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Limb bone strength and movement in laying hens from different housing systems

T. G. Knowles, D. M. Broom

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Walking and bouts of wing movement performed by 61-week-old ISA brown laying hens which had been taken from one batch of eggs and then kept in three different housing systems which allowed a gradation in spatial freedom, were recorded. After slaughter the breaking strengths of the humerus and tibia of birds from each system were measured. Birds from battery cages exhibited the fewest limb movements and had the weakest bones, their humeri having only 54 per cent of the strength of those of birds from a perchery. Birds from the Elson terrace system were heavier and had a stronger tibia than cage birds. Compared with perchery birds, terrace birds had weaker humeri and also performed fewer wing movements. The results indicate that the amount of movement possible for laying hens in battery cages was insufficient to avoid levels of osteopenia and consequent bone fragility much greater than in birds kept in the perchery and Elson terrace systems.

LIVE laying hens transported to slaughter have been shown to suffer from a high incidence of freshly broken bones in Denmark (Simonsen 1983) and in the United Kingdom (Gregory and Wilkins 1989). In the UK study a mean of 29 per cent of hens from battery cages were found to have freshly broken bones before they were stunned. These and other effects of transport on hens have been reviewed by Broom and Knowles (1989), Broom (1990) and Knowles and Broom (1990). The incidence of freshly broken bones in hens transported from perchery or free range systems has been shown to be considerably less than in similar hens from battery cage systems (N.G. Gregory and L. J. Wilkins, personal communication).

The term 'osteopenia' is used to describe a condition of lack of bone due to osteoporosis or osteomalacia or both (Randall and Duff 1989). It has been shown experimentally that restricting the birds' ability to move and exercise can affect the breaking strength and degree of osteopenia in the bones of poultry (Meyer and Sunde 1974, Nightingale and others 1974, Lanyon and others 1986). Using laying hen turkeys, Lanyon and others (1986) have shown that in order for bone to maintain its normal thickness and functional structure it must be subject to some level of dynamic loading; short periods of loading within a given range of strain and frequency were necessary to prevent bone degeneration. They also demonstrated that bone loss due to disuse and bone loss due to calcium insufficiency seem to be additive and that bone loading provided a substantial conservative influence on bone mass even under conditions of calcium insufficiency involving extensive resorption.

In order to investigate the effects of housing systems on bone strength and bird movements, hens were housed in three housing systems which allowed them a gradation of spatial freedom. The weight of the birds, the number of wing and leg movements made within each system and the breaking strength and length of the humerus and tibia were measured.

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Materials and methods

The three housing systems used in the experiment were, first, a commercial battery house containing 15,000 birds in BEC plastic cages. The cages were stocked at five birds per cage giving 430 cm²/bird, a maximum height in the cage of 43 cm and a minimum height of 33 cm; secondly, the ADAS experimental Elson terrace in which 150 birds were housed in four tiers interconnected by a stairwell. Each tier measured 98 cm × 320 cm with a maximum height of 50 cm and a minimum height of 40 cm. The tiers consisted of a lower littered level and three wire-floored upper decks with nest boxes, feeders, drinkers and rectangular perches (Elson 1989); thirdly, the Gleadthorpe experimental perchery which contained a 44·05 m² littered area and was stocked with 1318 birds at 16·9 birds/m² of total area.

The experimental hens were ISA brown birds obtained from one supplier from the same batch of eggs and housed at point of lay at 18 to 19 weeks old. The diet of the caged birds was slightly different from that of the other two treatments but offered similar levels of nutrition (Table 1). The diets were formulated to the recommended levels of calcium and available phosphorus for laying hens which are 4500 mg/hen/day and 350 mg/hen/day, respectively (ADAS 1983).

The perchery and terrace systems were in the same building and shared the same lighting system. The average light level in the perchery was 11·8 lux (mean of 24 random measurements).

