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Effects of dry sow housing conditions on muscle weight and bone strength

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Abstract

Confinement has been shown to affect bone strenth in poultry but this weakness has not been documented in other species housed in confinement. The objectives of this experiment were to compare muscle weight and bone strength in non-pregnant sows, of similar age and parity, housed throughout eight or nine pregnancies in two different dry sow systems: (1) individually in stalls and (2) communally in a large group. Following slaughter, the left thoracic and pelvic limbs were dissected and 14 locomotor muscles removed and weighed. A proportional muscle weight was then calculated by dividing individual muscle weight (g) by total body weight (kg). Where there were significant differences, stall-housed sows had lower absolute and proportional muscle weights than group-housed sows. The left humerus and femur were also removed. The bones were broken by a three-point bend test using an Instron Universal Tester. Both bones from stall-housed sows had breaking strengths that were about two-thirds those of group-housed sows. The results indicate that confinement of sows, with a consequent lack of exercise, results in reduction of muscle weight and considerable reduction of bone strength.

Keywords: *bone strength, housing, muscle weight, sows.*

Introduction

The modern domestic sow has changed greatly in size and shape over the last few decades due to selection for meat production (Whittemore, 1994). Consequent upon these changes, the anatomical and physiological demands on the skeletal system have increased. Over the same period, intensification of pig farming has lead to higher stocking densities and less space per animal. An extreme development has been housing systems in which sows are tethered, or confined in stalls throughout gestation. This confinement has resulted in alteration or prevention of many of the sow's normal behaviours, increases in abnormal behaviour and in various other indicators of poor welfare (Broom, 1989; Fraser and Broom, 1990).

The skeletal system of a breeding female mammal performs two highly important rôles. Firstly, it gives structural support, which necessitates a certain degree of mechanical strength, and secondly, it provides a reserve for calcium and phosphorus which may be required for foetal development during gestation and milk production during lactation. The demands of gestation and lactation can cause severe depletion of calcium and phosphorus from the mother's bones if dietary levels of these minerals are insufficient. This can make the bones susceptible to fracture; a susceptibility which may be increased if the bones are weakened in any way as a consequence of previous environmental factors.

A great deal of research in pigs has focused on the effects of dietary factors on bone strength (e.g. Rousseaux, Gill and Payne-Crosten, 1981; Reinhart and Mahan, 1986; Hall, Cromwell and Stahly, 1991), whilst others have highlighted differences associated with age (Arthur, Kornegay, Thomas, Veit, Notter, Webb and Baker, 1983), sex (Bayley, Arthur, Bowman, Pos and Thompson, 1975) and breed (Grandhi, Thornton-Trump and Doige, 1986). The effects of exercise have also been investigated (Anderson, Millin and Crackel, 1971; Perrin and Bowland, 1977). It has been proposed that exercise is required to maintain bone composition and strength and with decreased mechanical loading, calcium is mobilized from the bone by an unknown mechanism under hormonal control (Lanyon, 1984 and 1987).

For sows, the confinement imposed by stalls and tethers offers no opportunity for exercise, and this has been shown to affect cardiovascular fitness (Marchant and Rudd, 1993). The physical size of cardiac or skeletal muscle is dependent on the amount of exercise it is subjected to, on a regular basis. With regular exercise, certain muscles will increase in size, and it is the physiological diameter which determines the muscle's strength. Thus, if muscular exercise is greatly limited, as within confined housing systems, it is possible that muscular diameter and strength will decrease, and conformation will be altered. Lack of exercise in confined housing systems can cause bone weakness in other species. Studies on the bone strength of confined laying hens has shown that those confined in cages without sufficient room to carry out locomotor and wing-flapping behaviours, have humeri and tibiae that are significantly weaker than birds housed in a non-restrictive environment (Knowles and Broom, 1990). The objectives of this study were to determine any differences in locomotor muscle size and in the strength of the humerus and femur, between sows housed long-term in stalls and in open groups. A further aim was to identify possible factors influencing any differences between systems.

