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EFFECTS OF BREED AND SEX ON THE RELATIVE GROWTH AND DISTRIBUTION OF BONE IN PIGS

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The growth and distribution of bone from 179 pig carcasses were compared among five breeds (Duroc × Yorkshire (D×Y), Hampshire × Yorkshire (H×Y), Yorkshire (Y×Y), Yorkshire × Lacombe-Yorkshire (Y×L-Y) and Lacombe × Yorkshire (L×Y)) and two sex-types (barrows and gilts) over a wide range in carcass weight. The growth pattern for each bone relative to total side bone was estimated from the growth coefficient, b, in the allometric equation ($Y = aX^b$). Growth coefficients were homogeneous in this study among breeds and between sexes for each bone, indicating that the different breeds and sexes followed similar patterns of relative bone growth as they increased in size. The lowest growth coefficients ($b < 1.0$) were found among the limb bones (tarsus, femur, and radius/ulna). The thoracic vertebrae, carpus, tibia, humerus, sternum, pelvic and pectoral girdles had growth coefficients not significantly different from 1.0, while the ribs, lumbar and cervical vertebrae, patella and atlas had growth coefficients significantly greater than 1.0. Significant breed and sex differences were found in the weights of individual bones when adjusted to equal side bone weights. However, these were small and may reflect differences in stage of skeletal maturity.

La croissance et le développement relatif des os de 179 carcasses de porcs ont été étudiés sur cinq croisements ou souches pures Duroc × Yorkshire, Hampshire × Yorkshire, Yorkshire, Yorkshire × Lacombe-York et Lacombe × Yorkshire, ainsi que sur deux "sexes," castrats et jeunes truies de divers poids. Le profil de croissance de chaque os par rapport à l'ossature de la demi-carcasse a été estimé à partir de coefficients de croissance b dans l'équation allométrique ($Y = aX^b$). Les coefficients de croissance pour chaque os étaient homogènes parmi les races et les sexes, ce qui porte à croire que le développement osseux des races et des sexes a suivi une évolution semblable tout au long de la croissance. Les os qui ont manifesté les coefficients les plus forts ($b < 1.0$) étaient les os des membres: tarse, fémur et radius-cubitus. Ceux des vertèbres thoraciques et pelviennes ne s'écartaient pas significativement de 1.0 mais ceux des côtes, des vertèbres lombaires et cervicales, de la rotule et de l'atlas étaient significativement plus élevés. Nous avons observé des différences significatives dues au sexe ou à la race en ce qui a trait aux poids d'os particuliers après qu'on les ait corrigés en fonction de mêmes poids de demi-carcasses. Toutefois, ces différences étaient de faible importance et tiendraient peut-être à des différences de maturité du squelette.

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The early classical work of Hammond (1932) with sheep and of McMeekan (1940 a,b,c) with pigs demonstrated that the major tissues of the animal body (bone, muscle and fat) grow at relatively different rates postnatally. These authors showed that bone completed a greater proportion of its growth earlier in life than either muscle or fat. Little further information has been published on the growth of bone in pigs.

Bone weight growth and its distribution in a pig carcass has commercial significance as most cuts are sold with the bones in situ. The work of McMeekan (1940a,b,c) with pigs suggested an antero-posterior pattern of skeletal growth, and a centripetal pattern of growth within the limbs. More recent work (Cuthbertson and Pomeroy 1962; Richmond and Berg 1972) has conformed generally to this hypothesis of bone growth gradients in pigs. However, there is a deficit of published information on the effects of breed and sex on bone growth and distribution. Richmond and Berg (1972) reported no consistent effect of breed and sex on bone distribution, but their comparisons were not made with respect to growth impetus patterns of bone.

The objectives of the present study were to examine the effects of breed and sex on the relative growth and distribution of bone in pigs and to provide further information on the differential growth of bone.

MATERIAL AND METHODS

The data for the present paper were derived from experiments reported by Wilson (1971) and Richmond and Berg (1972). In total, 179 pig carcasses of five breeds (Duroc × Yorkshire (D×Y), Hampshire × Yorkshire (H×Y), Yorkshire (Y×Y), Yorkshire × Lacombe-Yorkshire (Y×L-Y) and Lacombe × Yorkshire (L×Y), and two sex-types (barrows and gilts) were used in this study. All pigs were weaned at 3 wk of age and fed a standard starting ration (14.64 joules digestible energy per kilogram (DE) and 20% crude protein) to 23 kg liveweight. Thereafter, various energy and protein levels were employed to measure the effect of plane of nutrition on live animal performance and carcass tissue growth. Pigs were slaughtered at 68, 91, or 114 kg liveweight (see Richmond and Berg (1971a,b,c) and Wilson (1971) for further details on the management of these experiments).

