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

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The relative growth and distribution of bone from 256 bovine carcasses were compared among three breed-types (British, up to 30% Charolais and 30–50% Charolais) and three "sexes" (heifers, steers and bulls) 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 among both breed-types and sexes for each bone relative to total side bone, indicating that different breeds and sexes followed similar patterns of relative bone growth as they increased in size. The lowest growth coefficients in the carcass were found in the neck and limb bones all of which had growth coefficients significantly less than 1.0. The thoracic and lumbar vertebrae and the sternum had growth coefficients not significantly different from 1.0 and the ribs, pelvic and pectoral girdles had growth coefficients significantly greater than 1.0. Significant breed-type and "sex" differences were found in the weights of individual bones when adjusted to equal side bone weight. However, these were small and probably reflected differences in stage of maturity.

Nous avons comparé sur trois races (type britannique, 1/4 sang Charolais et 30–50% sang Charolais), et sur trois sexes (génisses, bouvillons et taurillons) la croissance relative et la proportion des os de 256 carcasses recoupant un vaste éventail de poids. La courbe de croissance de chaque os par rapport à l'ossature de la demi-carcasse a été calculée à partir du coefficient b dans l'équation allométrique $Y=aX^b$. Les coefficients se sont révélés homogènes à l'intérieur d'une même race et d'un même sexe: ce qui montre que les races et les sexes conservent le même développement osseux relatif à mesure qu'ils grossissent. C'est dans le cou et dans les membres que les coefficients de croissance ont été le bas, se situant significativement en dessous de 1.0. Dans les vertèbres thoraciques et lombaires et le sternum, les coefficients se sont tenus aux alentours de 1.0, tandis que les côtes et les ceintures pelviennes et pectorales accusaient des coefficients significativement supérieurs à 1.0. Ramené à un même poids de demi-carcasse, le poids des os particuliers a montré des différences significatives entre les races et entre les sexes, quoique ces différences aient été de faible importance et qu'elles tiennent probablement à des différences de maturité au moment de l'abattage.

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The early classical growth work of Hammond (1932) with sheep and McMeekan (1940) with pigs suggested an antero-posterior pattern of skeletal growth, as well as a centripetal pattern of growth within the limbs. Recent work in pigs (Richmond and Berg 1972) and cattle (Seebeck and Tulloh 1968; Seebeck 1973; Berg et al. 1979) have conformed generally to this hypothesis on the differential growth of bone. However, little information is available on the genetic influences on bone growth and distribution. Seebeck (1973) and Truscott et al. (1976) both reported breed differences in bone distribution, but comparisons were not

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made with respect to growth impetus patterns of bone.

Berg et al. (1979) have conducted the most comprehensive studies on bone growth and distribution to date, and their results indicate that different breed groups follow similar patterns of differential bone growth as they increase in size. Significant sire breed differences were found in the proportion of bone in each joint when adjusted to equal side bone weight, but differences were small and considered by the authors to be commercially unimportant. No reports were found concerning the effect of sex on relative bone growth and distribution in cattle.

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

MATERIAL AND METHODS

Two hundred and fifty-six cattle consisting of three ''sexes'' (bulls, steers and heifers) were used in this study. All of the animals were from the University of Alberta beef research herd at Kinsella, Alberta. The breeding plan and general management of the project has been discussed elsewhere in detail (Berg 1975). The cattle were classified into three groups on the basis of their breed-type. The three breed-types were: British (B) which contained purebreds and crossbreds among Hereford, Shorthorn, Angus and Galloway breeds; British crossbreds with up to 30% Charolais (30% CH) and British crossbreds with 31–50% Charolias (50% CH).

Slaughter was conducted at a commercial packing plant following routine procedures. The carcass comprised the eviscerated body with the removal of the head at the atlanto-occipital articulation, the thoracic limbs at the carpo-metacarpal articulation, the pelvic limbs at the tarso-metarsal articulation and the tail at the first intercoccygeal articulation. Left sides of carcasses were removed to the University Meats Laboratory, where separation into muscle, fat and bone was done by the total anatomical dissection technique described by Butterfield and May (1966).

A detailed study of carcass dissection procedures reveals a wide variety of definitions for carcass bone (Williams 1976), particularly with respect to connective tissue. For our purposes, bone is defined as being trimmed clean of muscle and fat. Periosteum, all cartilage, ligaments and tendons are grouped apart from bone as connective tissue.

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 if its growth coefficient was lower than that of the the cervical vertebrae. The sacral vertebrae were included as part of the pelvic girdle.