Material and methods

Animals and housing

The study was carried out on 19 Large White × Landrace sows housed in two different dry sow housing systems. All sows were of similar genetic stock (Masterbreeders, Tring, UK) and in some cases, were litter-mates. They were kept to a similar age (eighth-ninth parity) and were being replaced as part of the ongoing herd management policy. The sows were housed in two adjacent building sections of identical design externally, but each modified internally to accommodate one of the two housing systems.

(1) Stalls (no. = 8). The sows were housed in individual stalls consisting of metal tubular frames bolted to a raised partially slatted floor. The stalls were 2·0 m long × 0·6 m wide × 1·0 m high.

(2) Large group with Electronic Sow Feeder (ESF) system (no. = 11 from a group of 38 including 27 non-experimental animals). This system consisted of an area 16·6 m × 5·5 m divided into a strawed lying area and an unstrawed dunging area, with an ESF station situated in one corner.

The general management was similar in both systems. The ambient temperature was increased in the stall house in cold conditions but was similar in the two building sections in warmer weather. All sows were given a commercial diet (Pigbreed 16 — BOCM Pauls, Ipswich, UK) containing 160 g/kg crude protein, 50 g/kg fibre, 9·5 g/kg calcium and 5·8 g/kg phosphorus and giving 13 MJ/kg digestible energy. The quantity of food given varied from 2·0 kg/day to 5·0 kg/day depending on body condition and stage of gestation or lactation. The sows housed in the large group also had access to straw. All sows were housed from 4 weeks after service to 1 week prior to farrowing and always returned to the same dry sow system. They were routinely weighed on entry to the farrowing house and at weaning, over each parity.

Experimental procedures

Each of the 19 non-pregnant sows was measured from crown to tailhead to determine body length, weighed and then slaughtered on-farm by lethal injection of pentabarbitone. After slaughter, 14 individual locomotor muscles, five from the left forelimb and nine from the left hindlimb, were dissected out from 18 of the 19 sows. Due to time constraints, the muscles from one group-housed sow were not dissected out. The muscles that were removed were:

forelimb: *deltoideus, biceps brachii, triceps brachii, brachialis, extensor carpi radialis;*

hindlimb: *gluteus superficialis, tensor fascia latae, biceps femoris, semitendinosus, gracilis, sartorius, tibialis cranialis, fibularis tertius, soleus/gastrocnemius.*

These were chosen partly on the basis of their perceived importance during locomotion, with reference to studies on quadripedal locomotion in the dog (Tokuriki, 1973a and b; 1974), and partly on the basis of ease of identification and removal. After removal, the muscle bellies were dissected away from their tendons and carefully cleaned of fascia and surface fat. The cleaned muscles were then weighed. In order to take account of differences in muscle weight between housing systems that were purely a result of differences in total body weight, a relative proportion of each muscle to total body weight was then calculated by dividing the absolute muscle weight (g) by the total live body weight (kg).

The left humerus and left femur were dissected out from all 19 sows with a quantity of muscle attached. They were then placed in air-tight plastic bags, to minimize drying out, and refrigerated overnight. The following day the remaining muscle, ligament and tendon attachments were removed, taking care not to cut the bone surface. The bones were measured to determine shaft length and diameter, which was taken as the outside width of bone at right angles to the direction of application of the breaking force. A pen mark was placed at the shaft mid point, which was the point at which the breaking pressure was applied. The bones were then replaced into the air-tight bag and transported to the breaking equipment.

Breaking strength was tested using an Instron Universal Testing Machine. The bones were supported at each end by supports separated by a distance of 20 cm. A force was then applied at a single point on the midshaft, at a loading rate of 5 mm/min until the bone broke cleanly. The maximum force exerted in kg was then read from the force-deformation curve plotted on the chart recorder.

