Exercising stall-housed gestating gilts: Effects on lameness, the musculo-skeletal system, production, and behavior¹


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ABSTRACT: Lameness in breeding-age gilts and sows is a major cause of culling, resulting in increased economic losses and welfare concerns. This study determined if exercise during gestation would affect the musculo-skeletal system, production variables, and behavior. Gilts were blocked by BW and assigned to 1 of 3 treatment groups: control (n = 10; no exercise), low exercise (n = 14; 122 m/d for 5 d/wk), and high exercise (n = 14; 122 m/d for 2 d/wk and 427 m/d for 3 d/wk). All gilts were stall-housed during gestation, and gilts were exercised between d 35 and 110 of gestation. Lameness score, BCS, BW, and blood were taken at multiple points before gestation, and during gestation and lactation. Blood serum was analyzed for carboxy-terminal telopeptide of type I collagen. Sow lying behavior was recorded for 3 d after farrowing. Farrowing data included litter weight and size at birth and weaning, and preweaning mortality. After weaning, 38 sows were slaughtered and muscles and the bones of the left fore- and hind-limbs were harvested. Bone density and quality were determined by computed tomography (CT) scans, dual energy x-ray scans, and bone-breaking force tests. The control group took longer to lie down than both exercise groups, and the low exercise group took longer to lie down than the high exercise group (P < 0.05). The number of pigs weaned was greater in the high exercise group than the control group (P < 0.05). Piglet preweaning mortality was greatest in the control group compared with both exercise groups (P < 0.05). The low exercise treatments exhibited a greater bone density (CT) in the humerus, radius, and tibia compared with that of the control group (P < 0.05). The bone density (CT) of the humerus in the low exercise group was greater than that of the high exercise group (P = 0.03). Breaking force in the humerus and femur was greater (P < 0.05) in the low exercise group than the control group. Breaking force in the tibia of the high exercise group was greater than the control group (P = 0.01). The tibia of both the low and high exercise groups had a greater breaking force (P < 0.05) than the control group. Although there was no benefit of exercise on lameness, differences in bone density and quality, lying behavior, and piglet survivability may provide useful insight into alternative housing for sows.

Key words: bone density, exercise, lameness, lying behavior, muscle weight, sow

INTRODUCTION

Lameness is 1 of the top 3 reasons for culling sows (Lucia et al., 1996; Paterson et al., 1997; Boyle et al., 1998), with a culling rate of 15% (USDA, 2007). In 2006, it was estimated that 79% of sows and gilts in the United States were housed in total confinement for gestation (USDA, 2007), which greatly restricts the amount of movement a sow can perform. Sather and Fredeen (1982) found that confinement housing may be the primary factor in the incidence and severity of structural weakness in swine. Several studies have found that the duration of confinement is positively correlated to the degree of joint damage in swine (Fredeen and Sather, 1978; Hani and Troxler, 1984). Conversely, exercise in swine has been shown to decrease the degree and delay the onset of leg weakness (Perrin and Bowland, 1977). In addition to decreasing leg weakness, consistent access to exercise has been shown to increase muscle...
weight, which may improve sow agility and possibly
decrease piglet crushing (Marchant and Broom, 1996a).
By understanding the amount of exercise needed to im-
prove the condition of the musculo-skeletal system of
gestating sows, we may also be able to decrease the
occurrence and severity of lameness.

This study was designed to determine if exercise during
gestation contributes to the decrease in occurrence
and severity of lameness and the rate of bone resorp-
tion, if exercise improves bone strength, production
variables, the ease of lying down, and the condition of
the hooves and articular cartilage. We hypothesized
that gilts that were exercised would have a decrease
in severity and occurrence of lameness, lie down slower
than nonexercised gilts, have greater muscle weight,
increased bone density, a decrease in osteoclastic ac-
tivity, and better condition of joints and hooves than
control gilts.

MATERIALS AND METHODS

All procedures were approved by the Purdue Univer-
sity Animal Care and Use Committee.

Animal Use and Experimental Procedures

Fifty-one crossbred gilts (approximately 8 mo of age)
from the swine herd of Purdue University were blocked
by BW and litter of origin and assigned to 1 of 3 treat-
ments on d 35 of gestation over 8 replicates between
February and November of 2006. Before introduction
into their experimental group, gilts were evaluated at
2 wk before breeding (d −14) and at d 35 of gestation
for BCS (scored 1 = underconditioned; 5 = overcondi-
tioned; Elanco Animal Health, Greenfield, IN), lame-
ness (0 = no postural or walking problems; 4 = unable
to walk; modified from Main et al., 2000), and BW was
measured at d 0 and 35 to ensure that under- or overcondi-
tioned or lame gilts were not admitted into the
study. Gilts were excluded from the experiment if the
BCS was less than 2 or greater than or equal to 4, or if
the lameness score was greater than 1.5. All gilts were
group-housed before breeding and stall-housed for the
duration of gestation and lactation. During gestation,
all gilts were fed approximately 2.3 kg of feed 1 time/d
of a standard gestation diet. Amount of feed was ad-
justed based on body condition for under- or overcondi-
tioned gilts, per standard farm practice. Stall-housing
was used to control for confounding variables (fighting,
individual variation in the amount of exercise, and feed
intake) common in group housing.

