A MODIFICATION IN SKELETAL BONE GROWTH BY THE SELECTION FOR BODY WEIGHT IN MICE

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Introduction

There is a variation in mature body shape among breeds within a species of domestic animals. For example, meat-type cattle differs from dairy-type cattle in their external body shapes. Body shape is economically important in assessing the carcass composition particularly for meat animals. The divergence in body shape is the result of differential growth rates in individual parts to other through the growing periods, which may often lead to a change in physiological and economical efficiency.

The relative growth on major tissues of the animal bodies (muscles, bones, fats), have been extensively studied in meat animals in relation to carcasss composition, demonstrating that bones are early developing but slow growing, muscles intermediate but more rapid, with the greatest proportion of fat being deposited later in life.[2,8,9,11~17,28]

Concerning the relative growth of individual bones to total bone weight, a centripetal growth gradient from distal to proximal limbs and an anterior-posterior gradient along the dorsal line have been demonstrated in sheeps[15], in pigs[10,25~27,32,33], in cattle[2,8,34] and mice[35]. JONES *et al.*[18] presented the results to be not in total agreement with the evidence. DAVIES[10] documented that the growth in bone well corresponded to those in adjacent bones and muscle groups with high growth rates, from the study on the relative growth in pigs. Several studies comparing the relative growth and the distribution of bone weight among breeds of pigs[11,33] and cattle[2,18] revealed that the growth coefficients were homogenous among breeds for each bone but the distribution were significantly different in some bones for both species. It was assumed that the significant differences probably resulted from the discrepancies in stages of maturity.

In laboratory animals, a sexual dimorphism in pelvic bones was investigated for rabbit[20,22], rats[3] and mice[7]. MACARTHUR and CHIASSON[23] showed the difference in relative length of appendages (the ratio of tail, ear and foot length to body length) betweeen the races selected for small and large body weight. KIDWELL *et al.*[19] investigated the inheritance of the relative growth of tail length to body weight in mice, and the heritability estimates was very low (0.0-0.03).

As in the above review of the studies on the relative growth in bone, most of the works on the relative growth in domestic animals were concerned with the growth in weight in its relation to carcass composition but not with the growth in length. The information obtained from the selected mice has also been limited to certain bones. The interest in this study is to investigate the alteration in body shape which may be a reflection of the selection for body weight. For this purpose, the influence of selection for increased body weight on the growth coefficient in each of the major skeletal bones was investigated in mice.

Materials and Methods

Two selected strains (MF and FF strains) and a control strain (CC strain) were used in this study. The MF strain were selected for increased body weight at six weeks of age for male and female mice, while the FF strain was done on females alone. The representative mice were sampled from the second mating at 15th and 16th generations of these selected and control strains. Mice sampled from litters were weighed and slaughtered at 3, 4, 5, 6 and 9 weeks of age, so that the number within each litter would be proportionately distributed among the five groups within each strain-sex sub-group. A total of 216 mice of different ages were included with 4 to 9 animals in each strain-sex-age group. The measurement of bone was carried out on 11 sites as follows: the length of scapula, humerus, ulna, left os coxae, tibia, 13 thoracic vertebrae, 6 lumbar vertebrae and 4 sacrae vertebrae, and the width of scapula and left os coxae. The preparation for measurement of bones, and the methods of the measurement have been previously presented in the paper on the sexual difference in bone growth.[35] General management and raising have been also presented in the paper.

The growth of bones was assessed from two aspects of the growth curve itself, and relative growth coefficient relative to body weight and to humerus length. The reason that the length of humerus was chosen as the basis to describe the relative growth of bone besides body weight, is due to the fact that major skeletal bones could be well grouped into three categories: positive, even and negative allometry, according to the growth coefficient to humerus length.[35] Logistic equation was fitted to the growth curve of body weight and bone sizes, in the form: $Y_t = A/(1+BK^t)$, where Y_t represents the body weight (g) or length or width (mm) at t weeks of age, and A, B, and K are parameters. Estimation of the parameters (A, B and K) was carried out by using the program package for Statistical Analysis with Least-Squares Fitting (SALS) at Hokkaido Computing Center[29]. Pictures in Fig. 1 and 2 were drawn by XY-Plotter at the same center. To describe the relative growth in each bone relative to body weight or humerus length, Huxley's allometric equation ($Y = aX^b$)[16] was used. In the above equation, Y represents the length or the width of the bone, X represents body weight or humerus length, b is a relative growth coefficient expressing the growth rate of Y relative to X, and a is a contant. Coefficients were estimated from regression analysis after converting two variables (X and Y) to logarithmic scale. Statistical comparison for the slope (b) and elevation on the regression line among strains was done acording to SNEDECOR and COCHRAN[36].