Statistical analysis
All values are expressed as mean ± standard error of the mean. Statistical analyses were carried out using StatView SE+Graphics, v1·04 (Abacus Concepts Inc., Berkeley, CA, USA) and Minitab v9 for Windows (Minitab Inc., Lebanon, PA, USA) statistical packages. Comparison of muscle weights and bone strength between housing systems were carried out using a non-parametric statistical test (Mann-Whitney U test) which was considered suitable for the small sample sizes of both treatments. To determine which factors were affecting bone strength, analysis of covariance (ANCOVA) and correlation and stepwise regression analyses were peformed. It could be argued that for litter-mates, mean data rather than individual data should be used. However, when this approach was taken, the significance of results became greater, indicating that intra-litter variation was greater than inter-litter variation. Thus, individual data from all sows were included in the analyses.

Results
The stall-housed sows were significantly heavier than the group-housed sows on entry to the dry sow system as gilts and prior to parturition during the first parity (Broom, Mendl and Zanella, 1995). However, from the fourth parity onwards and up to slaughter, the group-housed sows were significantly heavier than the stall-housed sows (see Table 1). The group-housed sows also tended to be significantly longer-bodied than the stall-housed sows at slaughter (1588 (s.e. 48) mm *v.* 1517 (s.e. 77) mm respectively, $P = 0·052$).

Group-housed sows had heavier absolute muscle weights ($P < 0·05$) than stall-housed sows for nine of the 14 muscles (see Table 1). However, this would be expected because of the difference in total sow body weight between systems and the fact that there were strong correlations between absolute muscle weights and total sow body weight for 13 of the 14 muscles (see Table 2). There were correlations between proportional muscle weights and total body weight for only three muscles for which there was no effect of housing system (see Table 2), and thus, by comparison of proportional muscle weights, difference in muscle weights due to total body weight is removed (see Table 1). There were significant differences in proportional muscle weight between the systems, in eight of the 14 muscles (one forelimb and seven hindlimb muscles) namely: *deltoideus, gluteus superficialis, tensor fascia latae, semitendinosus, gracilis, sartorius, fibularis tertius* and *soleus/gastrocnemius.*

The humeri and femurs from stall-housed sows had significantly lower breaking strengths (718 (s.e.

Table 1 *Comparison of absolute and proportional muscle weights of sows housed long term in two different sow systems*

	Absolute muscle weights (g)						Proportional muscle weights					
	Group sows		Stall sows				Group sows		Stall sows			
Muscle	Mean	s.e.	Mean	s.e.	*z*	*P*	Mean	s.e.	Mean	s.e.	*z*	*P*
Deltoideus	243	5	200	7	−3·47	<0·001	1·01	0·02	0·91	0·02	−2·60	0·007
Biceps brachii	179	5	173	7	−0·54	0·440	0·74	0·03	0·79	0·03	−1·20	0·323
Triceps brachii	1853	61	1702	60	−1·86	0·100	7·64	0·18	7·75	0·17	−0·08	0·655
Extensor carpi radialis	280	9	253	9	−1·86	0·054	1·15	0·03	1·15	0·03	−0·66	0·954
Brachialis	234	9	190	12	−2·64	0·008	0·96	0·03	0·87	0·05	−1·90	0·089
Gluteus superficialis	579	23	448	20	−3·22	<0·001	2·40	0·11	2·04	0·07	−2·31	0·020
Tensor fascia latae	582	20	466	17	−3·47	<0·001	2·40	0·06	2·12	0·05	−2·73	0·003
Biceps femoris	2954	78	2720	120	−1·74	0·110	12·19	0·24	12·38	0·42	0	0·673
Semitendinosus	1077	30	935	32	−2·73	0·006	4·45	0·14	4·27	0·13	−2·65	0·006
Gracilis	624	24	479	20	−3·47	<0·001	2·57	0·08	2·19	0·09	−2·81	0·004
Sartorius	74	5	49	4	−3·10	<0·001	0·30	0·02	0·22	0·02	−2·97	0·003
Tibialis cranialis	54	2	48	3	−1·99	0·059	0·22	0·01	0·21	0·01	−0·16	0·554
Fibularis tertius	189	7	146	6	−3·31	<0·001	0·78	0·03	0·67	0·02	−2·64	0·005
Soleus/Gastrocnemius	1108	35	919	38	−3·30	0·002	4·57	0·12	4·18	0·12	−2·15	0·044
Total body weight (kg)	242	6	219	4	−2·78	0·007						