Slaughter was conducted at a commercial packing plant following routine procedures. The carcass comprised the eviscerated body following the removal of the head at the atlanto-occipital articulation, the thoracic limbs at the carpo-metacarpal articulation, and the pelvic limbs at the tarso-metatarsal articulation. It was split into two sides by a longitudinal saw cut as close as possible to the mid-line. Left sides were dissected into individual muscles, fat and bones at the University of Alberta Meats Laboratory using modifications of the procedure of Butterfield and May (1966).

Bones were classified as being part of the vertebral column (atlas or 1st cervical vertebrae, cervical vertebrae, thoracic vertebrae, lumbar vertebrae), the sternum and ribs, and the appendicular skeleton (pectoral girdle, humerus, radius/ulna, carpus, pelvic girdle, femur, patella, tibia, tarsus). The atlas was considered separately to examine whether its growth coefficient was different than that of the cervical vertebrae. The sacral vertebrae were included as part of the pelvic girdle. Each bone was cleaned down to the periosteum; tendons and ligaments were cut close to the bone surface.

The growth of the individual bones relative to total carcass bone was examined using the allometric equation ($Y = aX^b$) (Huxley 1932). This followed the same approach as that used by Berg et al. (1978b) and Jones et al. (1978) in cattle. The data were transformed to logs, and the slopes of the regression lines for each breed and sex were compared using analysis of covariance. Plane of nutrition was not included in the model because of relatively low group numbers, and no work has shown that either energy or protein levels affect bone growth, provided the animal is in positive growth (Richmond and Berg 1972; Carden and Goenaga 1977). Group means for each bone were compared after adjusting to a common side bone weight. Differences among adjusted means were tested for significance using the Student-Newman-Keuls test (Steel and Torrie 1960).

RESULTS

The mean individual bone weights and total side bone are presented in Table 1 by breed

Table 1. Means (g) and standard deviations (SD) of unadjusted bone weights in left side of carcass by breed and sex-type

	Breed										Sex-type			
	D×Y		H×Y		Y×Y		Y×L-Y		L×Y		Barrow		Gilt	
No. of carcasses:	29		44		35		35		36		91		88	
Bone	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Tarsus	66	33.3	84	26.8	73	29.4	82	14.1	82	22.3	79	26.3	77	26.6
Femur	228	77.5	257	59.6	255	87.0	273	47.9	258	45.1	251	62.4	260	68.3
Radius/ulna	155	55.7	169	42.1	159	56.6	178	32.6	169	29.1	163	42.7	169	45.9
Thoracic vertebrae	292	141.6	297	114.5	351	178.2	341	104.2	341	108.3	314	124.7	335	138.7
Carpus	26	11.2	30	12.5	31	13.7	32	11.2	34	13.3	31	11.8	31	13.3
Tibia	168	57.5	179	44.2	178	61.5	195	37.1	170	30.5	177	45.8	184	48.9
Humerus	205	77.5	224	60.9	227	82.2	251	47.8	231	44.3	222	61.0	235	67.5
Pelvic girdle	232	87.1	268	74.3	268	98.9	290	60.4	257	54.6	255	71.4	274	82.4
Sternum	97	36.9	133	53.9	110	51.8	81	22.8	87	23.7	100	40.1	107	49.5
Pectoral girdle	141	54.2	161	43.4	141	53.8	145	31.7	137	31.3	139	38.8	153	47.9
Ribs	336	138.6	381	109.4	345	141.8	340	69.8	332	60.7	338	105.5	361	112.9
Lumbar vertebrae	182	96.5	188	73.9	213	105.8	205	56.4	200	50.1	190	74.3	206	82.1
Cervical vertebrae	131	68.1	165	74.2	154	69.0	162	51.9	144	54.4	147	61.5	158	68.2
Patella	16	7.1	20	6.1	19	7.5	19	3.8	18	4.1	18	5.9	19	6.0
Atlas	33	15.2	38	12.2	40	20.4	36	9.4	36	14.9	35	13.3	38	16.1
Total side bone	2307	862.3	2594	676.7	2564	947.6	2631	493.0	2505	494.5	2459	665.3	2607	751.0

D×Y = Duroc × Yorkshire, H×Y = Hampshire × Yorkshire, Y×Y = Yorkshire, Y×L-Y = Yorkshire × Lacombe-Yorkshire, and L×Y = Lacombe × Yorkshire.

and sex-type. The standard deviations were large in all cases because of the great range of liveweight at slaughter.