Results

Growth curve

The growth curves of body weight and bones are shown in Fig. 1 (male) and 2 (female) by each measurement. These pictures rest on the basis of the estimated Logistic equation. The growth curve of the MF strain are always predominant over the other two strains in all measurements of both sexes, particularly for body weight. However, there are little differences in the growth between the FF and CC strains, except for female body weight in which the FF strain exceeds the CC strain after six weeks of age. Each relative value of estimated measurements at six and nine weeks of age from Logistic equation in the selected strains (MF and FF strains) was expressed in per cent to the corresponding measurements of the CC strain, to numerically decribe the difference between the selected and control strains (Table 1). The MF strain exceeds the CC strain by 19 to 27 per cent in growth of body weight from six to nine weeks of age for both sexes. However, the difference is smaller in growth of bone than in body weight. The bone sites in which the predominant differences are larger than 5 per cent in both

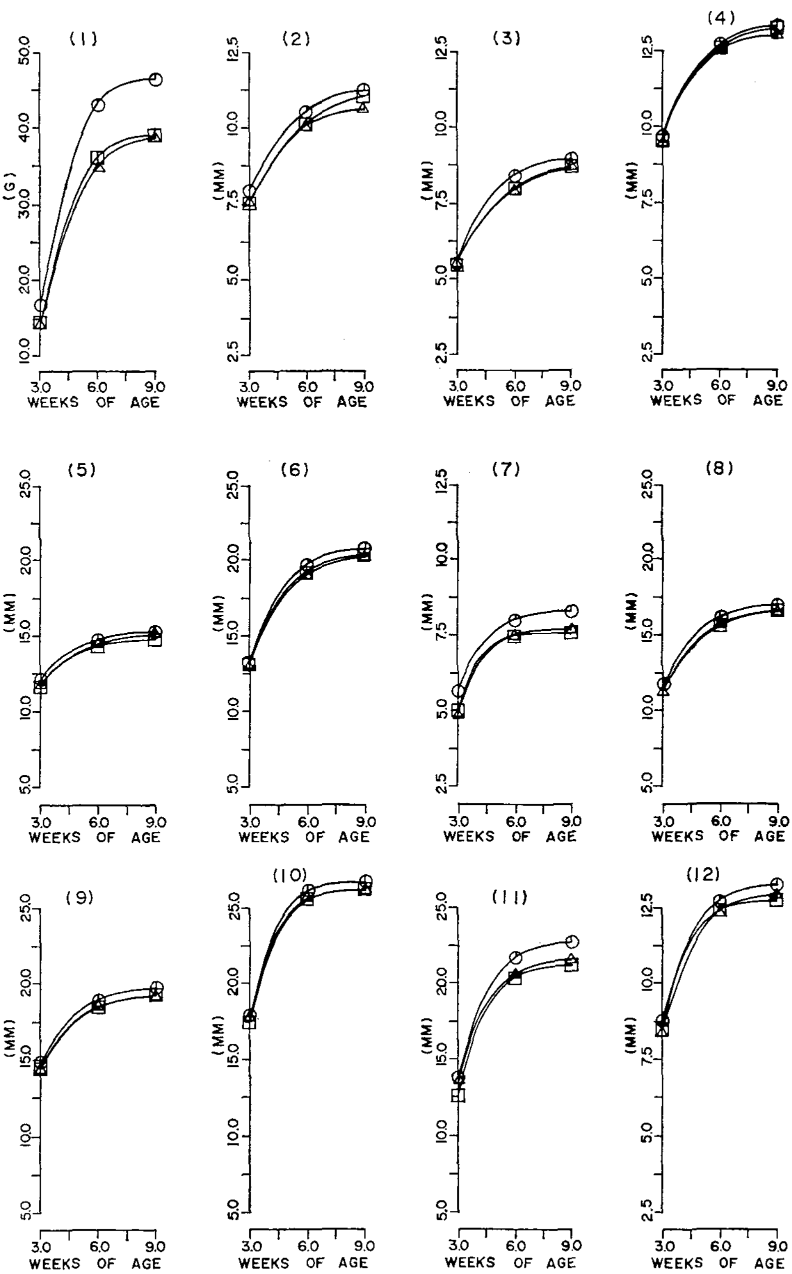

Fig. 1. Growth curves fitted to the Logistic equation for body weight and several bones sites (male mice).