Table 2 *Correlation between total body weight and absolute and proportional muscle weights for sows from both dry sow systems combined*

Muscle	Absolute weight *r*	Absolute weight *P*	Proportional weight *r*	Proportional weight *P*
Deltoideus	0·784	0·001	0·195	0·439
Biceps brachii	0·024	0·925	0·626	0·005
Triceps brachii	0·722	0·001	0·065	0·799
Extensor carpi radialis	0·724	0·001	0·001	0·998
Brachialis	0·672	0·006	0·237	0·345
Five forelimb muscles	0·795	0·001	0·101	0·690
Gluteus superficialis	0·559	0·016	0·120	0·636
Tensor fascia latae	0·885	0·001	0·103	0·687
Biceps femoris	0·673	0·002	0·475	0·047
Semitendinosus	0·514	0·029	0·254	0·309
Gracilis	0·777	0·001	0·399	0·101
Sartorius	0·789	0·001	0·326	0·186
Tibialis cranialis	0·796	0·001	0·615	0·007
Fibularis tertius	0·694	0·001	0·310	0·211
Soleus/Gastrocnemius	0·772	0·001	0·284	0·254
Nine hindlimb muscles	0·814	0·001	0·101	0·692

62) kg and 815 (s.e. 39) kg respectively) than those from group-housed sows (1150 (s.e. 71) kg and 1129 (s.e. 59) kg respectively — see Figure 1). There were no differences between systems, in bone dimensions and there was also no correlation between bone strength and bone dimensions, either within each system separately or across both systems combined.

In terms of reproductive output over eight parities, there was a tendency for stall-housed sows to give birth to more live piglets per sow than group-housed

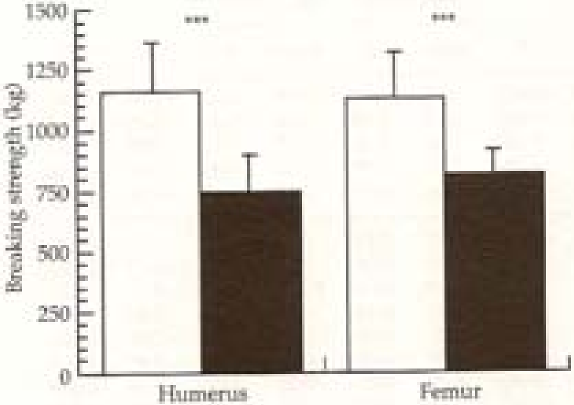

Figure 1 Mean (+s.e.) bone strength (kg exerted at fracture) of sows housed in two different dry sow systems: (❑) group sows, (■) stall sows.

sows (92·4 (s.e. 7·2) *v.* 80·1 (s.e. 17·7), $P = 0·069$). After normal commercial cross-fostering of piglets, stall-housed sows also tended to rear more piglets per sow than group-housed sows (76·7 (s.e. 6·1) *v.* 68·6 (s.e. 8·0), $P = 0·075$). There was no significant correlation between bone strength and the numbers of piglets born alive or reared over eight parities, across both systems combined. Looking at each system separately, the only tendency towards significant correlation was between femur breaking strength in stall-housed sows and both the number of piglets born alive and the number of piglets reared (see Table 3).

The bone strength of the 19 sows was positively correlated with total body weight (see Figures 2 and 3). However, there was no significant correlation between bone strength and total body weight within each sytem (see Table 4). There were positive correlations between humerus breaking strength and the total weight of the five forelimb locomotory muscles (see Figure 4) and between femur breaking strength and the total weight of the nine hindlimb locomotory muscles (see Figure 5). When each system was analysed separately, there were tendencies for forelimb muscle weights to be positively correlated with humerus breaking strength and hindlimb muscle weight to be positively correlated with femur breaking strength, in group-housed sows only.