TABLE 1: Mean dietary composition, feed, calcium and phosphorus intakes and weight at slaughter of birds kept in three housing systems

	Perchery	Terrace	Battery cage
Metabolisable energy of diet (MJ/kg)	11·3	11·3	11·55
Crude protein (%)	16·3	16·3	18·29
Calcium (%)	3·60	3·60	3·59
Available phosphorus (%)	0·350	0·350	0·359
Feed intake (g/bird/day)	125·0	136·0	118·0
Calcium intake (mg/bird/day)	4500	4896	4236
Phosphorus intake (mg/bird/day)	438	476	424
Weight at slaughter (g)	2063	2161	1807

The light level at the outer edges of the terrace varied with tier from 11·0 lux at the top tier to 4·1 lux at the ground. A level of 11·0 lux was found at the centre of the top tier and 1 lux at the centre of the three lower tiers. Only birds from the middle row of the battery cage system were used in the experiment. The light level in the centre of the floor of an empty middle row cage was 10·8 lux. After 50 weeks of age the behaviour of hens during the light period was video recorded using the normal light levels in the houses. Two cages of five hens were each video recorded for two periods of 1·5 hours. The birds' activities were recorded and their frequencies during the total time that the hens could be clearly seen were calculated. In order to obtain typical activity measures within the perchery and the terrace, video recordings were made at more than one site. In the perchery, 10, 30-minute recordings were made at five sites and at two times of day, making a total of five hours. In the terrace, 12, 30-minute recordings were made at three sites and at four times of day, making a total of six hours. The activities of all the birds in each field of view were recorded. For the analysis, bouts of wing movement were recorded in four categories: flight, flapping, stretching and ruffling. A single bout was defined as the period between the moment when the wings were moved from their normal folded position and the moment when they were returned to the folded position. Ruffling consisted of movements during which the wings were lifted from the body but not extended. Leg movements were recorded as the number of locomotor steps taken by a bird.

At 61 weeks of age, 50 birds from each system were killed and the right tibia and humerus were carefully dissected out. The samples were stored deep frozen both before and after dissection. The thawed bones were broken on a tensiometer using a three point bend with supports 30 mm apart and a load applied at 50 mm/minute to the mid-point of the long axis of the bone. The parts of the tensiometer which were in contact with the bone were covered with rubber tubing to avoid point stresses and care was taken to ensure that the bones were always in the same orientation. Systematic orientation of the bones was facilitated by two upright guides welded to the lower support of the tensiometer. The breaking strength was recorded as the peak load before the bone broke.

The behavioural data were analysed by a Kruskal-Wallis non-parametric analysis of variance, and individual differences between medians were examined by the Mann-Whitney test. The weights of the birds and the breaking strengths and the lengths of the bones were analysed by analysis of variance and Duncan's multiple comparison test.

Results

There were no differences between the lengths of the bones of birds from the different systems, so that the measurements of their breaking strengths were comparable. Had the treatments modified the length of the bones, the geometry of the bones presented to the tensiometer would have been different and the breaking strengths of bones from birds on the different treatments would not have been comparable.

The mean breaking strengths of the bones are shown in Fig 1. The mean breaking strength of the humerus was 176 N for caged hens, 241 N for terrace hens and 325 N for perchery hens. These differences were all significant ($P<0·001$). The mean breaking strength of the tibia was 303 N for caged hens, 348 N for terrace hens and 325 N for perchery hens. The breaking strength of the tibia of caged hens was significantly less than that of the terrace hens ($P<0·05$). The mean weight of the birds (Table 1) on each treatment was significantly different from the others ($P<0·05$). When weight was introduced as a co-variate into the analysis of variance of the breaking strengths of the tibia there was no longer a significant difference between treatments; there was a correlation of 0·36 ($P<0·01$, one-tailed) between weight and breaking strength. As a co-variate in the analysis of variance of the breaking strength of the humeri, the weights of the birds made a significant contribution to the differences found ($P<0·001$) but treatment differences were still significant ($P<0·001$); there was a correlation of 0·33 ($P<0·01$, one-tailed) between weight and breaking strength. Table 2 shows the correlations between breaking strength of bone and weight of bird by treatment. There was a correlation between the breaking strength of the tibiae and the weight of the birds from the terrrace and perchery, but not for those from the cages, and there was a correlation between the breaking strength of the humeri and the weight of the birds from the perchery.