(1) Body weight, (2) Length of scapula, (3) Width of scapula, (4) Length of humerus, (5) Length of ulna, (6) Length of os coxae, (7) Width of os coxae, (8) Length of femur, (9) Length of tibia, (10) Length of 13 thoracic vertebrae, (11) Length of 6 lumbar vertebrae, (12) Length of 4 sacrae vertebrae. □; CC strain, ○; MF strain, △; FF strain

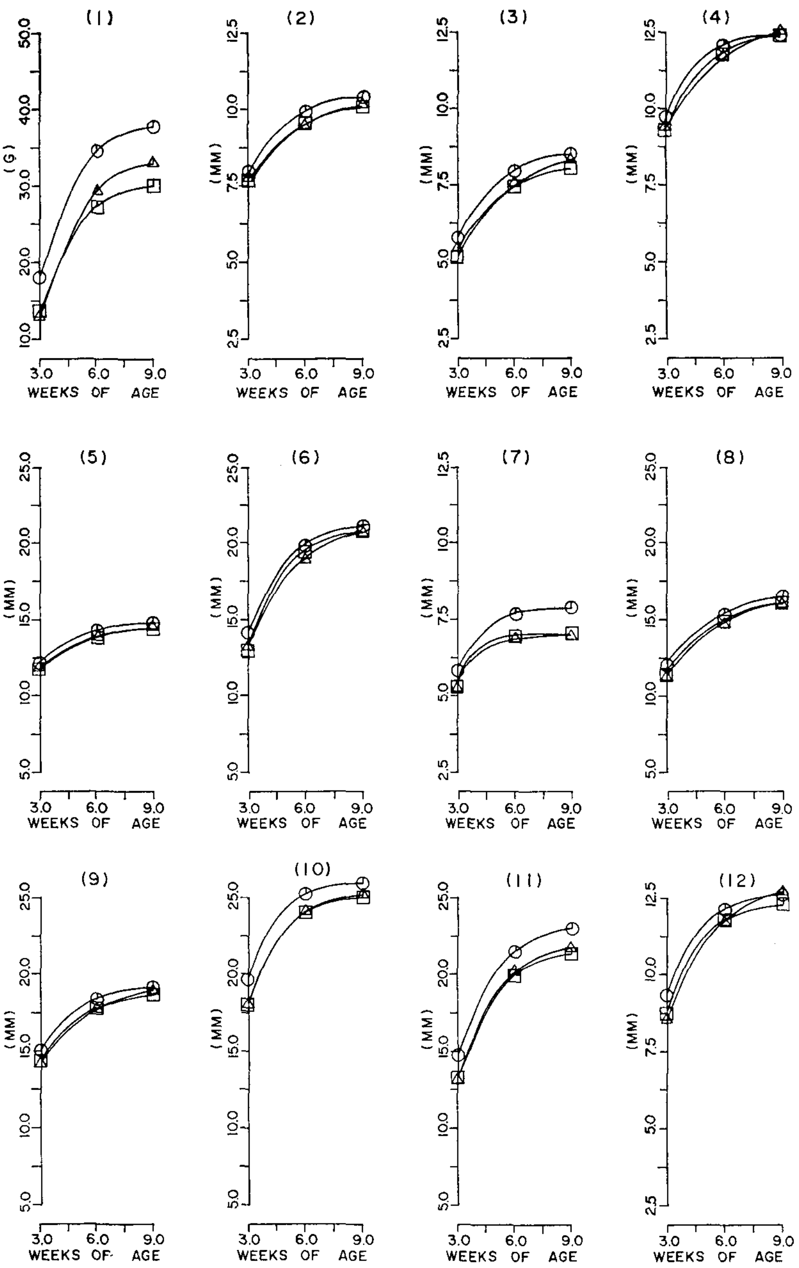

Fig. 2. Growth curves fitted to the Logistic equation for body weight and several bone sites (female mice).

(1) Body weight, (2) Length of scapula, (3) Width of scapula, (4) Length of humerus, (5) Length of ulna, (6) Length of os coxae, (7) Width of os coxae, (8) Length of femur, (9) Length of tibia, (10) Length of 13 thoracic vertebrae, (11) Length of 6 lumbar vertebrae, (12) Length of 4 sacrae vertebrae. □; CC strain, ○; MF strain, △; FF strain

sexes, are width of scapula and os coxae, and the length of lumbar vertebrae at six weeks of age. The difference in length of thoracic vertebrae is 5 per cent for females but for males it is only 3 per cent. Concerning the measurements at nine weeks of age, the width of os coxae and length of lumbar vertebrae have differences of more than 5 per cent between the two strains. The differences in width of scapula are 6 and 3 per cent for females and males respectively. It is thus observed that there are differences in some bone sites between the MF and CC strains. All of the bones with relatively large difference are part of the vertebrae column or girdle bones.

There appears to be little difference between the FF and CC strains in the growth of bones at two ages (Table 1 and Fig. 1, 2), though the FF strain is below the CC strain in scapula length and humerus length for males at nine weeks of age by only 4 and 2 per cent, respectively. The growth curve of bones in the FF strain are almost identical to the curve in the CC strain even for females, although the body weight is superior to those of the CC strain by 7 or 9 per cent, at six and nine weeks of age.

TABLE 1. Percentage of the measurements of growth in the selected strains (MF and FF) to the corresponding measurements in the control strain (CC) at six and nine weeks of age (%).