It could be that the majority of the difference in bone strength between the systems was due to the differences in reproductive output, body weight and limb muscle weight. This hypothesis was explored by re-analysing the data using a general linear model in the form of an analysis of covariance (ANCOVA). The number of piglets born alive, number of piglets reared, total body weight, total forelimb muscle weight, humerus length and humerus width were used as covariates during the analysis of humerus breaking strength, with total forelimb muscle weight being replaced by total hindlimb muscle weight and humerus length and width being replaced by femur

Table 3 *Correlation between bone strength and reproductive output over eight parities*

System	Bone	Piglets born alive *r*	Piglets born alive *P*	Piglets reared *r*	Piglets reared *P*
Combined	Humerus	0·333	0·163	0·310	0·198
Combined	Femur	0·362	0·127	0·340	0·154
Group	Humerus	0·091	0·791	0·192	0·571
Group	Femur	0·026	0·924	0·222	0·513
Stalls	Humerus	0·204	0·628	0·034	0·937
Stalls	Femur	0·677	0·065	0·648	0·082

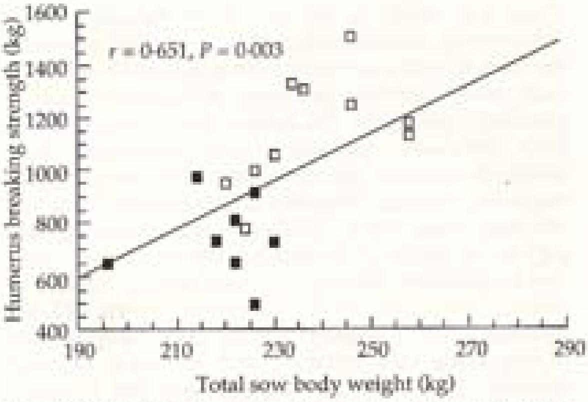

Figure 2 Correlation between humerus breaking strength and total body weight for all sows: (□) group sows, (■) stall sows.

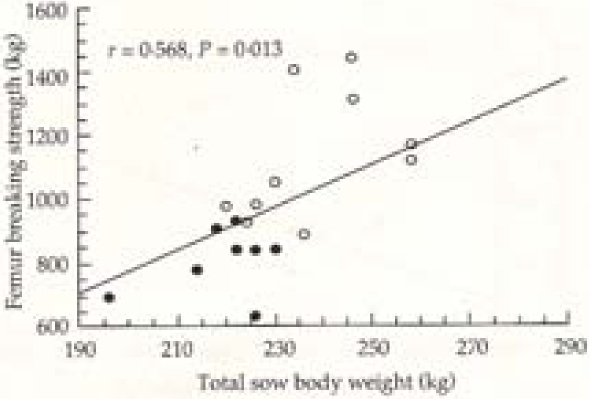

Figure 3 Correlation between femur breaking strength and total body weight for all sows: (○) group sows, (●) stall sows.

length and width during the analysis of femur breaking strength.

With all six covariates included, there was no longer any significant difference in femur breaking strength (F = 1·82, P = 0·207) or humerus breaking strength (F = 1·53, P = 0·244) between housing systems. Stepwise regression analyses were then carried out in order to eliminate unnecessary variables. For the femur data, housing system was the only significant factor affecting femur breaking strength (t = 4·18, P < 0·005, d.f. = 17). For the humerus data, both forelimb muscle weight and housing system were significant factors affecting humerus breaking strength (t = 2·49, P < 0·01, d.f. = 16 and t = 3·22, P < 0·005, d.f. = 16 respectively).