Experimental treatments consisted of a control
group, a low exercise group, and a high exercise group
(n = 17, 19, and 15 gilts/treatment, respectively). Gilts
in the control group were not exercised and were left
in their stalls for the duration of gestation. The low
exercise group was encouraged to walk/run 122 m/d for
5 d/wk from d 35 to 110 of gestation. The high exercise
group was encouraged to walk/run on an increasing ex-
Figure 1. Diagram of the room in which all gilts
and sows were housed during gestation and where all
exercise occurred. For exercise, each gilt or sow was
individually backed out of the stall and followed the di-
rection of the arrows. During exercise, the center aisle
was blocked by wood boards approximately 1 m high.
The reward corner remained constant throughout all
replicates. For behavioral testing, production measure-
ments, and blood sampling gilts/sows were let out from
the front of the stall.
of her stall and had begun to move down the alleyway (see Figure 1). During exercise, all animals were encouraged to move (light pats and vocal signals) until the given distance requirement for that day was met. Sugar cubes were given once per lap in the same corner to encourage the gilt to continue moving and reduce time exploring and sniffing. If the gilt was refusing to exercise (excessive pushing and coaxing), and thus was being forced to exercise, the gilt was returned to her stall and the total distance and time for that day were recorded. Throughout the entire study, there were only 9 cases of refusal to exercise (all high exercise gilts) in which the gilt was returned to her stall before completing all the preset number of laps. When a gilt was exhibiting symptoms of lameness, the distance for that day was reduced or eliminated. A total of 2 low exercise and 6 high exercise gilts at 1 point during exercising were deemed to be lame enough to reduce or eliminate the amount of exercise for at least 1 d. When all gilts had been exercised, additional sugar cubes were given to all gilts (the largest number of sugar cubes given to a gilt plus 1 sugar cube) so that all gilts (including control gilts) would receive the same number of sugar cubes during the day to balance for extra energy.

**Blood Collection and Production Data**

Gilts were led out of the front of the stalls for blood sampling so that there would not be a strong association between negative events (snaring and blood sampling) and exercise. Approximately 10 mL of blood was collected in serum tubes on d −14, 35, 56, and 110 of gestation and at the end of lactation and at the end of lactation via jugular venipuncture. Blood was allowed to sit overnight (12 to 16 h) at 4°C and then was centrifuged at 1,600 × g at 4°C for 15 min. Serum was stored at −80°C until the assay for carboxy-terminal telopeptide of type I collagen (ICTP) was performed (see below).

On d −14, 35, 56, 84, and 110 of gestation and at the end of lactation, BCS and lameness scores were measured. Body weight was recorded on d 0, 35, 56, 84, 110 of gestation, and at the end of lactation. All measures were conducted in the front of the stalls before exercising.

**Fear Testing**

Gilts in replicate 7 and 8 were subjected to avoidance testing (n = 8/replicate). The purpose of the test was to ensure that the gilts did not exercise because of fear of the people exercising them. The test was conducted on d 35 (before handling), 56, and 84 of gestation. The avoidance test consisted of the gilt entering a 4.8-m × 1.2-m pen directly in front of the home stall (Figure 1) in which the gilt was allowed a 1-min adjustment period. At the end of the adjustment period, a person who did not regularly handle the gilts would enter the pen and walk up to the gilt and attempt to touch or pet her. The response of the gilt to being touched was recorded. Observations from the avoidance test were ranked on a scale of 1 to 3 (1 = no reaction, ignoring, or investigating the individual; 2 = a slight avoidance, slow movement from the individual, eventually ignoring the individual; and 3 = vocalizations, running off, and escape attempts from the pen. The avoidance test was performed before taking any other measure or exercising.

**Lying Behavior and Farrowing Data**

At approximately d 110 of gestation, gilts were moved into the farrowing house where they were placed in farrowing crates. Sow lying behavior was recorded (DVR Clear Vision Multi-Camera System, Inter-Pacific Inc., Northbrook, IL; 10 frames/s) for 3 consecutive days after parturition. Cameras were mounted to the ceiling so that each sow could be viewed clearly on 1 side. Sow lying down behavior (time it took for the sow to lower her body to the ground from a standing position) was defined from a modified sequence described by Baxter and Schwaller (1983). For this study, lying down behavior was broken into 3 stages: stage 1) standing to when both knees are placed on the ground; stage 2) ended when the shoulders have rotated; and stage 3) ended when the hind-limbs are lowered to the ground.

The litter size of all sows was adjusted either up or down to 8 to 10 piglets from other sows in the farrowing barn by 3 d after farrowing to control for lactation stress. Number and BW of piglets born and weaned, adjusted litter size, mortality rate, cause of piglet death, days of gestation, and days of lactation were recorded.

**Musculo-Skeletal Sample Collection**

At 3 d after weaning, approximately 3 sows (1/treatment/replicate) from replicates 1 to 4 and all sows from replicates 5 to 8 were killed by electrical stunning and exsanguination. A total of 10 control, 14 high exercise, and 14 low exercise sows were harvested at the end of parity 1. Sows not slaughtered from the first 4 replicates were re-bred and placed back on treatment for the duration of parity 2. However, due to small sample size, none of the data for parity 2 are presented.