Measurements	Male				Female			
	At six weeks of age		At nine weeks of age		At six weeks of age		At nine weeks of age	
	MF strain	FF strain	MF strain	FF strain	MF strain	FF strain	MF strain	FF strain
Body weight	120	96	119	99	127	107	125	109
Scapula length	104	99	102	96	104	99	103	101
Scapula width	105	99	103	100	107	101	106	103
Humerus length	101	99	101	98	102	99	100	102
Ulna length	103	101	104	103	103	100	103	101
Os coxae length	102	99	102	99	102	97	102	99
Os coxae width	107	100	109	101	110	98	112	99
Femur length	104	100	103	100	103	98	103	100
Tibia length	103	100	102	100	103	99	102	101
Thoracic v. length	103	100	102	100	105	100	104	101
Lumbar v. length	107	101	107	102	108	101	108	102
Sacrae v. length	103	99	104	101	103	100	103	103

Relative growth to body weight

Relative growth coefficients were calculated in the logarithmic regression. The results of the regression analysis of bones to body weight are summarized in Table 2 (male) and 3 (female). These tables show a general tendency for the growth coefficients to body weight to be small in distal limb bones (especially for ulna and tibia length), but relatively large in axial skeletal bones and girdle bones adjacent to axial skeleton (especially for scapula length, os coxae and lumbar vertebrae length) for both sexes.

Comparison of coefficients among strains (MF, FF and CC) for male mice reveals that statistically significant differences are found in scapula width (0.33 vs. 0.38) between the MF and FF strains, and in thoracic vertebrae length (0.37 vs. 0.33) and lumbar vertebrae length (0.47 vs. 0.41) between the CC and FF strains. However, there is no significant difference in any coefficients between the CC and MF strains for male mice.

For female mice, many sites of bone are significantly different in the coefficient among strains. The FF strain has a smaller coefficient than the CC strain in scapula length (0.26 vs. 0.32), scapula width (0.41 vs. 0.52), humerus length (0.28 vs. 0.34), os coxae length (0.43 vs. 0.57), os coxae width (0.30 vs. 0.36), femur length (0.34 vs. 0.40), thoracic vertebrae length (0.32 vs. 0.40) and lumbar vertebrae length (0.49 vs. 0.57). As previously described, the FF strain predominates over the CC strain in growth of body weight, but is almost identical to the CC strain in that of bone sites. This fact partially reflects the differences in growth coefficient between the two strains. Thus in the coefficient of thoracic vertebrae length and lumbar vertebrae length in females, the FF strain is also found to be significantly smaller than the CC strain. The MF strain is significantly smaller in the coefficients of os coxae length (0.47 vs. 0.57) and thoracic vertebrae length (0.36 vs. 0.40) than the CC strain, and significantly larger in those of scapula length (0.32 vs. 0.26) and os coxae width (0.37 vs. 0.30) than the FF strain. The coefficient of scapula width to body weight is larger in the FF strain than in the MF strain for males, but for females the reverse is true. The bone sites which are not significantly different in the coefficient among strains for both sexes are ulna, tibia and sacrae vertebrae length. Among these bones, ulna and tibia have two of the smallest coefficient of bones within strain and sex, and already attain three quarters of mature size at three weeks of age (Fig. 1 and 2).

In comparing animals of equal body weight, significant differences among the strains in the elevation of regression line on body weight, were found as follows : for male mice, in humerus length, os coxae length, femur length,

TABLE 2. Growth coefficient estimates (b) from the allometric relationship $Y=aX^b$ of individual bone sites (Y) with body weight (X) for three strains on male.

Bone sites	Strains			Significant difference	
	CC	MF	FF	Slope	Elevation
Scapula length	0.31±0.02	0.29±0.02	0.28±0.01	(NS)	(NS)
Scapula width	0.41±0.02	0.41±0.02	0.42±0.04	(NS)	CC>MF
Humerus length	0.29±0.01	0.27±0.01	0.27±0.01	(NS)	CC>MF, MF<FF
Ulna length	0.21±0.01	0.20±0.01	0.21±0.01	(NS)	CC<FF, MF<FF
Os coxae length	0.40±0.01	0.38±0.01	0.36±0.01	(NS)	CC>MF, MF<FF
Os coxae width	0.36±0.02	0.33±0.01	0.38±0.02	MF<FF	
Femur length	0.31±0.01	0.30±0.02	0.32±0.01	(NS)	CC>MF, MF<FF
Tibia length	0.25±0.01	0.25±0.01	0.24±0.01	(NS)	CC>MF, MF<FF
Thoracic v. length	0.37±0.01	0.35±0.01	0.33±0.01	CC>FF	CC>MF, MF<FF
Lumber v. length	0.47±0.01	0.43±0.02	0.41±0.03	CC>FF	MF<FF
Sacrae v. length	0.37±0.01	0.37±0.01	0.36±0.02	(NS)	CC>MF, MF<FF

Significant difference: (NS); non-significant, AA>BB or AA<BB present AA strain is greater or smaller than BB strain.