Discussion

In this study, confinement of sows in stalls has been shown to decrease the proportional weight of certain locomotor muscles and to decrease femur and humerus strength in comparison with sows which have been loose-housed. These effects have been examined in relation to one another and to body weight and reproductive output. Whereas the stall-housed animals were heavier than the group-housed animals as gilts, by the fourth parity onwards and up to slaughter, the stall-housed sows were significantly lighter. There may be a number of reasons for this difference in total body weights. Firstly, confinement during the growing phase may have had an effect on skeletal and muscular development. The stall-housed sows used in this study were found to have a significantly shorter body length than the group-housed sows, although they were of similar body length when housed as gilts. This may illustrate that exercise is important to allow growth and development of bone and muscle to their full genetic potential. However, differences in weight due to the catabolic effect of cortisol during growth can be discounted, as there were no differences in pituitary-adrenal function between these stall-housed and group-housed sows in either the first or fourth parities (Mendl, Broom and Zanella, 1993).

A second possible explanation is that levels of activity differed. The stall-housed sows spent a small amount of time inactive (Broom *et al.*, 1995) and a

Table 4 *Correlation between bone strength and total body weight, within each system*

System	Bone	r	P
Group	Humerus	0·493	0·123
Group	Femur	0·240	0·476
Stalls	Humerus	0·016	0·971
Stalls	Femur	0·333	0·421

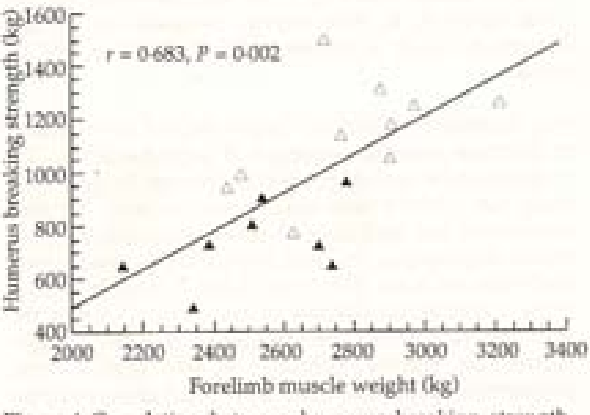

Figure 4 Correlation between humerus breaking strength and forelimb muscle weight for all sows: (△) group sows, (▲) stall sows.

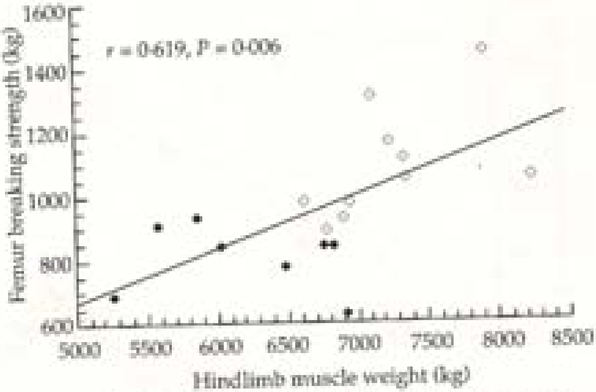

Figure 5 Correlation between femur breaking strength and hindlimb muscle weight for all sows: (○) group sows, (◆) stall sows.

There are likely to be two consequences of this difference in muscle weight. The decreased muscular strength in stall sows may contribute to the difficulty seen when carrying out basic movements such as standing and lying (Marchant and Broom, 1993). Such difficulties indicate poorer welfare in these confined systems for dry sows. However, in the farrowing system, difficulty in controlling lying and standing may have welfare implications for the piglets, in terms of increasing the chance of death due to crushing. The second consequence may be an altered susceptibility to lameness. With weaker muscles, there is a greater chance of the sow slipping during lying and standing and incurring physical damage. There is also the possibility that different conformation affects the incidence of lameness, by changing joint angles and increasing strain on particular muscles or ligaments, rendering them more prone to injury.

large amount of time performing energetically costly stereotypies (Cronin, 1985). However, there was no correlation between body weight and time spent performing stereotypies within the stall-house system. A third factor may be cold stress. Ambient temperature was consistent between the two systems in warmer weather and supplementary heating was provided in the stall house in cold weather so air temperature should not have had a major effect on metabolism. However, the stall-housed sows were bedded on insulated concrete which gives rise to a greater conductive heat-loss from the sow to the floor substratum than the straw on which the group-housed sows were bedded. Potentially, over the long term, this may represent a large energy loss for sows housed on concrete, since thermoregulation may be achieved by an increase in metabolic rate which would be consistent with a corresponding increase in basal heart rate (Marchant and Rudd, 1993). A fourth possible factor affecting body weight could be the small amount of extra energy available to group-housed sows as a consequence of their access to straw.