The left fore- and hind-limbs were removed and dissected. On the basis of previous work (Marchant and Broom, 1996b), the following muscle groups were collected and weighed: deltoideus, biceps brachii, triceps brachii, extensor carpi radialis, and brachialis muscles were taken from the fore-limb, and the gluteus superficialis, semitendinosus, gracilis, sartorius, peroneus tertius, and soleus/gastrocnemius muscles were taken from the hind-limb. The following bones of the left fore- and hind-limbs were dissected clean of muscle and tendons, taking care not to cut the bone surface; rib (T-2), humerus, radius/ulna, femur, tibia/fibula, patella, and calcaneous. The rib was taken to serve as a positive control for bone density data to control for natural variation between gilts (Tommerup et al., 1993). Both the
right and left hooves were removed and the severity of hoof lesions and bruising were recorded and later scored on a scale from 1 (no to few lesions, no bruising) to 4 (severe bruising on at least 1 digit, and severe, deep splits or cracks in both horns). Articular cartilage from the left fore-limbs (scapula, proximal and distal humerus, proximal and distal ulna and radius, proximal carpal bones) and hind-limb (acetabulum, proximal and distal femur, patella, proximal and distal tibia and fibula, calcaneous, proximal metacarpal bones) were scored using a system by Perrin and Bolland (1977) with 0 indicating normal cartilage and 4 indicating severely damaged cartilage.

**Blood Assay**

Blood serum samples were analyzed for ICTP, a bone osteoclast marker (bone resorption). Carboxy-terminal telopeptide of type I collagen is liberated with the degradation of mature type I collagen and is found immunologically intact in the blood. It can serve as a blood marker of bone resorption and loose connective tissue degradation (Risteli et al., 1993). Serum ICTP (Orion Diagnostica, Espoo, Finland) was measured by ELISA using monoclonal antibodies measuring intact protein. The assay was developed for human ICTP reactivity but has been validated for swine and used to study ICTP in swine (Wiggers et al., 1997; Liesegang et al., 2002). A positive control sample was used in all plates to measure interassay variation. All samples and standards were run in duplicate. The maximum acceptable interassay CV was less than 10% and less than 5% for the intraassay CV. The minimum detection limit of the assay is 0.3 µg/dL, and recovery averaged 93%. Interfering substances include bilirubin if greater than 340 µmol/L, hemoglobin if greater than 5 g/L, and triglycerides if greater than 30 g/L.

**Bone Density and Breaking Strength Measures**

Computed tomography (CT) scans (GE 9800; GE Medical Systems, Milwaukee, WI) were utilized to measure bone density for the rib, humerus, radius/ulna, femur, tibia, and fibula. Bones from each sow were placed side by side on the scanning plate (right to left: femur, fibula, tibia, humerus, radius, ulna, and rib) in the same orientation (proximal/distal) on a pad that contained 3 hydroxyapatite bone density standards (0, 75, and 150 mg/cm²; Image Analysis Inc., Columbia, KY). These standards served as internal controls for each CT image to account for x-ray energy fluctuations that may occur between images. A single 10-mm thick image in the transverse plane was acquired at 120 kV, 80 mA, 2 s, 512 × 512 matrix, and small scan field of view, in the bone algorithm. The bone mineral density of each specimen was determined by comparing the x-ray linear attenuation coefficient of the bone to that of the hydroxyapatite standards. Total and cortical cross-sectional areas were measured by tracing the endosteal and periosteal margins of the bones.

Dual energy x-ray scans (DEXA; Norland pDEXA Sabre X-Ray Bone Densitometer, Fort Atkinson, WI) were used to measure bone mineral density, which is the bone mineral content divided by the scan area. For this assay, a 40-mm long section of the mid-shaft of the bone of the rib, humerus, radius/ulna, femur, patella, tibia, and fibula were scanned. The width of the scan area for each bone was also recorded. The tibia and fibula were separated before scanning by cutting through the proximal and distal ends of the bone. The cross section measured in the DEXA scan included the section measured in the CT scan.

Following scanning, bone breaking strength and shear force were measured by carrying out a bone shear test using an MTS/Sintech Universal Materials Testing Machine (MTS Systems Corporation, Eden Prairie, MN) with a custom machined double shear apparatus (ASABE, 2007). The clearance between the loading bar and supports was 0.05 mm. An elliptically shaped groove was machined into the supports and loading bar and was designed to fit the shape of a typical bone. The radius and ulna were not used in the bone breaking strength test due to the inability to separate the 2 bones and thus the great difference in the shape of the bone compared with others being tested. All bones were thawed overnight and kept at 4°C until testing. Before testing, the diameter of the midshaft of each bone was measured. For this test, the bones were supported horizontally at each end by supports separated by a distance of 20 cm. A force was then applied vertically at the mid-shaft of the bone at a width of 20 cm. The crosshead moved at a rate of 5 mm/min until the force applied to the bone dropped below 100 N (thus sheared or fractured), indicating that the bone had reached its maximum weight load. The maximum force exerted in N was then read from the force-deformation curve recorded by the software. The bone was then cut in the mid-shaft (as close as possible to the breaking site) to achieve a smooth area for measuring cortical bone thickness. Cortical bone thickness was measured by first hollowing out the shaft and then taking 4 measures of thickness in the mid-shaft of the bone. Using cortical bone thickness data, the bone cross sectional areas were calculated by assuming it to be a hollow elliptical cross section (an ellipse within an ellipse). The shear force (τ) was calculated by dividing the breaking force by 2 times the area (ASABE, 2006).

**Group Housing Observations**

We felt it was important to be able to compare the amount of exercise that the low and high treatment groups in the study were receiving compared with what a sow would typically get in a group housing situation. To do this, a total of 4 open-fronted group-housed pens of different stocking densities [4.46 m²/sow (n = 2 pens), 3.56 m²/sow (n = 1 pen), or 2.74 m²/sow (n =
1 pen) were observed for distance traveled from 0730 to 1200 h and 1300 to 1700 h. Two pens were observed each day, with 2 target multiparous sows per pen (n = 4 sows at 4.46 m²/sow; n = 2 sows at 3.56 m²/sow; n = 2 sows at 2.74 m²/sow). Each sow was observed continuously for 5 min every 10 min throughout the times of day observed. The observer would track the position of the sow in the pen on a map drawn to scale. The observer would alternate between pens every 30 min and receive a 30 min break every 60 min. A new map was used every 30 min for each pen. Distance was determined by measuring the length of all lines for each 30-min period and adjusting the value to represent the full scale pen.