Statistical methodology for studying the growth of carcass tissues has been examined by Seebeck (1968) and Berg et al. (1978a). The latter demonstrated that the allometric equation (Huxley 1932) is superior to the linear model in describing the relationship between many of the common carcass variables. Growth coefficients (b values) from the linear form of Huxley's equation — $\log Y = a + b \log X$, where X = total side bone — were used to describe relative bone growth, and as a basis for adjusting group means. Group means for each bone were compared after adjusting to a common side bone weight where appropriate. Differences between means were tested for significance using Duncan's multiple range test corrected for unequal subclass numbers (Steel and Torrie 1968).

RESULTS

The mean individual bone weights and total side bone are presented in Table 1 by breed-type and sex. A wide variation in individual bone weight was recorded for each breed-type and sex, indicating a great range of weights at slaughter.

Table 2 lists the parameter estimates from the allometric relationships of the individual bones. The growth coefficients show that the proportion of bone found in the hind-limb (tarsus, tibia, patella, femur), fore-limb (carpus, radius/ulna, humerus) and cervical vertebrae decreased as total side bone increased. The thoracic, lumbar vertebrae and sternum remained a constant proportion of total side bone, while the

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

	Breed-type						Sex					
	B		30% CH		50% CH		Heifer		Steer		Bull	
Number of carcasses:	113		112		31		48		87		121	
Bone	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Atlas	139	42	144	42	191	74	109	28	152	28	160	60
Cervical vertebrae	784	257	798	220	1,020	312	609	153	852	165	878	304
Thoracic vertebrae	1,164	397	1,201	401	1,624	652	848	217	1,308	318	1,339	532
Lumbar vertebrae	665	266	665	252	865	372	484	153	736	202	738	331
Ribs	2,126	773	2,175	703	2,843	1,015	1,647	570	2,295	449	2,423	948
Sternum	832	277	937	234	1,114	273	686	224	1,006	791	934	322
Pectoral girdle	739	261	748	229	971	368	544	166	785	131	851	327
Humerus	1,148	340	1,203	309	1,538	393	888	226	1,281	186	1,305	408
Radius/ulna	845	244	879	221	1,168	472	661	168	934	143	969	353
Carpus	181	58	191	47	246	64	142	37	206	38	204	65
Pelvic girdle	1,559	513	1,555	456	2,084	713	1,258	387	1,660	322	1,736	655
Femur	1,442	412	1,582	374	1,982	481	1,209	297	1,684	254	1,629	509
Patella	104	41	104	30	132	37	85	50	117	27	110	33
Tibia	980	332	994	234	1,291	334	763	189	1,069	164	1,095	368
Tarsus	512	160	533	142	665	135	398	103	581	107	566	172
Total side bone	13,220	4,025	13,709	3,609	17,734	4,900	10,331	2,762	14,666	2,236	14,937	4,924

†British (B), 10–30% Charolais (30% CH), 31–50% Charolais (50% CH).

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

						Effect of breed-type		Effect of sex	
Bone	*a*	*b*	SE*b*	t-test†	*R*	Slope	Intercept	Slope	Intercept
Tarsus	−0.31	0.73	0.041	<1.0	0.43	NS	*	NS	NS
Femur	−0.26	0.83	0.019	<1.0	0.65	NS	*	NS	*
Cervical vertebrae	−0.64	0.85	0.028	<1.0	0.61	NS	NS	NS	NS
Tibia	−0.71	0.89	0.034	<1.0	0.58	NS	NS	NS	NS
Carpus	−1.41	0.89	0.040	<1.0	0.53	NS	NS	NS	NS
Patella	−1.71	0.90	0.033	<1.0	0.60	NS	NS	NS	*
Atlas	−1.64	0.92	0.024	<1.0	0.66	NS	NS	NS	NS
Radius/ulna	−0.85	0.92	0.019	<1.0	0.68	NS	NS	NS	**
Humerus	−0.83	0.94	0.008	<1.0	0.72	NS	**	NS	***
Thoracic vertebrae	−0.96	0.98	0.027	1.0	0.62	NS	NS	NS	*
Lumbar vertebrae	−1.24	0.98	0.053	1.0	0.49	NS	NS	NS	NS
Sternum	−1.13	0.99	0.050	1.0	0.52	NS	NS	NS	NS
Pelvic girdle	−1.42	1.12	0.021	>1.0	0.76	NS	NS	NS	*
Pectoral girdle	−2.21	1.23	0.016	>1.0	0.77	NS	*	NS	***
Ribs	−2.18	1.33	0.017	>1.0	0.80	NS	*	NS	**

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

†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.

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pelvic and pectoral girdles and ribs increased as a proportion of total side bone as growth proceeded. The individual breed-type and sex regression coefficients were in all cases homogeneous, indicating similar growth patterns among breed-types and sexes for each bone relative to total side bone.