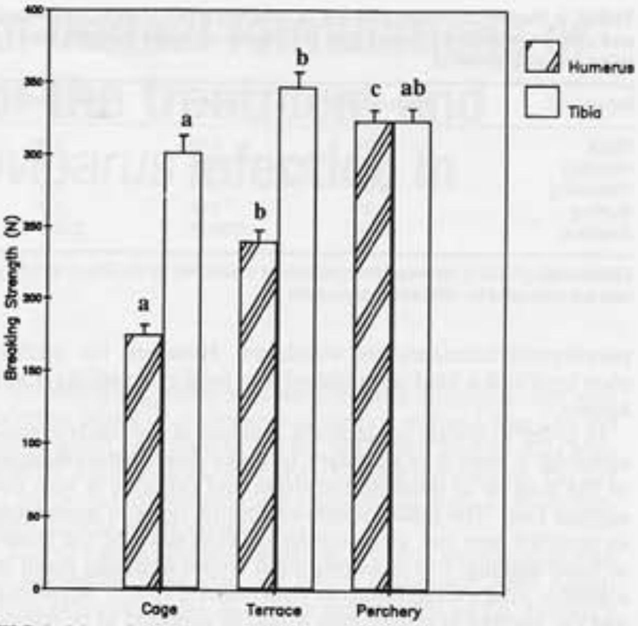

FIG 1: Mean bone breaking strengths in Newtons. Significant differences, as measured by the Duncan's multiple comparison test, are shown by different letters (humerus $P<0·001$, tibia $P<0·05$)

The median amount of limb activity of the birds in the different systems is summarised in Table 3. Kruskal-Wallis tests showed that there were significant differences between medians within types of limb movement for flight, flapping and stretching movements ($P<0·01$) but not for ruffling movements. Flight occurred only in the perchery and flapping of wings was impossible in the cages. Birds in the Elson terrace system flapped their wings once every five hours but walked much more than birds in the other systems. The loading on the wing bones would be substantial during flight, considerably less during flapping and less still during stretching and ruffling. The wing stretching recorded in the cages occurred most often when a bird extended its wing or wings for balance, when it was pushed by or climbing over another bird.

Discussion

The humeri of the hens from the battery cages had a substantially lower breaking strength than those of the birds from the perchery or Elson terrace, probably because of the lack of wing movement rather than any inadequacies of diet. Dynamic loading is known to play an important role in the remodelling of bone. Lanyon (1984) proposed that remodelling involves the opposing effects of loading, which serves to build and preserve bone structure, and the systemic action of hormones involved in calcium regulation, which serve to mobilise calcium from the bone. This view is supported by Lanyon's own work and by the work of Burkhart and Jowsey (1967) which has shown that disuse osteoporosis can be prevented if thyroid and

TABLE 2: Correlation coefficients between breaking strength of the humerus and tibia, and the weight of birds kept in three housing systems

Housing system	Humerus	Tibia
Battery cage	-0·1062 (NS)	0·0248 (NS)
Terrace	0·0419 (NS)	0·3004 ($P<0·025$)
Perchery	0·4816 ($P<0·001$)	0·3734 ($P<0·01$)

NS Not significant

TABLE 3: Median numbers of bouts of different types of wing movement and median numbers of steps (per bird per hour) made by birds kept in three housing systems

Movement	Battery cage	Terrace	Perchery
Flight	$0 \cdot 0^{a}$	$0 \cdot 0^{a}$	$0 \cdot 4^{b}$
Flapping	$0 \cdot 0^{a}$	$0 \cdot 2^{b}$	$1 \cdot 9^{c}$
Stretching	$4 \cdot 0^{a}$	$0 \cdot 1^{b}$	$0 \cdot 0^{c}$
Ruffling	$1 \cdot 3^{ab}$	$0 \cdot 9^{a}$	$0 \cdot 3^{b}$
Stepping	$72 \cdot 0^{a}$	$1058 \cdot 3^{b}$	$208 \cdot 2^{c}$

Differences (P<0·01) between the systems as measured by the Mann-Whitney test are indicated by different superscripts

parathyroid hormones are withdrawn. However, the mechanism by which a load is translated into bone remodelling is not known.

In order to obtain an accurate measure of the loads experienced by a bone it is necessary to make direct measurements of the load or to measure the strain and calibrate it with the applied load. The measurement of specific types of movement as reported here can give only an intuitive sense of the extent of bone loading. For example, flight would normally result in a greater load on the humerus than either flapping or ruffling and the number of movements would be expected to be related to the probability of an event occurring which would influence bone remodelling.