**Statistics**

Data were checked for normality using the Univariate procedure and analyzed using the GLM procedure (SAS Inst. Inc., Cary, NC). Least square means (least square mean ± SE) were calculated for all treatments. Where appropriate, differences among means were compared using the Tukey-Kramer procedure for multiple comparisons. Nonparametric data (non-normal data, hoof, cartilage scores, behavioral data, BCS, and lameness scores) were analyzed by the Wilcoxon-Mann-Whitney test. For all nonparametric data, mean ± SE was calculated for all treatments. None of the data sets served to be lame or have an injury for more than 1 wk, then it was counted as 1 incidence. If the same gilt was observed of lameness or an injury within a week were only counted as 1 incidence. If the same gilt was observed to be lame or have an injury for more than 1 wk, it was counted as 2 incidences. There were a total of 4 gilts culled from the study for lameness (1 control, 2 low, and 1 high). The incidence of both injuries (cuts or sores), there were 2 in the control treatment, 8 in the low exercise treatment, and 11 in the high exercise treatment. For the incidence of lameness (difficulty walking), there were 3 in the control treatment, 21 in the low exercise treatment, and 21 in the high exercise treatment. An incidence was defined as observing an injury or lameness at least once in a week. Multiple observations of lameness or an injury within a week were then counted as 1 incidence. If the same gilt was observed to be lame or have an injury for more than 1 wk, it was counted as 1 incidence. If the same gilt was observed to be lame or have an injury for more than 1 wk, it was counted as 2 incidences. There were a total of 4 gilts culled from the study for lameness (1 control, 2 low, and 1 high). The incidence of both injuries and lameness may be numerically less in the control treatment due to the fact that it is harder to identify lameness problems and injuries when the sow is in a confined space and unable to move freely.

**Farrowing Data.** A total of 6 sows (1 control, 1 low exercise, and 3 high exercise gilts) were removed from the farrowing data due to low total number of piglets born (<5 piglets). There were no effects (P > 0.10) among treatment on days of gestation, number of piglets born live, total number of piglets born, percentage still born, and litter weaning weight (Table 2). The high exercise group had a greater live litter BW (P < 0.03) than both the control and low exercise groups. The number of piglets weaned in the high exercise group was greater (P < 0.01) than both the control and low exercise groups. Litter weaning weight was adjusted to 21 d of lactation using the following equation: adjusted
weaning weight = weaning weight\[2.218 − 0.0811(age) + 0.0011(age^2)\]\] (National Swine Improvement Federation, 2003). The adjusted weaning weight was greater (\(P < 0.02\)) in the high exercise group than both the control and low exercise groups. The piglet preweaning mortality was calculated by dividing the number of piglets weaned by the adjusted litter size (adjusted to 8 to 10 piglets/litter). Piglet preweaning mortality was greater (\(P < 0.03\)) in the control group compared with that of the low and high exercise groups.

**Behavior Data**

**Avoidance Test.** At d 35, the mean avoidance score among treatments did not differ (control 2.12 ± 0.35; low exercise 2.33 ± 0.21; high exercise 2.44 ± 0.29; \(P > 0.10\)). There were no differences (\(P > 0.10\)) in the change in the level of avoidance among treatment groups between d 54 and 84 (Figure 3). No differences were detected (\(P > 0.10\)) among day in severity of response in the control group. The severity of response was greater (\(P < 0.03\)) at d 35 than at both d 54 and 84 in the low exercise group. The severity of response at d 35 was greater than that at d 84 (\(P < 0.01\)) and tended to be greater than the response at d 54 (\(P = 0.07\)) in the high exercise group.

**Lying Behavior.** The high exercise group laid down faster (\(P < 0.04\)) in stage 1, 2, and 3 than the control group (Figure 4). Also during stage 1, there was a tendency for the high exercise group to lie down faster than the low exercise group (\(P = 0.09\)). In stage 3, the high exercise group laid down faster than the low exercise group (\(P = 0.05\)), and the low exercise group lay down faster than the control group (\(P = 0.01\)). The total time taken to lie down was greatest (\(P < 0.02\)) for the control group compared with both the low and high exercise groups, and the low exercise group tended to lie down slower than the high exercise group (\(P = 0.08\)).

**Group Housing Observations.** Data obtained during observations of group-housed sows to evaluate typical activity levels are presented in Table 3. Table 3 shows the average distance traveled at 3 different stocking densities per half hour period. The distance moved each day was greatest (\(P < 0.05\)) in the time periods surrounding feeding (feeding occurred between 0800 and 0830 h).

**Blood Data**

There were no differences (\(P > 0.10\)) among treatments in ICTP concentration over time or between time points (Figure 5).

