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Effect of bone strength on the frequency of broken bones in hens

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Bird weight, breaking strength of humerus and tibiotarsus and the number of bones broken during culling were recorded for four breeds of end-of-lay hens housed in battery cages. The probability of a bone being broken increased with bird weight and decreased with increasing bone strength. Bone strength increased with bird weight within each breed but the increase in strength was not great enough to prevent the extra damage suffered by heavier birds. There were differences in tibiotarsal strength between the four breeds of bird but overall no breed was more likely to suffer from broken bones than another. The rate of increase of bone strength with weight was similar between breeds and between humerus and tibiotarsus. The results show that differences in bone strength due to the type of housing system in which birds are kept are great enough to affect the ease with which bones are broken during bird handling during removal from cages at the end of lay.

GREGORY et al (1990) have shown that the incidence of freshly broken bones in live hens taken for slaughter from farms at the end of lay is related to the housing system from which the birds are removed. Hens taken from battery cages tended to suffer more breaks than free range birds or birds housed in percheries. Knowles and Broom (1990) demonstrated that there can be a large difference in the bone strengths of birds that are kept in different housing systems and that this difference is, to a large extent, due to variation in the amounts of natural mechanical loading of bones. Variations in the amount of loading occurred as a consequence of the spatial restrictions on the type and amount of exercise that hens could perform and that was imposed by the different housing systems. The most restrictive system, the battery cage, resulted in humerus strength of only 54 per cent of the strength found in birds from a perchery system. Nørgaard-Nielson (1990) obtained similar results. Thus birds from battery cages have weaker bones and they also suffer a higher incidence of broken bones when they are removed from cages. However, it is important to note that this is not necessarily a causal relationship. The higher incidence of broken bones in caged birds could be entirely due to the increased likelihood of a physical insult occurring when a bird is removed from a battery system, which contains more obstructions, rather than from a more extensive system with fewer obstructions.

This study was carried out to determine to what extent breaking strength, within the range normally found in battery caged laying hens, is a factor in determining the probability of a broken bone occurring during removal from the cage.

Materials and methods

Four commercial breeds of layer were used in the study as Rowland et al (1972) have shown that breed can have a measurable effect on bone breaking strength and it was important to produce as wide a range of strengths as possible within the one type of housing system in order to pick up any effect on the frequency of breaks. The four strains used were ISA Brown, Shaver, Ross G Link and Starcross Brown. The birds were cage reared from one day old on an ad libitum starter diet of 12·2 MJ metabolisable energy

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(ME) kg^{-1}, 18·8 per cent crude protein, 1 per cent calcium and 0·78 per cent phosphorus with eight hours light per day. They were fed from week 6 a grower diet of 11·7 MJ ME kg^{-1}, 15·5 per cent crude protein, 1·1 per cent calcium and 0·70 per cent phosphorus, and from week 18 a layer diet of 11·3 MJ ME kg^{-1}, 16·3 per cent crude protein, 3·6 per cent calcium and 0·35 per cent phosphorus. From weeks 18 to 22, day length was increased by one hour per week and from week 22 by 15 minutes per week to a limit of 17 hours of light per day. Four birds were kept in each cage with 600 cm^2 per bird in three tiered battery cages.

At 82 weeks, 150 randomly selected birds from each breed were taken from the house as in a commercial depletion, weighed and then killed with an overdose of pentobarbitone (Euthatal; RMB) and stored in such a way as to avoid bone breakage. After cold storage the carcases were dissected and those bones listed in Table 1 were examined for any complete fractures. Where a bone spanned the midline of the body and there were complete fractures on either side of the midline, each was counted separately.

One unbroken humerus and tibiotarsus were dissected from each carcase and the breaking strength determined from a three point compression test using a tensiometer (Knowles 1991). The distance between the two fixed points used for supporting the tibiotarsus was 69 mm and for the humerus 30 mm. The bones were positioned so that when the third compression point moved down it made contact with the midpoint of the bone between its two ends, and with the same facial plane.