The decreases in muscle weight would be expected to decrease muscular strength. It is probable that the differences in muscle proportion would be greater if body fat content was taken into account. During dissection, the stall-housed sows appeared to have less subcutaneous fat than the group-housed sows, and thus the total weight of skeletal muscle should form a higher proportion of total body weight for stall-housed sows, proportional muscle weight would be similar because of the higher total proportion of muscle in the body. Therefore, because of the perceived differences in body fat, it is likely that the differences in proportional muscle weight are even greater in real terms.

The results also show that confinement leads to a decrease in bone strength. All bones were subjected to the same treatment, and care was taken to ensure that all bones were stored at the same temperature and not frozen as this is known to affect breaking strength (Merkley and Wabeck, 1975). The amount of tissue removal was consistent across samples, as presence of flesh has been shown to increase the amount of energy required to break bones (Currey, 1968). Loading rate was kept constant between samples as this can also affect the final breaking strength (Wright and Hayes, 1976; Knowles, 1990). Other factors which may have influenced the difference in breaking strength between stall-housed sows and group-housed sows include genetic strain, which has been demonstrated as a factor in poultry (Rowland, Fry, Christmas, O'Steen and Harmes, 1972), and diet. Genetic strain is not a possible factor in this study, as both sets of sows came from the same stock and in some instances were litter-mates.

There have been numerous studies of the effects of differing levels of calcium and phosphorus in the diets on bone strength (e.g. Reinhart and Mahan, 1986; Combs, Kornegay, Lindemann, Notter, Wilson and Mason, 1991; Hall *et al.*, 1991). In this study, the diet was the same for both systems, and the amounts and ratio of calcium and phosphorus were well within the guidelines of recommended daily intake. There is the possibility that calcium and phosphorus available in straw in the group-housing system may have affected the results. It has been noted in humans that fibre can bind dietary calcium, decreasing absorption and decreasing transit time through the gut (Reinhold, Farndji, Abadi, and Mismail-Beigi, 1976). The effect of dietary fibre on gut transit time has also been demonstrated in pigs (Schnabel, Bolduan and Güldenpenning, 1983) and, although the effect on calcium absorption and utilization is uncertain (Low, 1993), it has been shown that increased crude fibre significantly reduces the amount of phosphorus retained (Jongbloed, 1987). When the retention of phosphorus is decreased, the urinary excretion of calcium increases to reduce the amount of calcium retained in the body and maintain the calcium : phosphorus balance. Thus, if access to straw did affect bone strength, it would have decreased, rather than increased, bone strength in the group-housed sows.

The correlation analyses suggest that differences in total sow body weight, total limb muscle weight and reproductive output may be contributing to the differences in bone strength between systems. Total body weight could be taken as a measure of the static loading exerted on the limb bones when the animal is standing and appeared to be a factor influencing bone strength (see Figures 2 and 3), when both systems are combined. However, when the data were re-analysed using the general linear model, total body weight was not a significant factor in the difference between systems. Correlation analyses within dry sow systems (see Table 4) confirmed that there was no relationship between body weight and bone strength among stall-housed sows or among group-housed sows.

Reproduction has also been reported to have an effect on bone strength, due to the high calcium demands placed on the female during foetal growth, lactation and, in the case of poultry, formation of egg shell. Kornegay, Thomas and Meacham (1973) have shown that the breaking strength of sows' femurs decreases with increasing parity number. This effect was also demonstrated by Nimmo (1980) using two sets of gilts, one set having undergone a single gestation and lactation, and the other remaining unserved. In the study reported here, sows were matched for parity number (eighth to ninth) and there was no difference in average parity between systems.