**Muscle Weight**

There were no differences (\(P > 0.10\)) among treatments in the muscle weights collected from the muscles of the fore or hind-limbs. There was an effect of BW at
slaughter ($P < 0.05$) on muscle weight, but no effect of treatment. The mean muscle weight across treatments for the muscles of the fore- and hind-limbs were: deltoideus 0.36 ± 0.01 kg, biceps brachii 0.34 ± 0.01 kg, triceps brachii 3.04 ± 0.06 kg, extensor carpi radialis 0.42 ± 0.01 kg, brachialis 0.38 ± 0.01 kg, gluteus superficialis 0.84 ± 0.03 kg, semitendinosus 1.72 ± 0.05 kg, gracilis 1.05 ± 0.02 kg, sartorius 110.7 ± 4.90 g, per-

Table 2. Least square means for farrowing and weaning data

<table>
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<tr>
<th>Item</th>
<th>Exercise group</th>
<th>SE</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Low</td>
</tr>
<tr>
<td>No. of gilts</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>Days of gestation</td>
<td>116.21</td>
<td>116.76</td>
</tr>
<tr>
<td>No. of piglets born live</td>
<td>7.30</td>
<td>7.56</td>
</tr>
<tr>
<td>No. of piglets born</td>
<td>9.15</td>
<td>8.81</td>
</tr>
<tr>
<td>Still born, %</td>
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<td>13.01</td>
</tr>
<tr>
<td>Live litter BW, kg</td>
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<td>12.18</td>
</tr>
<tr>
<td>Live piglet BW, kg</td>
<td>1.55</td>
<td>1.66</td>
</tr>
<tr>
<td>No. of piglets weaned</td>
<td>7.90^b</td>
<td>8.12^b</td>
</tr>
<tr>
<td>Litter weaning weight, kg</td>
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<td>35.89</td>
</tr>
<tr>
<td>Adjusted weaning weight, kg</td>
<td>39.35^b</td>
<td>42.64^b</td>
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<tr>
<td>Piglet preweaning mortality^3</td>
<td>12.26^a</td>
<td>4.11^b</td>
</tr>
</tbody>
</table>

^a,bMeans within the same row with different superscripts differ, $P < 0.05$.

1Gilts in the low exercise treatment were encouraged to walk/run 122 m/d for 5 d/wk from d 35 to 110. Gilts in the high exercise treatment were encouraged to walk/run on an increasing exercise schedule: 122 m/d for 2 d and 183 m/d for 3 d for the first week; 122 m/d for 2 d and 305 m/d for 3 d for the second week; 122 m/d for 2 d and 427 m/d for 3 d for each of the remaining 9 wk.

2Adjusted weaning weight = weaning weight$[2.218 - 0.0811(age) + 0.0011(age^2)]$ (National Swine Improvement Federation, 2003).

3Piglet preweaning mortality = (number of piglets weaned)/(adjusted litter size).
Figure 4. Mean ± SEM for the average time to lie down during lactation for each of the 3 stages of lying and the total lying down time (the start of stage 1 to the end of stage 3). Stage 1 is from a standing position until both knees are on the ground. Stage 2 is from the end of stage 1 until the sow has rotated her shoulders. Stage 3 is from the end of stage 2 until the sow has completely lowered her hind-quarters to the ground. a–c Values differ within a stage, *P < 0.05. Gilts in the low exercise treatment were encouraged to walk/run 122 m/d for 5 d/wk from d 35 to 110. Gilts in the high exercise treatment were encouraged to walk/run on an increasing exercise schedule: 122 m/d for 2 d and 183 m/d for 3 d for the first week; 122 m/d for 2 d and 305 m/d for 3 d for the second week; 122 m/d for 2 d and 427 m/d for 3 d for each of the remaining 9 wk.

Table 3. Mean ± SEM for the distance (m) moved per time period for multiparous gestating group-housed sows at different stocking densities

<table>
<thead>
<tr>
<th>Item</th>
<th>Stocking density</th>
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<tr>
<td></td>
<td>4.46 m²/sow</td>
</tr>
<tr>
<td>Time, h</td>
<td></td>
</tr>
<tr>
<td>0730</td>
<td>4.5 ± 1.8</td>
</tr>
<tr>
<td>0800</td>
<td>38.5 ± 3.3</td>
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<tr>
<td>0830</td>
<td>34.9 ± 2.4</td>
</tr>
<tr>
<td>0900</td>
<td>24.1 ± 1.8</td>
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<tr>
<td>0930</td>
<td>2.5 ± 2.5</td>
</tr>
<tr>
<td>1000</td>
<td>15.6 ± 15.6</td>
</tr>
<tr>
<td>1030</td>
<td>10.1 ± 4.4</td>
</tr>
<tr>
<td>1100</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>1130</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>1300</td>
<td>0.0 ± 0.0</td>
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<tr>
<td>1330</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>1400</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>1430</td>
<td>1.7 ± 1.7</td>
</tr>
<tr>
<td>1500</td>
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</tr>
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<td>1530</td>
<td>0.0 ± 0.0</td>
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<tr>
<td>1600</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>1630</td>
<td>0.0 ± 0.1</td>
</tr>
<tr>
<td>Total distance, m</td>
<td>136.1</td>
</tr>
</tbody>
</table>

1To obtain data on how much a sow in group housing might move on its own, multiparous sows were observed in group pens differing in stocking density. Two sows from each pen (2 pens at the 4.46 m² sow density, 1 pen for the other 2 densities) were observed throughout the day and movement in each 30-min period was calculated and totaled for the day.
Articular Cartilage and Hoof Scores

Although there were no differences in the articular cartilage among treatments, there was slight damage apparent on all joints examined. The mean articular cartilage score across all treatments for each joint examined were scapula 0.29 ± 0.07, proximal humerus 0.91 ± 0.10, distal humerus 1.03 ± 0.13, proximal ulna and radius 0.51 ± 0.09, distal ulna and radius 0.41 ± 0.08, proximal carpal bones 0.35 ± 0.08, acetabulum 0.17 ± 0.05, proximal femur 0.89 ± 0.09, distal femur 0.61 ± 0.10, patella 0.17 ± 0.05, proximal tibia and fibula 0.24 ± 0.08, distal tibia and fibula 0.44 ± 0.08, calcaneous 0.68 ± 0.10, and proximal metacarpal bones 0.60 ± 0.08.