Table 2 lists the growth coefficients derived from the allometric relationships between the weights of the individual bones and total bone weight. These growth coefficients show that the proportion of bone found in the tarsus and femur in the hind-limb and radius/ulna in the fore-limb decreased as total side bone increased. The carpus, humerus (fore-limb), tibia (hind-limb), sternum, thoracic vertebrae, pelvic and pectoral girdles remained a constant proportion of total side bone, while the ribs, lumbar and cervical vertebrae, patella and atlas increased as a proportion of total side bone as growth proceeded. The individual breed and sex-type regression coefficients were in all cases homogeneous indicating that the different types followed similar patterns of relative bone growth.

Breed had a significant influence on the weights of several bones, and sex-type on one bone when compared at equal side bone weight (Table 2). The breed × sex interaction was non-significant for every bone.

Breed means, adjusted by applying the common regression to the experimental mean of side bone are presented in Table 3. Differences among breeds for several bones (tarsus, femur, radius/ulna, tibia, humerus, pelvic girdle, sternum, pectoral girdle and ribs) were statistically significant as already noted, but the differences were small. However, bone weight distribution was similar for (D×Y) and (H×Y) animals, which was different from that found for (Y×L-Y) and (L×Y) animals. The (Y×Y) animals had an intermediate bone weight distribution.

Sex means, adjusted by the common regression to the experimental mean of side bone are shown in Table 4. Only in the case of one bone (pectoral girdle) was there shown to be any difference between barrows and gilts in bone weight distribution at equal total bone weight.

DISCUSSION

A. Growth Patterns of Bone

Hammond (1932) demonstrated differential growth in bones of sheep and suggested that a wave of growth, beginning at the head, spreads posteriorly along the trunk, and secondary waves which start at the extremities of the limbs pass dorsally; these all meet at the junction of the loin with the last rib. Further evidence supporting this theory of growth gradients was provided by McMeekan (1940a,b,c) and Cuthbertson and Pomeroy (1962). The present study is not in total agreement with their results.

Growth coefficients of some of the limb bones (tarsus, femur, and radius/ulna) relative to total side bone were significantly less than 1.0, while the others (carpus, tibia, humerus) were not different from 1.0 over the weight range of this study. According to Hammond (1932), growth gradients should be evident in the limbs, and growth coefficients should therefore increase with increasing proximity to the pectoral or pelvic girdles. A similar situation can be demonstrated in the vertebral column. The growth gradient theory of Hammond (1932) would predict that growth coefficients for these groups of bones would increase from the atlas to reach a maximum value for the lumbar vertebrae. There was no evidence in this study of any antero-posterior pattern of skeletal growth. Highest growth coefficients were computed for the atlas and cervical vertebrae. Cuthbertson and Pomeroy (1962) and Richmond and Berg (1972) both found that the cervical vertebrae tended to increase rather than decrease at heavier liveweights.

There are a number of reasons why this deviation from classical growth theory may have occurred. Hammond (1932) used sheep which could have different bone growth patterns than pigs, and his data covered a much wider range of post-natal growth than those reported in this study. However, the work of Hammond (1932), McMeekan (1940a,b,c), Cuthbertson and Pomeroy (1962) and Richmond and Berg (1972) were difficult to interpret because comparisons of

Table 2. Parameter estimates from the allometric relationship $Y = aX^b$ of the individual bones (Y) with total side bone (X) for the five breeds and two sex-types

					Effect of breed		Effect of sex-type	
Bone	*b*	SEb	*t* test†	*r*‡	Slope	Elevation	Slope	Elevation
Tarsus	0.57	0.079	<1.0	0.48	NS	**	NS	NS
Femur	0.91	0.014	<1.0	0.98	NS	***	NS	NS
Radius/ulna	0.93	0.019	<1.0	0.96	NS	***	NS	NS
Thoracic vertebrae	0.93	0.060	1.0	0.76	NS	NS	NS	NS
Carpus	0.95	0.062	1.0	0.76	NS	NS	NS	NS
Tibia	0.96	0.023	1.0	0.96	NS	***	NS	NS
Humerus	0.99	0.022	1.0	0.96	NS	***	NS	NS
Pelvic girdle	0.99	0.018	1.0	0.97	NS	***	NS	NS
Sternum	1.01	0.051	1.0	0.84	NS	***	NS	NS
Pectoral girdle	1.03	0.021	1.0	0.96	NS	***	NS	*
Ribs	1.10	0.020	>1.0	0.97	NS	***	NS	NS
Lumbar vertebrae	1.13	0.047	>1.0	0.88	NS	NS	NS	NS
Cervical vertebrae	1.15	0.055	>1.0	0.85	NS	NS	NS	NS
Patella	1.16	0.033	>1.0	0.94	NS	NS	NS	NS
Atlas	1.21	0.053	>1.0	0.87	NS	NS	NS	NS

†The results of a *t* test to determine if the coefficient (*b*) is significantly ($P<0.05$) less than, greater than or not significantly ($P>0.05$) different from 1.