The breaking strengths of the same bone from either the left or the right side of a hen are very similar. Alexander et al (1984) estimated an upper limit for the coefficient of variation between left and right in the breaking strength of the long bones of hens as 5·2 per cent and showed that any asymmetry that was present was random.

TABLE 1: Bones examined for breakage during dissection

Femur
Tibiotarsus
Fibula
Humerus
Radius
Ulna
Keel
Lateral processes of sternum
Scapula
Coracoid
Furculum
Dorsal ribs (1-7)
Ventral ribs (1-5)
Ilium
Ischium
Pubis

The data were analysed by fitting a generalised linear model using the GLIM77 statistical package. Bone breakage was modelled as a binary response using a logit link (Healy 1988, Aitkin et al 1989).

Results

Out of a total of 600 birds 490 had no broken bones, 85 suffered from one, 19 suffered from two and six birds suffered from three.

Tibiotarsal breaking strength, humerus breaking strength, bird weight and breed were entered as predictor variables into the model which was based on how many bones, out of three, had been broken. There were 11 missing values due to the mislabelling and loss of individual bones. The inclusion, in the model, of the breed of a bird made no significant contribution to the fit so this was excluded. Tibiotarsal breaking strength and bird weight were the best predictors of the number of broken bones a bird was likely to sustain. There was a positive correlation between humerus breaking strength and tibiotarsal breaking strength ($r=0·335$, $n=598$, $P<0·0001$) and these measures fulfilled similar predictive rôles within the model if fitted separately. The inclusion of bird weight and tibiotarsal breaking strength but not humerus breaking strength, resulted in the most parsimonious model. The final model had a scaled deviance of 556·5 with 585 degrees of freedom. The deviance is a good approximation to a χ^2 distribution when the sample size is large (Healy 1988) and thus, as the scaled deviance was less than the number of degrees of freedom, the model and the data were not significantly different and the model fitted the data well. The parameter estimates are shown in Table 2 and these gave a final model of the form:

$$\log_e(y/1\text{-}y) = -3{·}476 + 8{·}377\text{e-}4(bw) - 4{·}55\text{e-}3(tbs)$$

where y = probability of a bone being broken, 1-y = probability of a bone not being broken, bw = bird weight in grams, tbs = tibiotarsal breaking strength in Newtons, and the expected number

TABLE 2: The parameter estimates of the best fit model

Parameter	Estimate	SE	*t*	Significance
Constant	–3·476	0·745	4·610	P<0·0001
Bird weight	8·377e-4	3·158e-4	2·653	P<0·005
Tibiotarsal breaking strength	–4·550e-3	2·150e-3	2·116	P<0·025

of broken bones per bird was equal to 3y (the probability of one break multiplied by the total number of breaks found in any one bird).

As it was difficult to examine the model using the large number of estimated and actual values, contingency tables of the estimated and actual values were constructed by dividing the bird weights into three categories and the tibiotarsal breaking strengths into three categories using the standard deviations as delimiters. The real and predicted values were found to be in good agreement in all categories. The predicted values and the expected number of broken bones per bird for each category are shown in Table 3.

The model showed that as bird weight increased the probability of a broken bone increased and as tibiotarsal strength increased the probability of a broken bone decreased. The size of the coefficients is not an indicator of the importance of a variable as the size of any coefficient is dependent on the type of units in which that variable is measured.

To assess the relative effect that the range of breaking strengths found had on the probability of a broken bone, compared to the effect that the range of bird weights found had, the changes in $\log_e(y/1\text{-}y)$ produced by moving from the 10 to 90 percentiles of breaking strength and bird weight were compared. The percentiles for breaking strength and bird weight produced changes of –0·9176 and 0·9885, respectively. Therefore bird weight and tibiotarsal breaking strength were both approximately equally important in determining the number of broken bones a bird was likely to sustain.