TABLE 3. Growth coefficient estimates (b) from the allometric relationship $Y=aY^b$ of individual bone sites (Y) with body weight (X) for three strains on female.

Bone sites	Strains			Significant difference	
	CC	MF	FF	Slope	Elavation
Scapula length	0.32±0.02	0.32±0.02	0.26±0.02	CC>FF, MF>FF	CC>MF
Scapula width	0.51±0.03	0.44±0.03	0.41±0.02	CC>FF	CC>MF, MF<FF
Humerus length	0.34±0.02	0.30±0.02	0.28±0.02	CC>FF	CC>MF, MF<FF
Ulna length	0.23±0.02	0.23±0.02	0.20±0.01	(NS)	CC>MF, MF>FF
Os coxae length	0.57±0.02	0.47±0.02	0.43±0.02	CC>MF, CC>FF	MF<FF
Os coxae width	0.36±0.03	0.37±0.03	0.30±0.02	MF>FF, CC>FF	
Femur length	0.40±0.02	0.37±0.02	0.34±0.02	CC>FF	CC>MF, MF<FF
Tibia length	0.31±0.02	0.28±0.02	0.27±0.01	(NS)	CC>MF, MF<FF
Thoracic v. length	0.40±0.02	0.36±0.02	0.32±0.01	CC>MF, CC>FF	
Lumber v. length	0.57±0.02	0.54±0.02	0.48±0.02	CC>FF	CC>MF, MF<FF
Sacrae v. length	0.42±0.02	0.39±0.02	0.41±0.02	(NS)	CC>MF, CC>FF, MF<FF

See the footnote to Table 2.

tibia length, thoracic length and sacreae vertebrae length, the MF strain is smaller than the CC and the FF strains ; in scapula length the MF strain is smaller than the CC strain ; in ulna length the FF strain is larger than CC and MF strain ; and in lumbar vertebrae length the FF strain is larger than the MF strain ; for female mice, in scapula width, humerus, ulna, femur, tibia, lumbar vertebrae and sacrae vertebrae length, the MF strain is smaller than the CC and FF strains ; in scapula length the MF strain is smaller than the CC strain ; in os coxae length the MF strain is smaller than the FF strain ; and in sacrae vertebrae length the FF strain is smaller than the CC strain (in the last column of Table 2 and 3). Thus the increased body weight realised particularly in the MF strain by artificial selection, reflects the significant differences among strains in several bone sizes when compared at equal body weight.

Relative growth to the length of humerus

The general tendency of variation among strains in relative growth coefficients to the length of humerus is similar to those relative to body weight. However, the only significant difference in the coefficient observed among strains are for os coxae width for both sexes. On this bone site, the coefficient is significantly larger in FF strain than those in the CC and MF strains for males, but the inverse is true in the female case (1.39 vs. 1.21 and 1.17). The MF strain has a larger coefficient than the FF strain (1.20 vs. 0.93). There is no significant difference among strains in any other bone sites.

In the last columns in Table 4 and 5, it is indicated that the MF strain is significantly larger in size in some bone sites than the CC and FF strains when compared at equal humerus length, as follows : for male mice, the MF strain is larger than the CC strain in all sites except for os coxae length, and is larger than the FF strain in scapula length, femur length and lumbar vertebrae length ; the FF strain is larger than the CC strain in ulna length ; for female mice, the MF strain is larger than the CC strain in three bone sites, os coxae width, thoracic and lumbar vertebrae length, and the FF strain is larger than the CC strain in scapula length. Though significant differences were found in elevation between the MF and CC strains on more sites of male bones than on those of female bones, the MF strain significantly exceeds the CC strain in the elevation of os coxae width, thoracic vertebrae length and lumbar vertebrae length at equal humerus length on both sexes. This indicates that a selection for increased body weight influences the length or width of those bone sites relative to humerus length.

TABLE 4. Growth coefficient estimates (b) from the allometric relationship $Y=aX^b$ of individual bone sites (Y) with humerus length (X) for three strains on male.

Bone sites	Strain			Significant difference	
	CC	MF	FF	Slope	Elevation
Scapula length	1.10±0.05	1.06±0.05	1.04±0.04	(NS)	CC<MF, MF<FF
Scapula width	1.43±0.05	1.48±0.06	1.56±0.13	(NS)	CC<MF
Ulna length	0.70±0.04	0.70±0.05	0.77±0.03	(NS)	CC<MF, CC<FF
Os coxae length	1.36±0.04	1.36±0.05	1.33±0.05	(NS)	(NS)
Os coxae width	1.21±0.07	1.17±0.06	1.39±0.06	FF>CC, MF<FF	CC<MF
Femur length	1.08±0.04	1.07±0.06	1.17.±0.04	(NS)	CC<MF, MF>FF
Tibia length	0.87±0.03	0.92±0.04	0.90±0.03	(NS)	CC<MF
Thoracic v. length	1.25±0.05	1.22±0.07	1.22±0.05	(NS)	CC<MF
Lumber v. lengte	1.57±0.06	1.54±0.06	1.52±0.09	(NS)	CC<MF, MF>FF
Sacrae v. length	1.23±0.05	1.30±0.06	1.33±0.07	(NS)	CC<MF

See the foot note to Table 2.