Breed-type and sex had a significant influence on the weight of several bones when compared at equal side bone weight (Table 2). The breed × sex interaction was nonsignificant for every bone. Breed-type means, adjusted by applying the common regression to the population mean are presented in Table 3. Differences among breed-types for several bones (tarsus, femur, humerus, pectoral girdle and ribs) were statistically significant as already noted, but the overall differences were small. The B group shows the earliest maturity having a significantly ($P < 0.05$) greater weight of bone in the ribs and pectoral girdle (bones with high growth coefficients) and less weight in the humerus, femur and tarsus (bones with low growth coefficients) than the 50% CH group.

Sex means, adjusted by the use of the common regression to the population mean of side bone are shown in Table 4. Differences among sexes for many of the bones were statistically significant, but again the overall differences were small. Heifers generally had more bone in the ribs, pectoral and pelvic girdles and less bone in the fore- and hind-limbs than bulls or steers.

DISCUSSION

A. Growth Patterns of Bone

Hammond (1932) demonstrated differential growth in bones of sheep and suggested an antero–posterior pattern of skeletal growth and a centripetal pattern of growth within the limbs, which all met at the junction of the loin with the last rib. Further evidence supporting this theory of growth gradients was provided by McMeekan (1940) and Richmond and Berg (1972) using pigs, and Seebeck (1973) and Berg et al. (1979) in cattle. The present study is not in total agreement with their results.

Growth coefficients of all limb bones and cervical vertebrae were significantly less than unity ($P < 0.05$). This agrees with the general growth waves described by Hammond (1932), Seebeck and Tulloh (1968), Seebeck (1973) and Berg et al. (1979) though distal to proximal growth gradients within the limbs were not clearly evident in the present work. Neither was the atlas earlier maturing than the other vertebrae, as might be expected if a true antero–posterior growth gradient existed along the axial skeleton.

The growth coefficients of the sternum and the thoracic and lumbar vertebrae were not significantly different to 1.0. The work of Seebeck (1973) and Berg et al. (1979) indicated that these bones had growth coefficients significantly greater than 1.0 with the lumbar region being the latest maturing in agreement with the growth gradient theory of Hammond (1932). However, Seebeck (1973) and Berg et al. (1979) both failed to separate the ribs from the thoracic and lumbar veretebrae, respectively, and the latter also included part of the pelvic girdle. The results of our study show the ribs and limb girdles as having the highest bone growth coefficients; Seebeck (1973) and Berg et al. (1979), by including these other bones with vertebrae were thus confounding an intermediate with a late-maturing part of the skeleton.

Overall, the present study clearly showed that for these cattle, the limb-bones and cervical vertebrae had the lowest growth coefficents (were earliest maturing), the thoracic and lumbar vertebrae and the sternum were intermediate and the ribs and limb girdles had the highest growth coefficients (were latest maturing).

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

Many reports have demonstrated the extent of the differences among breeds (Fahmy

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Table 3. Individual bone weights† (g) by breed-type† adjusted to the population mean of total side bone

Bone	Log bone weight			Residual mean square	Bone weight		
	B	30% CH	50% CH		B	30% CH	50% CH
Atlas	2.1440	2.1408	2.1533	0.0029	139	138	142
Cervical vertebrae	2.8921	2.8837	2.8866	0.0039	780	765	770
Thoracic vertebrae	3.0599	3.0520	3.0556	0.0037	1,148	1,127	1,137
Lumbar vertebrae	2.8082	2.7909	2.7893	0.0136	643	618	616
Ribs	3.3168 *a*	3.3184 *a*	3.2959 *b*	0.0015	2,074 *a*	2,082 *a*	1,976 *b*
Sternum	2.9160	2.9275	2.9490	0.0123	824	846	889
Pectoral girdle	2.8581 *a*	2.8545 *a*	2.8358 *b*	0.0012	721 *a*	715 *a*	685 *b*
Humerus	3.0567 *a*	3.0646 *b*	3.0606 *ab*	0.0003	1,139 *a*	1,160 *b*	1,150 *ab*
Radius/ulna	2.9266	2.9293	2.9363	0.0017	844	850	863
Carpus	2.2464	2.2641	2.2579	0.0079	176	184	181
Pelvic girdle	3.1914	3.1788	3.1761	0.0023	1,554	1,509	1,500
Femur	3.1652 *a*	3.1862 *b*	3.1800 *ab*	0.0017	1,463 *a*	1,535 *b*	1,513 *ab*
Patella	2.0134	2.0017	2.0197	0.0055	103	100	105
Tibia	2.9816	2.9861	3.0005	0.0059	985	968	1,001
Tarsus	2.6976 *a*	2.7078 *a*	2.7408 *b*	0.0082	498 *a*	510 *a*	550 *b*

†Least square means.
a,b Means in same row with different letters differ significantly at $P < 0.05$.
†British (B), 10–30% Charolais (30% CH), 31–50% Charolais (50% CH).