The results show that the weight of a bird varied with the strength of both bones. The significant difference between the breaking strengths of the tibiae of birds on the different treatments was entirely accounted for by the differences in the weights of the birds and some of the difference between the breaking strength of the humeri was also due to the differences in weight. Even after account had been taken of the effect of weight on the strength of the humeri, however, there still remained a substantial and significant treatment effect. The known effect of loading on bone remodelling would suggest that the relationship between bird weight and bone strength is a causal relationship rather than just coincidental. The correlations and lack of correlations in Table 2 and the amounts of movement shown by birds within the different systems appear to be related. Where it would be expected that the birds' weight would most influence the loading of a bone there is a correlation between bird weight and bone strength, as with the humerus of the birds able to fly in the perchery. The strengths of the humeri of birds in the terrace, where flapping was possible, and in the cages where only ruffling and stretching of the wings could occur show no influence of bodyweight on bone strength. Similarly, the differences between the amounts of walking undertaken by the birds in the diferent systems could explain the correlations between the strength of the tibiae and the weight of the birds.

No flight was possible within the battery cages or the terrace and no wing flapping was recorded within the cages. Wing flapping within the terrace was only recorded on the litter and in the stairwell. As shown in Table 3 the movements such as flight, wing flapping and walking which are likely to involve load bearing by bone were much less frequent in the cages than in the other systems and the bones from the caged birds were weaker (Fig 1). The breaking strength of the humerus of terrace birds, which flapped their wings only 10 per cent as much as the perchery birds, was greater than that of the caged birds but not as great as that of the perchery birds which had ample opportunity for both flight and wing flapping. The wing flapping displayed by the terrace birds provided a level of bone loading which probably prevented their humeri from becoming as weak as those of the caged birds. The humerus appeared to be most affected by confinement and is one of the bones most frequently broken when spent hens are transported. Gregory and Wilkins (1989) reported that the bones most commonly broken during the transport of live caged hens are the keel (7 per cent of birds), ischium (6 per cent), humerus (5 per cent) and furculum (5 per cent).

The use of a perch has been shown to increase the breaking strength of the tibiae of hens (Hughes and Appleby 1989). Both the perchery and the terrace birds had the use of perches. The absolute values of bone breaking strength measured by different researchers are not directly comparable unless the handling of the bones and the method of breaking them has been rigidly standardised. Large systematic variations may otherwise confound any comparisons. When comparing two trials it is thus usually only valid to say that a treatment increases or decreases breaking strength compared with a treatment which is common to both trials. It seems possible from the work of Hughes and Appleby (1989) that the inclusion of perches in the cages in the trial reported here would have increased the breaking strength of the tibiae, but the extent of any increase compared with the strength found in terrace or perchery birds would require further investigation. McLean and others (1986) compared the breaking strengths of the tibiae of birds in cages and in a perchery and, in agreement with the trend found in this work, found that the perchery birds had significantly stronger tibiae. They did not report the weight of the birds.

The legislation in the European Community (in the UK the Welfare of Battery Hens Regulations 1987) requires new battery cages to have a minimum area of 450 cm^2/bird, when four or more hens are caged together, and a minimum height of 40 cm over at least 65 per cent of the cage area. The results presented here show that such a space allocation does not ensure the birds sufficient freedom of movement to allow adequate bone loading to develop normal bone strength through functionally adaptive changes in bone architecture.

There can be no doubt that a bird's welfare is inadequate if its bones are broken, for example when it is transported to slaughter, and a housing system which results in an increased likelihood of such breakage is clearly undesirable. However, when considering the effects of housing systems on the welfare of hens it is necessary to take into account other welfare indicators (Broom 1988, Fraser and Broom 1990). The frequency of old healed breaks in birds from different housing systems has been measured (N. G. Gregory and L. J. Wilkins, personal communication). Such breaks would cause pain over a longer period than would a break in a bird which was soon to be slaughtered. Furthermore, the incidence of old healed breaks was higher in birds from perchery and free range systems than in birds from battery cages. This is of considerable importance as an indicator of welfare, as is the bone fragility reported in this paper, when housing systems are being compared.

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