TABLE 5. Growth coefficient estimates (b) from the allometric relationship $Y=aX^b$ of individual bone sites (Y) with humerus length (X) for three strains on female.

Bone sites	Strain			Significant difference	
	CC	MF	FF	Slope	Elevation
Scapula length	0.89±0.05	1.02±0.07	0.90±0.06	(NS)	(NS)
Scapula width	1.49±0.07	1.44±0.09	1.36±0.09	(NS)	CC<FF
Ulna length	0.66±0.05	0.74±0.05	0.67±0.05	(NS)	(NS)
Os coxae length	1.60±0.06	1.50±0.07	1.42±0.03	(NS)	(NS)
Os coxae width	1.00±0.09	1·20±0.07	0.93±0.10	MF>FF	CC<MF
Femur length	1.14±0.05	1.17±0.06	1.15±0.06	(NS)	(NS)
Tibia length	0.90±0.04	0.89±0.05	0.93±0.05	(NS)	(NS)
Thoracic v. length	1.09±0.07	1.11±0.06	1.03±0.08	(NS)	CC<MF
Lumber v. length	1.59±0.07	1.69±0.08	1.58±0.10	(NS)	CC<MF
Sacrae v. length	1.19±0.05	1.20±0.07	1.34±0.08	(NS)	(NS)

See the foot note to Table 2.

Discussion

Comparisons of growth patterns and growth coefficients among bone sites have revealed the differentiation in bone growth among sites. This fact was first demonstrated as anterior-posterior skeletal growth and centripetal pattern of limb bone growth by HAMOND[15] on sheeps and confirmed by some researchers in many species of animals.[2,8,10,11,18,25,32,35] This evidence was also found in mice and discusses in a previous paper[35].

The MF strain which has been selected for increased body weight at six weeks of age for both sexes, predominates the unselected control strain (CC) in the growth of all bone sites examined, as well as body weight, though there are some variations among sites between strains. The correlated responses observed in bone size of this strain are generally expected from the fact that in multivariate analysis for body weight and body size in cattle, the body weight has a positive relationship with most measurements of body size and the first primary component obtained was interpreted as a measure of general size[5,6,24].

The major tissues of the animal body (muscles, bones and fats) grow at different rates postnatally. Bones are considered early developing but slow growing, muscles intermediate but more rapid, and fats are depositted in the greatest proportion later in life. These patterns of growth have been also demonstrated in comparing relative tissue growth in cattle[2,18,28] in sheeps[13], and pigs[8,9,11,12]. The common factor through the first principal component affects on their growth of many bone sites as well as those of body weight, but total live weight includes not only bones but also muscles, fats, internal organs and other things. These facts may explain the differenciation in the percentage of genetic change between the selected traits (body weight) and correlated traits (bone sites). MACARTHUR and CHIASSON[23] compared the growth of body length, tail length and ear length between two reaces (large and small races) which were derived from the same foundation stock and selected for large and small body size respectively, for eight generations. The divergent differences between the two races in body weight at 60 days of age amounted to 109 per cent of small race weight, while those in body, tail, ear and foot length were only 20.2, 12.9, 9.7 and 11.3 per cent respectively. These values were calculated from Table 1 (for males) in their paper.

In contrast with the MF strain, the FF strain, which has been selected for same body weight as the MF strain but only in females, shows identical growth the CC strain in bones, even though its female mice appear to exceed the CC strain in body weight at six and nine weeks of age by 7 and 9 per cent respectively. Allometrical analysis for individual bones in pigs suggested an early growth in bone length followed by a later circumference growth[8,23]. Though an increase in each bone weight might partially result from an increase in its circumference, the majority of change in female live weight of the FF strain might be owing to the increased weight in tissues other than bone. The heterogenous response between the sexes in the weight of the FF strain, will be discussed in another paper.

LERNER[21] suggested that a body form might be changed by artificial selection for growth coefficient estimates in fowls, and attempted to select for high and low values of the coefficient of shank length relative to body weight of chickens between 4 and 8 weeks of age. However, his trial was not successful. Little further information has been published on the modification in growth ratio of bone in animals by dircet selection.

In the previously noted paper on selected races of mice by MACARTHUR and CHIASSON[23], the relative length of appendages (tail, ear and foot) to body length were larger in the small race than those in the large race at 60 days of age, but both races followed the same pattern and course in allometric development. KIDWELL *et al.*[19] reported the genetic parameters for the allometiric coefficient of tail length and width to body weight to be low (0.0 to 0.03).