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Table 4. Individual bone weights† (g) by sex adjusted to the population mean of total side bone

Bone	Log bone weight			Residual mean square	Bone weight		
	Heifer	Steer	Bull		Heifer	Steer	Bull
Atlas	2.1397	2.1435	2.1549	0.0029	138	139	143
Cervical vertebrae	2.8732	2.8945	2.8946	0.0039	747	784	784
Thoracic vertebrae	3.0271 *a*	3.0752 *b*	3.0653 *b*	0.0037	1,064 *a*	1,189 *b*	1,162 *b*
Lumbar vertebrae	2.7840	2.8151	2.7893	0.0136	608	653	616
Ribs	3.3385 *a*	3.2917 *b*	3.3009 *b*	0.0015	2,180 *a*	1,957 *b*	1,999 *b*
Sternum	2.9560	2.9220	2.9145	0.0123	904	836	821
Pectoral girdle	2.8582 *a*	2.8335 *b*	2.8567 *a*	0.0012	721 *a*	681 *b*	719 *a*
Humerus	3.0463 *a*	3.0657 *b*	3.0699 *b*	0.0003	1,112 *a*	1,163 *b*	1,175 *b*
Radius/ulna	2.9262 *a*	2.9230 *a*	2.9431 *b*	0.0017	844 *a*	837 *a*	877 *b*
Carpus	2.2321	2.2713	2.2649	0.0079	171	187	184
Pelvic girdle	3.2019 *a*	3.1709 *b*	3.1735 *b*	0.0023	1,592 *a*	1,482 *b*	1,491 *b*
Femur	3.1659 *a*	3.1903 *b*	3.1751 *a*	0.0017	1,465 *a*	1,550 *b*	1,496 *a*
Patella	2.0147 *ab*	2.0262 *a*	1.9939 *b*	0.0055	103 *ab*	106 *a*	99 *b*
Tibia	2.9891	2.9911	2.9880	0.0059	975	980	973
Tarsus	2.7004	2.7322	2.7136	0.0082	502	540	517

†Least square means.
a,b Means in same row with different letters differ significantly at $P < 0.05$.

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and Lalande 1975; Broadbent et al. 1976; Koch et al. 1976) and sexes (Harte 1969; Brannang et al. 1970) in the proportion of bone, mainly at constant carcass weight. However, few authors have examined bone distribution, particularly at a common bone weight.

Truscott et al. (1976) studied the bone distribution of early (Angus) and late (Friesian) maturing breeds. Compared to the Friesian, the Angus had less bone in the limbs and a greater weight of bone in the thoracic regions at equal bone weight. Truscott et al. (1976) suggested that this was probably a reflection of the Friesians being at an earlier stage of development than the Angus. These differences are compatible with the concept that the Angus are earlier maturing and were thus higher in percent bone in those regions with high growth coefficients. Seebeck (1973) also reported similar results with Africander cross steers having lighter leg bones at the same total bone weight as Brahman crosses.

Berg et al. (1979) reported on bone distribution as influenced by eight sire breeds. Sire breed regressions were homogeneous, but significant differences were found in the proportion of bone in each anatomical joint when adjusted to equal total side bone weight. They suggested that these differences reflected differences among breed groups in maturity at a standard weight of bone, comparable to the Angus–Friesian comparison of Truscott et al. (1976).

The results of this study agree with those of Berg et al. (1979) in this respect. Breed regressions were homogeneous in all cases for each bone relative to total bone, indicating that bone growth followed a similar pattern for all breed-types over the weight range in this study. The small differences in adjusted means reflected more bone in the limbs of the 50% CH breed-type and less bone in the ribs and pectoral girdle when compared to the B breed-type. The small differences in distribution at equal total bone weight reflect differences in maturity among the breeds.

No reports were found on the effect of sex on bone distribution in cattle. Richmond and Berg (1972) reported sex to have no consistent effect on the distribution of bone in the carcasses of pigs. Sex regressions were in all cases homogeneous for each bone relative to total bone. Thus, as with breed, bone growth was following similar patterns for all sexes. The small differences in adjusted means generally reflected more bone in the limbs of bulls and steers and less bone in the limb girdles and ribs, when compared to heifers. These small differences in distribution at equal total bone weight reflect differences in maturity among sexes.

It has been demonstrated that breed and sex influences on bone distribution at constant bone weight are small and probably reflect maturity differences. Differential bone growth does occur, but appears to follow similar patterns for different breed types and sexes. For these reasons commercial differences in bone distribution found between different breeds and sexes are likely to be economically unimportant.

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