‡Partial correlation coefficient for each bone and total bone partialling out the effects of breed, sex and the breed × sex interaction.

* = $P<0.05$, ** = $P<0.01$, *** = $P<0.001$.

Table 3. Least square mean weights (g) of individual bones by breed† adjusted to the experimental mean of total side bone (2409 g)

	Log bone weight					Residual mean square	Bone weight				
Bone	D×Y	H×Y	Y×Y	Y×L-Y	L×Y		D×Y	H×Y	Y×Y	Y×L-Y	L×Y
Tarsus	1.7734 *a*	1.8849 *b*	1.8287 *ab*	1.8932 *b*	1.8927 *b*	0.0231	59 *a*	77 *b*	67 *ab*	78 *b*	78 *b*
Femur	2.3763 *a*	2.3827 *a*	2.3837 *ab*	2.4021 *b*	2.3975 *b*	0.0007	238 *a*	241 *a*	242 *ab*	252 *b*	250 *b*
Radius/ulna	2.2068 *ac*	2.1972 *bc*	2.1746 *b*	2.2142 *a*	2.2137 *ac*	0.0014	161 *ac*	157 *bc*	149 *b*	164 *a*	163 *ac*
Thoracic vertebrae	2.4724	2.4314	2.5018	2.4799	2.5047	0.0133	297	270	322	302	320
Carpus	1.4308	1.4388	1.4556	1.4476	1.4907	0.0142	27	27	28	28	31
Tibia	2.2467 *a*	2.2171 *b*	2.2268 *b*	2.2539 *a*	2.2386 *ab*	0.0019	176 *a*	165 *b*	168 *b*	179 *a*	173 *ab*
Humerus	2.3251 *ac*	2.3148 *ac*	2.3307 *abc*	2.3610 *b*	2.3478 *bc*	0.0018	211 *ac*	206 *ac*	214 *abc*	230 *b*	223 *bc*
Pelvic girdle	2.3837 *a*	2.3938 *ab*	2.4015 *ab*	2.4217 *b*	2.3912 *a*	0.0013	242 *a*	248 *ab*	252 *ab*	264 *b*	246 *a*
Sternum	2.0011 *ac*	2.0767 *ac*	1.9962 *abc*	1.8638 *b*	1.9169 *bc*	0.0096	100 *ac*	119 *ac*	99 *abc*	73 *b*	82 *bc*
Pectoral girdle	2.1673 *a*	2.1737 *a*	2.1177 *b*	2.1194 *b*	2.1168 *b*	0.0017	147 *a*	149 *a*	131 *b*	132 *b*	131 *b*
Ribs	2.5433 *a*	2.5431 *a*	2.4994 *b*	2.4886 *b*	2.5021 *b*	0.0015	349 *a*	349 *a*	316 *b*	288 *b*	317 *b*
Lumbar vertebrae	2.2640	2.2212	2.2807	2.2618	2.2774	0.0081	184	166	191	183	189
Cervical vertebrae	2.1128	2.1605	2.1477	2.1543	2.1231	0.0111	129	144	140	142	133
Patella	1.2257	1.2550	1.2453	1.2302	1.2256	0.0041	17	18	18	17	17
Atlas	1.5261	1.5361	1.5429	1.5105	1.5104	0.0105	34	34	35	32	32

†Duroc × Yorkshire (D×Y), Hampshire × Yorkshire (H×Y), Yorkshire (Y×Y), Yorkshire × Lacombe-Yorkshire (Y×L-Y), Lacombe × Yorkshire (L×Y).
a–c Means in the same row with different letters differ significantly at $P = 0.05$.