The right front hoof of the high exercise group tended to have a worse hoof score than that of the control group ($P = 0.06$), but was not different from the low exercise group (Figure 6). Hoof scores of the hind hooves appeared to be greater than that of the front hooves. The data for the left and right hooves were pooled and analyzed to determine if differences existed among treatment in the front and hind hooves. When scores were combined, the front hooves of the high exercise group had a greater scores than the control group ($P = 0.04$, data not shown). There were no differences ($P > 0.10$) in score between the hoof scores of the front and hind limbs when the left and right limbs were pooled.

Bone Density and Breaking Strength

**CT.** Sows in the low exercise treatment exhibited a greater ($P < 0.04$) bone density (Figure 7) in the humerus, radius, and tibia compared with that of the control group. The high exercise group had a greater ($P < 0.05$) bone density in the radius and tibia than that of the control group, but was not different from the low group. Bone density of the humerus in the low exercise group was greater than that of the high exercise group ($P = 0.03$).

**Dual Energy X-Ray Scans.** The data for the DEXA scans could not be normalized and were therefore analyzed by the Wilcoxon Mann Whitney test. There were no differences among treatments ($P > 0.10$) in any of the bones tested (Figure 8).

**Bone Breaking Force and Shear Force.** The breaking force of the humerus, femur, and tibia was greater ($P < 0.03$) in the low exercise treatment than the control group (Figure 9). The breaking force of the tibia in the high exercise treatment was greater than the force of the control group ($P = 0.01$). There was no difference ($P > 0.10$) in breaking force between the low and high exercise groups. There was no difference ($P > 0.10$) in shear force ($\tau$) among treatments for any of the bones tested (Figure 9). No differences ($P > 0.10$) were
Figure 6. Mean ± SEM for hoof scores. A score of 1 indicates no bruising and no to few lesions. A score of 4 indicates severe bruising on at least 1 digit and severe, deep splits or cracks in both horns. a,bValues that tended to differ within a hoof, $P < 0.10$. Gilts in the low exercise treatment were encouraged to walk/run 122 m/d for 5 d/wk from d 35 to 110. Gilts in the high exercise treatment were encouraged to walk/run on an increasing exercise schedule: 122 m/d for 2 d and 183 m/d for 3 d for the first week; 122 m/d for 2 d and 305 m/d for 3 d for the second week; 122 m/d for 2 d and 427 m/d for 3 d for each of the remaining 9 wk.

Figure 7. Least squares means ± SEM for bone density by computed tomography (CT) scans. a,bValues differ among treatments, $P < 0.05$. Gilts in the low exercise treatment were encouraged to walk/run 122 m/d for 5 d/wk from d 35 to 110. Gilts in the high exercise treatment were encouraged to walk/run on an increasing exercise schedule: 122 m/d for 2 d and 183 m/d for 3 d for the first week; 122 m/d for 2 d and 305 m/d for 3 d for the second week; 122 m/d for 2 d and 427 m/d for 3 d for each of the remaining 9 wk.
found in the cortical bone thickness of any of the bones among treatments.

**DISCUSSION**

Few if any studies have examined a comprehensive picture of effects of exercise in gestating animals. There have been several studies examining the effects of exercise in swine; however, these studies have concentrated on either dry multiparous sows or boars and nonbred gilts (Raab et al., 1991; Tommerup et al., 1993; Marchant and Broom, 1996a). Reproducing females are the most valuable animals in the herd. However it is estimated that 40 to 50% of sows are culled before their third or fourth parity (D’Allaire et al., 1987; Boyle et al., 1998), a time at which initial replacement costs have not been met (Stalder et al., 2003). Dijkhuisen et al. (1989) reported that culling for locomotor problems represents the greatest economic losses related to culling. The occurrence of culling for locomotor problems decreases with sow age (Dagorn and Aumaitre, 1979), possibly because unsound sows have already been removed from the herd. Dewey (2006) stated, “the environment in which young animals are raised may have an effect on the skeletal system only apparent later in life”, and a change of housing design may result in a decrease in the culling rate due to lameness. The goals of this study were to investigate if exercising gilts during gestation would decrease the occurrence of lameness and rate of bone resorption, as well as improve bone strength, production parameters, the ease of lysing down, and the condition of the hooves and articular cartilage.

Although no differences were found in lameness scores among treatments, there may be long-term effects from the treatments imposed in this study. Further research needs to be conducted to look at the long-term effect of differing environments and the exercise these animals may get in these environments. Although not measured statistically, more injuries and lameness were apparent during daily exercise in exercised gilts compared with control gilts. This may be due to the possibility that it was easier to detect injuries and lameness in gilts that are out of their stalls for several minutes each day, as opposed to identifying problems in a stall. Another reason for the incidence of injuries in exercised gilts could be that the exercised gilts had the opportunity to encounter objects that can cause injuries, such as corners of stalls or other gilts, compared with the control gilts.

The high exercise group had the greatest live litter BW compared with the control and low exercise groups. Although there were no differences in the number of piglets born live or average piglet BW at birth, the high exercise group had numerically the greatest value in both of these measures, possibly explaining the difference in the live litter BW. The high exercise group also had the greatest adjusted weaning weight compared with the control and low exercise groups. This may be due to having a greater live litter BW and number of piglets weaned, and the lowest preweaning mortality rate.