Studies have been reported comparing the relative growth and distribution in each bone weight among some breed-types in pigs[11,33] and cattle[2,18]. Generally the coefficients were homogeneous among breed-types for each bone relative to total side bone in both species, though in some bones significant differences were found in the distribution of individual bone to side bone weight, which were small and probably reflected differences in stages of maturity[2,11,18]. DAVIES[9] reported significant differences between pigs for meat production and miniature pigs in relative bone growth to carcass, which was not always the same as the results by DAVIES[10] using other breeds and miniature pigs. The disagreement would be due to the difference in the range of body weight. Breed groups has no statistically significant influence on the growth coefficient for total bone weight to live weight or carcass weight in cattle[2,28]. Thus, in pigs and cattle, different breeds within species generally followed similar patterns of relative growth in each bone as they increase in size. In these studies using pigs and cattle, the weight was measured as the criterion of growth in each bone, while the length was measured in this study.

On the growth coefficient of bone to body weight in this study, significant differences are not found between the MF and CC strains for male mice, and they were founded in only os coxae length and thoracic vertebrae length for female. Thus the selection for body weight appears to influence few growth coefficient for individual bone site relative to body weight in the MF strain except for os coxae length and thoracic vertebrae length. The length of ulna, tibia and sacrae vertebrae length show homogenous growth coefficient to body weight among three strains. This evidence seems to partially agree with the results described above in pigs and cattle. Among the three bones, ulna and tibia are most distal limb bone sites investigated in this study and are very early maturing, as shown in Fig. 1 and 2 and Table 2–5. This fact suggests that the development in these bones is already prepared in advance for increasing body size early in life.

The comparison of growth coefficients in individual bone sites relative to body weight between different strains of mice included in this study shows that differentiated strains do not always follow similar patterns of relative bone growth as they increase in size. Female mice of the FF strain have a significantly smaller growth coefficient than the CC strain, for any sites of bones except for ulna, tibia and sacrae vertebrae length. The difference is probably a reflection of the fact that body weight of the FF exceed those of the CC strain after six weeks of age but bone growth are almost similar in both strains. However, for male mice, heterogenous allometric growth among strains is also found in only three sites of bones (os coxae width, thoracic vertebrae length and lumbar vertebrae length). On the four sites of bone including the length of scapula, os coxae, thoracic vertebrae and lumbar vertebrae, strain differences are relatively large and also show their consistent trend between male and female mice. For os coxae width, the FF strain has larger coefficient in males than the MF strain, but inversely smaller in females than the CC strain. Thus an interaction effect of strain with sex clearly influences the relative growth pattern of os coxae width.

Furthermore, to compare relative growth in each major skeletal bone to each other, growth coefficients are examined in individual bone sites relative to humerus length. A significant strain effect was observed on the coefficient for only os coxae width of male and female mice. There was no significant difference among strains in the coefficient on other bone sites, and no consistent trend in the value among sexes. This indicates that different strains follow similar patterns of relative bone growth in linear dimension but for not os coxae as they increase in humerus length. Apparent interaction effect of strain with sex are shown on the coefficient of os coxae width to humerus length in the same manner as those to body weight, though the differences among strains are not always significant.

There is no available report published on the genetical properties about relative growth in individual bones to body weight. In comparing the evidence reported using pigs and cattle with the result of this study, the relative growth to humerus length is preferable to that of body weight though there are some differences in measurement in this study on mice, for example, relative growth is evaluated on the growth coefficient in each bone site to a particular bone site (humerus length), but it is based on bone weight to total weight in the papers about pigs and cattle. Besides, the bone length is considered early developing, width relatively late developing and bone weight late but rapid[32]. Thus, although this study is somewhat discrepancy from the reported studies in the way of measuring and the animal species, the evidence obtained in this study about relative growth in each bone to humerus length are in good agreement with those concerning pigs[11,12,33], and cattle, except for os coxae length. However the results showing that there are significant differences among strains in growth coefficients to body weight for some of the axial sketeton and girdle bones, appear to be in disagreement with those showing that breed growps had no significant influence on growth coefficient in total bone weight to live weight or carcass weight in cattle[2,28].