Since there was an association between bone strength and bird weight, two further models were constructed of the breaking strength of the tibiotarsus and of the humerus, respectively, in terms of bird weight and breed. This type of model, with both factors and variables as predictors is described by Healy (1988). Table 4 details the significant parameter estimates of both final models, and the model of tibiotarsal breaking strength is shown graphically in Fig 1. The breeds have been coded A, B, C and D to maintain the confidentiality of the breeding companies. The main conclusion drawn from this analysis is that breed influenced tibiotarsus but not humerus breaking strength.

TABLE 3: Predicted number of broken bones in each tibiotarsal breaking strength/weight category over the total number of bones in that category which could possibly have been broken. The expected number of broken bones per bird (3 × the probability one bone is broken) is shown in brackets below

Bird weight	Tibiotarsal breaking strength Low <171N	 Medium 171 – 264N	 High >264N
Low (<2·0 kg)	4·69/66 (0·21)	8·46/177 (0·14)	0·87/21 (0·12)
Medium (2·0 to 2·6 kg)	16·29/150 (0·33)	65·53/885 (0·22)	10·18/159 (0·19)
High (>2·6 kg)	3·02/24 (0·38)	15·02/174 (0·23)	6·96/93 (0·22)

TABLE 4: Parameter estimates for the models of tibiotarsal breaking strength and humerus breaking strength in terms of breed and bird weight

Parameter	Estimate	SE	*t*	Significance
Model of tibiotarsal breaking strength				
Constant	95·02	13·52	7·028	P<0·0005
Weight	0·0527	0·0059	8·989	P<0·0005
Breed (B)	26·15	4·208	6·214	P<0·0005
Breed (D)	–17·86	4·251	4·201	P<0·0005
Model of humerus breaking strength				
Constant	83·28	6·020	13·834	P<0·0005
Weight	0·0542	0·0067	8·063	P<0·0005

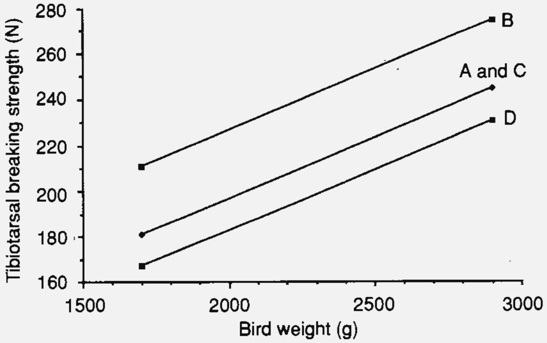

FIG 1: The model of tibiotarsal breaking strength as determined by bird weight and breed

Table 5 shows the mean bird weights and humerus and tibiotarsal breaking strengths.

Table 4 shows which factors were associated

TABLE 5: Mean weight and humerus and tibiotarsal breaking strengths for each breed of hen (SEM)

Breed	Weight (g)	Humerus breaking strength (N)	Tibiotarsal breaking strength (N)
A	2264 (22)	182·4 (3·6)	210·7 (3·1)
B	2279 (23)	186·5 (4·4)	241·3 (4·3)
C	2267 (25)	180·8 (4·4)	217·4 (3·8)
D	2371 (26)	192·0 (4·6)	202·1 (3·3)

with breaking strength. There was no interaction effect of weight and breed on either tibiotarsus or humerus breaking strength. Within the data from this experiment tibiotarsal breaking strength was associated with both breed and weight within each breed, while humerus breaking strength was only associated with bird weight. The tibiotarsal breaking strength of breed C was not significantly different from breed A and when included in the model gave a parameter estimate of 6·525, SE=4·816, t=1·355, $P>0\cdot05$ and so it was dropped from the final model.

Had the breaking strength of a bone been associated with the interaction term and both independent terms, then the graphical model represented in Fig 1 would have been a series of non-parallel lines of bone strength against weight, with each line representing the relationship between bone strength and weight for a different breed. With no significant interaction effect the model was similar but the lines representing each breed were parallel (Fig 1). The results in Table 4 for the tibiotarsus show that the data were best represented by three parallel lines in which breeds A and C were represented by the central line, breed B by the upper line and D by the lower line. A and C were both represented by the same line as there was no detectable difference between these breeds. The lines for B and D are a vertical distance of 29·82 and 14·17 N, respectively, from the lines representing breeds A and C. Breed D had a significantly weaker tibiotarsus than all other breeds and breed B had a significantly stronger tibiotarsus than all other breeds.