**Figure 8.** Mean ± SEM for bone mineral density from dual energy x-ray scans. No differences were found among treatments (P > 0.10) in any of the bones. Gilts in the low exercise treatment were encouraged to walk/run 122 m/d for 5 d/wk from d 35 to 110. Gilts in the high exercise treatment were encouraged to walk/run on an increasing exercise schedule: 122 m/d for 2 d and 183 m/d for 3 d for the first week; 122 m/d for 2 d and 305 m/d for 3 d for the second week; 122 m/d for 2 d and 427 m/d for 3 d for each of the remaining 9 wk.
Some sows may not be able to control the descent of their hindquarters to the ground (Marchant and Broom, 1996b), thus causing a greater risk of crushing to the piglets (Damm et al., 2005). Lying down has been shown to take between 7 and 20 s for penned sows (Marx et al., 1989; Harris and Gonyou, 1998). In this study, the control group took the longest time to lie down when compared with the high exercise sows in stages 1 and 2, and compared with both exercise groups in stage 3 and in the total time to lie down. The control group also had the greatest preweaning mortality compared with the exercised sows. This may indi-

Figure 9. Least squares means ± SEM for the breaking force and shear force for each bone. Shear force (τ) was calculated by dividing the force by 2 times the area. No differences were found among treatments (P > 0.10) for the shear force. \(^a,b^\) Breaking force values differ among treatments, P < 0.05. Gilts in the low exercise treatment were encouraged to walk/run 122 m/d for 5 d/wk from d 35 to 110. Gilts in the high exercise treatment were encouraged to walk/run on an increasing exercise schedule: 122 m/d for 2 d and 183 m/d for 3 d for the first week; 122 m/d for 2 d and 305 m/d for 3 d for the second week; 122 m/d for 2 d and 427 m/d for 3 d for each of the remaining 9 wk.
cate that exercised sows in the current study may be able to control the descent of their bodies to the ground with more ease, thus both decreasing the time taken to lie down and preweaning mortality. A decrease in time to lie down could reduce the time that piglets have to move out from under the sow, but also it could reduce the chance of allowing the piglets to get back under the sow, possibly causing the decrease in preweaning mortality.

Although the relationship between lying time and crushing is not clear, it seems reasonable to assume that either decreased lying time (allowing enough time for piglets to move away from the sow, but not return) or increased lying time (allowing the piglets more time to move away from the sow) would decrease piglet crushing. Piglet crushing was not measured for this study due to the high variation that is present in the amount of piglet crushing within a herd. With the sample sizes in this study, we did not feel that we would be able to accurately depict piglet crushing. Another reason for not measuring piglet crushing was due to the fact that postmortem examinations were not performed on dead piglets to be able to determine the exact cause of death; only records from the farm staff were recorded.

Marchant and Broom (1996a) found that group-housed parity 8 sows had higher deltoideus, gluteus superficialis, semitendinosus, gracilis, sartorius, and soleus/gastrocnemius than stall-housed sows. The study by Marchant and Broom examined multiparous dry sows that had been stall- or group-housed for several parities. Results found in their study may indicate long-term effects of the availability to exercise on muscle weight. The amount of time in which sows were exercised each day or the amount of exercise in the current study may not have been sufficient to cause a change in muscle weight. The 28-d prefarrowing and lactation period with no access to exercise may have also eliminated any changes in muscular weight that may have been present before lactation. If previous thoughts that a decrease in muscular strength observed in stall-housed sows may contribute to difficulty seen when basic movements are carried out (Marchant and Broom, 1996b) are correct, then it may be safe to assume that similar muscle weights are not indicative of muscular strength when taking into account the lying down behavior observed in this study.

There were no differences in serum ICTP concentration among treatments or time. An increase in ICTP concentration at d 35 and a subsequent decrease in concentration in the exercise groups by d 54 were expected. An increase in concentration was expected in all treatment groups at weaning as well, due to a lack of movement, and therefore less mechanical stress on the bones. The lack of difference may be due to the fact that there were few or no changes in bone density depending on the bone being examined. Unlike other confinement studies in horses and humans (Hoekstra et al., 1999; Inoue et al., 2000), no differences were seen after 35 d of confinement or at weaning (approximately 140 d of confinement for control gilts). Despite the fact that all gilts in this study were group-housed before d 0 of the study, the sudden restriction of movement in the stall-housing environment did not stimulate an increase in osteoclastic activity. The modern pig is a relatively sedentary animal, and the amount of activity in group-housing (before breeding) may have been low and thus not sufficient enough to cause changes in osteoclast activity when gilts were confined.

Although there were no differences in articular cartilage scores among treatments, it was surprising to find some damage in all joints examined in the young sows. Vanwanseele et al. (2002) stated that a lack of movement is detrimental to articular cartilage, causing loss of proteoglycans and thinning of the cartilage. A forced exercise study by Perrin and Bowland (1977) in immature boars housed in pens (2.0 × 0.4 m) found that overall articular cartilage scores were less severe (average score of 0.33) in all joints than those found in this study (average across treatments of 0.54). Differences found in cartilage scores between the studies could be due to age, genetics, gender, or the amount of exercise received. Several studies have found that most skeletal adaptations occur in humans and young animals, indicating that the best time for prevention of musculo-skeletal problems is early in development (Loitz and Zernicke, 1992; Umemura et al., 1995; Iwamoto et al., 2000). The incidence of damage to the articular cartilage of young animals, although not severe, may indicate that increased exercise before puberty or reproductive stresses could maintain or improve cartilage condition, possibly decreasing the risk of locomotor problems.

