness in pigs has resulted in alterations or differences in resting angles and range of motion values for the elbow, carpal and hock joints of pigs. These changes could be related to differential growth patterns of muscles, tendons or bones, or to degenerative joint disease, alterations in tendon tensile strength or redistribution of muscle mass resulting in redirected mechanical forces acting on the limb. Selection for leg structure used a scoring system based on what was perceived to be a preferred leg structure. High-line pigs moved significantly better than control-line pigs did, and control-line pigs moved significantly better than low-line pigs. These leg weakness results suggest that joint angle measurements for the control-line pigs should be intermediate when compared with low- and high-line pigs. Generally they were not. This may have resulted from previous natural selection for movement and for overall structure. Results presented here suggest that there is considerably more to learn about the mechanics of movement and structure in the pig and about what should be considered normal and ideal.

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