Discussion

The major result of this study confirmed that birds with weaker bones were more likely to have their bones broken during handling.

It is interesting to note that an increase in the chance of a broken bone was associated with increased bird weight and decreased bone strength (Table 3) and yet increased bone strength was associated with increased bird weight within each breed (Table 4 and Fig 1). It seems that although a heavier weight was associated with increased bone strength any beneficial effect of strong bones decreasing the likelihood of breakage was overridden by the consequential increase in broken bones due to the weight of the bird.

The parameter estimate of the rate of change of tibiotarsal breaking strength with weight from the model of tibiotarsal breaking strength can be substituted into the term involving tibiotarsal breaking strength in the first model of the frequency of broken bones. By doing this it is possible to compare quantitatively the relative effect of weight through its direct association with break frequency and also through its indirect effect on break frequency due to its association with breaking strength. The rate of change of tibiotarsal strength with weight was 0·0527 N g^{-1} and substituting this as the term for tibiotarsal strength in the model of break frequency gave the probability of a break as proportional to –2·4 e-4 times bird weight (from –0·00455 × 0·0527). But the model already had a term for bird weight in which the probability of a break was proportional to 8·4 e-4 times the bird weight. As this term is 3·5 times as large, the ultimate effect of bird weight was to increase the likelihood of a break occurring.

It was likely that, when handled, the heavier birds experienced greater momentum, causing greater loading, during a physical insult. The increased strength with bird weight was probably due to the increased mechanical loading on the bone (Lanyon et al 1986) over the lifetime of the bird.

The final model of the odds of a broken bone occurring used bird weight and the tibiotarsal breaking strength as explanatory variables. The inclusion in the model of tibiotarsal breaking strength rather than humerus breaking strength could indicate that in caged birds the tibiotarsus was a better predictor of the overall robustness of the skeleton or alternatively the experimental error in measuring tibiotarsal breaking strength could have been less as breaking strength is more easily measured because the tibiotarus is a longer and more uniform bone than the humerus.

The results presented here are in agreement with the findings of Rowland et al (1972) that breed affects bone breaking strength. However, the differences in strength found here were not great enough to affect the frequency with which bones were broken in the different breeds, within the sensitivity of this study. Table 4 demonstrates that there were no differences in humerus breaking strength between breeds once the effects of bird weight were considered. It also shows that the rate of change of breaking strength with weight was similar between the humerus and tibiotarsus and between all breeds.

There can be no doubt that welfare is poor if bones are broken in a live bird, for example, when birds are transported to slaughter. A housing system which results in a greater likelihood of bone breakage is clearly undesirable. The results presented here show that the previously found differences in bone breaking strength caused by different types of housing system (Knowles and Broom 1990) are of sufficient magnitude to have an effect on the incidence of broken bones. In the previous study increases in mean tibiotarsal breaking strength of up to 15 per cent were found in birds from alternative systems compared with the battery system. It is likely that there is also an effect due to the environment from which birds are removed on the incidence of breaks but, without further studies using birds with a similar bone strength removed from these different housing systems, it is not possible to say which housing systems are more likely to produce broken bones than others. The results also show that, among the four breeds used, the problem of broken bones does not have a breed basis. While there was some difference in bone strength between the breeds studied it was not of sufficient magnitude to lead to identifiable differences in the number of bones broken in the different breeds.

In addition to the above results it should be remembered that bone fragility is only one contributing factor to the problem of broken bones in spent hens. It is certain that birds with bones of apparently normal strength also suffer broken bones during handling. For example, fresh breaks are still common in hens caught from alternative housing systems (Gregory et al 1990) even though bone strength in such systems is greater than in the battery system (Knowles and Broom 1990, Nørgaard-Nielson 1990). The primary cause of breaks is the whole process of catching and handling large numbers of small, fragile animals in as short a time as possible by workers paid on a piece rate basis.

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