Table 4. Least square mean weights of individual bones (g) by sex-type adjusted to the experimental mean of total side bone (2409 g)

	Log bone weight		Residential mean	Bone weight	
Bone	Barrow	Gilt	square	Barrow	Gilt
Tarsus	1.8729	1.8362	0.0231	75	68
Femur	2.3914	2.3855	0.0007	246	243
Radius/ulna	2.2044	2.1982	0.0014	160	158
Thoracic vertebrae	2.4779	2.4781	0.0133	300	301
Carpus	1.4685	1.4369	0.0142	29	27
Tibia	2.2391	2.2341	0.0019	173	171
Humerus	2.3372	2.3345	0.0018	217	216
Pelvic girdle	2.3950	2.4017	0.0013	248	252
Sternum	1.9707	1.9712	0.0096	93	94
Pectoral girdle	2.1309*a*	2.1471*b*	0.0017	135*a*	140*b*
Ribs	2.5124	2.5182	0.0015	325	330
Lumbar vertebrae	2.2565	2.2656	0.0081	180	184
Cervical vertebrae	2.1419	2.1375	0.0111	139	137
Patella	1.2407	1.2321	0.0041	17	17
Atlas	1.5277	1.5227	0.0105	34	33

a,*b* Means in the same row with different letters differ significantly at $P = 0.05$.

results were made at different tissue weights. The only adequate way of overcoming this problem is by regression, as the use of percentages and percentage increases are misleading (Miller and Weil 1963; Berg et al. 1978a). However, it is worthwhile mentioning that limb bones more distal than the carpus or tarsus were not measured in this study and a centripetal pattern of limb bone growth may have been more evident if this had been the case.

Overall, the present study clearly showed that although the lumbar vertebrae may be one of the latest maturing groups of bones, there was no clear pattern of growth gradients along the vertebral column or the appendicular skeleton, during the period of growth from 68 to 114 kg liveweight.

B. Genetic and Sex Influences on Bone Growth Patterns and Distribution

Breed regressions were homogeneous in all cases for each bone relative to total bone, indicating that individual bone growth followed a similar pattern for all breeds over the weight range in this study. Only one previous report (Richmond and Berg 1972) has examined the effect of breed and sex on bone growth distribution. Their general conclusion was that breed and sex had no consistent effect on the distribution of bone. This study showed small but significant differences among the five breeds for bone distribution, when adjusted to the experimental mean of total side bone. The (D×Y) and (H×Y) animals tended to have a slightly different bone distribution to the (Y×L-Y) and (L×Y) animals. The (Y×Y) animals were intermediate. These differences were manifest by (D×Y) and (H×Y) animals having less bone in the femur (bone with low growth coefficient), and more bone in the pectoral girdle and ribs (bones with high growth coefficients) than the (Y×L-Y) and (L×Y) animals. These differences are compatible with a concept that the (D×Y) and (H×Y) animals were skeletally more mature at the same total bone weight (more bone located in bones with high growth coefficients than (Y×L-Y) and (L×Y) animals).

Sex regressions were in all cases homogeneous for each bone relative to total bone. Thus, as with breed, bone growth followed similar patterns in both sex-types. Only one significant difference between adjusted means showed slightly more bone in the pectoral girdle of gilts than barrows at equal total bone weight.

C. Comparison of Bovine and Porcine Bone Growth Patterns

Several recent reports have examined the relative growth of bone in cattle (Kempster et al. 1977; Berg et al. 1978b; Jones et al. 1978). The only anatomical study (Jones et al. 1978) showed that although the growth coefficients of the limb bones were significantly less than 1.0, distal to proximal growth gradients within the limbs were not evident. Neither was a complete antero-posterior growth gradient found along the axial skeleton. The fact that limb bones were found to have growth coefficients less than 1.0 in cattle and pigs is assumed to result from the functional need to stand and walk soon after birth.

Comparing the present results with the above cattle studies, species differences were found for the relative growth of most bones. All three bones with growth coefficients significantly less than 1.0 in this study were also reported to have growth coefficients significantly less than 1.0 in cattle (Jones et al. 1978). Of the seven growth coefficients reported here to be not different to 1.0 in pigs, only two (thoracic vertebrae and sternum) were similarly classified in cattle. Only the ribs had growth coefficients greater than 1.0 in both species. Species differences could be the result of comparisons made at different physiological ages, and adaptations to different patterns of fighting, feeding and locomotion peculiar to each species. Berg and Butterfield (1976) have discussed similar species adaptations in muscle distribution.

It has been demonstrated that breed and sex influences on bone distribution in pigs at constant bone weight are small and may reflect maturity differences. This indicates that the stability of bone development in the carcass is probably related to function. Differential bone growth does occur, but follows similar patterns for different breeds and sexes. These reasons are sufficient to establish that commercial differences in bone distribution found among different breeds and sexes of pigs are likely to be economically unimportant.

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