There are significant differences among strains in the elevation levels in the estimated regression line on body weight for many bone sites and this indicates that the MF strain has a shorter bone size than the CC and FF strains in comparing the bone size adjusted to the same body weight. However, in the regression analysis on humerus length, the MF strain has a significantly larger elevation level than the CC strain for os coxae width, thoracic and lumbar vertebrae length for both sexes. Furthermore, for male mice, the MF strain is larger in the elevation than the CC strain in all bone sites except os coaxe length, and also larger than the FF strain in scapula, femur and lumbar vertebrae length. The evidence revealed that a selection for increased body weight leads to a greater increase in body length and depth than in height, and results in a mouse with a long and deep body and short legs, particularly for female mice. In the studies on the relative growth of bones in pigs and cattle, significant differences were reported among breed groups in proportion of individual bones by several researchers[2,11,18] and they described that it was probably due to the differences in stages of maturity. In their studies, the range of age investigated was early age before maturity in the life, but in this study the period from three to nine weeks of age is studied. As clearly shown in Fig. 1 and 2, body weight and individual bone almost reach their mature levels at nine weeks of age. FUKUDA *et al.*[14] reported that in mice the bone growth approached the plateau at eight to ten weeks of age and body weight continued to increase at a later age than bone growth. The differences in stages of maturity seem to have little influence on the growth coefficients particularly in individual bones to humerus length in this study. A further discussion on the physiological and genetic mechanism in differentiated growth of bone necessitate a collection of more growth data including muscles, fats and internal organs.

In growing animals, particularly mice, oestrogen exerts a major influence on the structure of the skeleton, inducing inhibition of linear growth, acceleration of skeletal development, and condensation of bone, and androgen is suggested to increase growth hormone responsiveness and to be in part responsible for the spurt at puberty[37]. Significant interaction effects between strains and sexes was observed in the relative growth in skeletal bones. It is suggested that sex hormones, oestrogen and/or androgen, are probably responsible for differentiation of growth patterns in individual bone sites between strains and sexes, and its interaction effect somewhat confuses the complicated relationship between bone growth and selection intensity for body weight.

In the studies reported on the growth of pelvic bones and other body measurements[4,30,31] to investigate the relationship with dystocia in beef cattle, the relative growth pattern of external pelvic width and dimension to hip height appeared to differ between breeds, indicating that particularly for hip height, the taller breeds of cattle (Simmental and Santa Gertrudis) have smaller pelvic dimension than moderate height breeds (Angus and Polled Hereford). Also, pelvic bone size had little relationship with other body measurements and its heritability estimates were lower than the height. In this study, the growth particularly in os coxae width relative to body weight and to humerus length, shows different patterns between strains and sexes from other bone sites. It is suggested that the growth of os coxae width is influenced by the factors different from those common to other bone sites. The differences in bone distribution are associated with the functional demands of an increase in body size, and the growth of bone was found to correspond well to those of muscle groups attached to it in pigs[9~11]. One of the most interesting aspects of this study is to investigate whether a selection for body weight would lead to genetical differentiation in relative growth patterns in each bone sites. In our lavoratory, another selected strain (MM strain) has been selected for body weight in only male mice, together with three strains used in this study. However, sufficient numbers of mice for statistical analysis could not be obtained from this strain because of their poor fertility, so its data was excluded from this paper. Concerning this problem, however, it is supposed that selection for increased body weight in both sexes or probably in male mice increases skeletal dimension but the selection using female does not greatly infiuence bone size. The growth of os coxae in width is supposed to be related to growth of muscle attached to it and probably to the growth of reproductive organs.

Summary

Bone growth patterns were compared using two selected strains that were selected for increased body weight at six weeks of age for both sexes (MF strain) or only female (FF strain) and the control strain of mice. The relative growth of bone was assessed from growth coefficients (b) derived from Huxley's allometric equation : $Y_t = aX^b$, in which Y_t represents length or width of bones, X represents body weight or humerus length, b is a relative growth coefficient, and a is a constant. The measurement of bone was carried out on 11 sites as follows : the length of scapula, humerus, ulna, left os coxae, femur, tibia, 13 thoracic vertebrae, 6 lumbar vertebrae and 4 sacrae vertebrae and width of scapula and left os coxae. The cross-sectional data from 216 representative mice were analysed.

The growth curve of the MF strain is always predominant over the other two strains in all measurements of bones for both sexes. However, the FF strain showed an almost identical growth pattern to those of the CC strain in each bone site, though this strain exceeded the CC strain in female body weight after six weeks of age.

Significant differences in the growth coefficient to body weight are found between strains for some sites of bones, though no significance were found in any male sites between the CC and MF strains. Particularly on the four bone sites including the length of scapula, os coxae, thoracic vertebrae and lumbar vertebrae, the strain differences in the coefficients are relatively large and also shown to be somewhat same in male and female mice ; the CC strain tended to be larger than the MF and FF strains and the FF strain was smaller than other two strains, in all of these four sites. An interaction effect of strain with sex clearly influences the coefficient of os coxae width.

On the growth coefficient in each bone site relative to humerus length, a significant difference was found only in os coxae width, indicating that the FF strain was larger than the CC and MF strains for males but smaller

for females. The bone size adjusted to the same body weight or humerus length represented significant differences among strains in some bone sites. The differences were not always indicated in the same sites between male and female.

The evidence obtained in this study, suggested that a selection for body weight result in alteration of body shape and sexual dimorphism for body shape.

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