However, the number of piglets born alive per sow and the number reared over eight parities tended to be higher for stall-housed sows. Thus, it could be argued that reproductive demand for calcium and phosphorus during gestation and lactation was higher for stall-housed sows and could therefore contribute to the difference. Correlation analyses of reproductive output and bone strength (see Table 3) showed no relationship when both systems were combined, but when each system was analysed separately there was a tendency for femur breaking strength to be correlated with both the number of piglets born alive and the number of piglets reared, in the stall-housed sows only. Analysis of covariance showed that overall, reproductive output did not contribute significantly to the differences in bone strength.

The difference in bone strength between systems is probably due to the different amounts of dynamic loading that each system permits, i.e. the loading exerted by the muscles during exercise. Exercise has been implicated in studies on bone strength, with much work having been carried out on hens, where large numbers are easily obtainable for comparison. Meyer and Sunde (1974) increased bone breaking strength of caged layers by a few minutes on an exercise machine. McLean, Baxter and Michie (1986) found stronger tibiae in aviary layers than caged layers, and noted that aviary birds typically moved seven times as far during a specified time period. Knowles and Broom (1990) have also noted substantial differences in wing and leg bone strength associated with exercise levels in hens housed in different systems. Lanyon (1984) has proposed that with decreased dynamic loading, calcium is mobilized from the bone under hormonal control. The mechanism by which this occurs is not known (Lanyon, 1987).

As individual muscle weight increases, volume and cross-section will enlarge, leading to an increase in the force that the muscle can transmit. Thus, absolute muscle weight can indicate the amount of force that a muscle can exert through its origin and insertion and addition of the individual muscle weights for each limb can indicate the potential muscular force that can be exerted on the bone during movemement. The results shown in Figures 4 and 5 and the correlational analyses within systems (see Table 5) suggest that as the potential force increases, bone strength increases, although the small number of muscles measured in this study can give only an impression of the total potential force acting on the bone. Analysis of covariance demonstrates that in this study, total forelimb muscle weight is a significant factor influencing the difference in humerus bone strength between systems. This supports the theory of dynamic loading influencing calcium mobilization, proposed by Lanyon (1984).

Table 5 *Correlation between bone strength and total limb muscle weight, within each system*

System	Bone	r	P
Group	Humerus	0·540	0·087
Group	Femur	0·560	0·073
Stalls	Humerus	0·512	0·194
Stalls	Femur	0·213	0·612

The fact that forelimb muscle weight is a significant factor affecting bone strength whilst hindlimb muscle weight is not, may be explained by the extent to which these muscles are used. During standing up and lying down, the majority of dynamic loading occurs in the forelimb. The hindquarters usually fall to the floor during lying down and are pulled up by the forward momentum generated during standing up (Baxter and Schwaller, 1983). Thus, during these behaviours, dynamic loading in the hindlimb is minimal. The fact that stall-housed sows still have lighter locomotor muscle weights than group-housed sows even when the total body weight variable is removed (see Table 2), indicates the substantial effect that confinement has on locomotor muscle strength.

Group-housed sows are also able to exercise their limb muscles by walking, during which dynamic loading should act on both the humerus and the femur to a similar extent. This may explain why there is no effect of reproductive demand on the femur strength of these sows; reproductive demand may be compensated for by dynamic loading during locomotion. Stall-housed sows, however, are restricted to exercising their limb muscles only during standing up and lying down. Thus, overall dynamic loading on the femur may be relatively slight and this may account for why reproductive ouptput has an effect on the femur breaking strength in these stall-housed sows.

This decrease in bone strength may also influence the incidence of lameness, in conjunction with the differences in muscular conformation. Lameness has been reported as being more frequent in confined sows (Bäckström, 1973; Tillon and Madec, 1984). Krohn and Munksgaard (1993) have also noted a greater incidence of hock inflammation in dairy cows housed in confinement, illustrating the fact that confinement poses locomotor problems in other domestic species.

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