Both DEXA and CT scans were used to measure bone density. Dual energy x-ray scanning technique is an aerial density measurement (bone absorption of radiation for a given area of bone), whereas CT is a volumetric density measurement (bone absorption of radiation for a given volume of bone). The CT scans were conducted on a single 10-mm slice of bone and the DEXA scans included a 40-mm section of bone that included the 10-mm slice of the CT scans. Overall, DEXA bone mineral density was less than that of the CT scan bone density, which agrees with previous work in humans (Wren et al., 2005). The largest difference between the 2 measures is apparent in the fibula. The fibula and tibia were separated after the CT scans for the DEXA scans. In having the bones attached in the CT scans, this may have affected the reading for the fibula, and the bone mineral density from the DEXA scans may be a better reading for the true density of the fibula. Although both tests yielded similar densities for all bones (with the exception of the fibula), the CT scan may be a more sensitive way to identify changes in bone density within a population.

Results from the bone breaking strength test showed a difference in the maximum force for fracture in the
humerus, femur, and tibia; however, no differences were found in the shear force. Shear force was measured by dividing the breaking force by 2 times the area of the bone, which included measures of cortical bone thickness. 

Woo et al. (1981) found that in exercised immature swine, cortical bone remodels according to the functional demand placed upon it. Due to the fact that no differences were found in the shear force among treatments and that there were no differences in cortical bone thickness, the data indicate that exercise did not have an effect on the quality of the macro-architecture of the bones. Another factor to consider when evaluating these data is that the position of the bone in which the cortical bone thickness measures were taken was not the same location as the breaking strength test. This was due to the fact that the bone had to be cut back to reveal bone that had not been fractured or destroyed by the breaking strength test. Our best attempts were made to measure the cortical bone thickness as close to the point of the breaking force as possible, but some variation may have been caused by the location of the cortical bone measurement.

When comparing the results from the different measures of bone density and quality, there are similarities and trends between the data. All measures tend to have the same pattern for all bones with the exception of the fibula. The DEXA and breaking force measures, and the CT and shear force measures for the fibula were similar to each other. The reason for this could be the fact that the DEXA and breaking force measurements include both cortical and medullary bone, whereas the CT and shear force measure only the cortical bone. The small medullary area in the fibula may be the reason for such results.

For this study, we expected to find differences in bone density among treatments, particularly, greater bone density and quality in the exercise groups. The bone density in the low exercise group tended to be greater in most of the bones, compared with that of the high exercise group. This could be explained if the low exercise gilts actually ran faster, thus with more impact, than the high exercise sows. Our data cannot confirm this because the entire lap time was measured to obtain an average time per lap and did not measure the speed or time for those sows that often had bursts of activity followed by nonmovement investigative activity. The cumulative effect of movement with nonactivity resulted in there being no difference in average lap time in the first or second halves of exercise because the time was not stopped when the gilt stopped exercise. Hence, the average lap time includes stopping time, investigation time, time a gilt was slowed down by another gilt in the alleyway, and any other time that the gilt was not moving in a forward direction. The increased impact on the bones that occurs when an animal runs may have lead to the differences seen in the bone density measures.

Another reason for the lack of differences in both exercised groups for bone density and quality could be the 28-d period during prefarrowing and lactation when the sows were not exercised. According to Wolff’s law, bone responds to the forces placed upon it. In sedentary animals where mechanical stress is lacking, osteoclast activity will increase, depleting the bone density. Hoekstra et al. (1999) found that horses placed in stalls had a decrease in bone formation after 28 d compared with horses housed on pasture. Inoue et al. (2000) showed that humans subjected to bed rest had a decrease in bone formation by d 50. The 28-d period of decreased forces on the bone during prefarrowing and lactation may have eliminated any differences that may have been present at the end of gestation due to the exercise treatments.

Results from the group-housing observations have shown that the vast majority of movement occurs around feeding. Data presented for distance moved each day are essentially a representation of how far a sow moves for 4 h during an 8-h period. Although this is only a fraction of the day, the time covers the period of the day in which sows tend to be most active. If we assume that the sows moved the same distance during the times that they were not observed during the 8-h period, the distance moved for an 8-h period would be approximately double what was reported. Taking into account that modern swine tend to be relatively sedentary, it is reasonable to state that sows are not active for the majority of the day. Therefore, sows observed in this study may have only moved 2 to 3 times more than what was recorded during the 4-h period in an entire day (total of between 400 and 800 m/d). Assuming this is true, gilts in the high exercise group in this project moved a little less a day than the group-housed sows moved, thus indicating that some of the musculo-skeletal problems in sows may be alleviated by increased movement. However, with the increase in hoof damage seen in this study in the high exercise group, care needs to be taken to identify the balance of the proper amount of exercise on different types of flooring to decrease locomotor problems. In examining the distances moved in group-housed sows, sows in greater stocking density pens (densities for the observations were greater than the recommended required space of 6.1 m$^2$/sow according to Harmon et al., 2001) moved more than sows in groups with lesser stocking densities. This may be due to an increased number of animals to interact with and competition over resources (food and water).

This study provides a comprehensive picture of effects of exercise in gestating gilts on the musculo-skeletal system, lameness, production, and behavior. Exercise during the gestation of the first parity resulted in faster lying down time, decreased preweaning mortality, and increased bone density in some of the bones of locomotion. To improve bone density and quality, articular cartilage, and production parameters and to decrease lameness, new methods of housing gilts early in life to increase exercise may be needed. Simple housing adjustments, such as increased frequency of feed-
ing and changing the location of water and feed, may be able to increase the movement performed each day in a group-housing situation.

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