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Original article

The effect of breed-type and castration on bone growth and distribution in cattle

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Summary — Data from carcasses of 210 cattle (119 bulls and 91 steers) from 4 breed types, serially slaughtered from ≈ 200–800 kg kg liveweight were used to test the hypothesis of similar gender dimorphism among breeds in relation to carcass bone growth and distribution. Relative to total bone weight, breed types tended to have similar growth rates for all bones other than the cervical vertebrae, ribs, tibia and fibula, and tarsus. Adjusted to the same total bone weight there were significant differences among breed types in bone weight distribution, but the differences were very small and probably of little economic importance. Castration stimulated growth of the lumbar vertebrae, hindlimb bones, patella and hindquarter bones but inhibited growth of the ribs, scapula, carpus, forelimb bone, and forequarter bone. At the same total bone weight, steers as compared to bulls showed a shift in bone weight distribution towards the hindquarter, pistol and long bones. There were small but significant breed x gender interactions in the distribution of some bones.

bone growth / bone distribution / breed / gender / castration / interaction / cattle

Résumé — Effet de la race et de la castration sur la croissance et la distribution osseuse chez les bovins. *Des mesures de carcasses de 210 bovins (119 taureaux et 91 bœufs) de 4 races différentes abattus par séries entre 200 et 800 kg de poids vif, ont servi à tester l'hypothèse d'un dimorphisme sexuel similaire intrarace pour la croissance et la distribution osseuse de la carcasse. Pour ce qui est du poids osseux total, les races tendent à avoir des taux de croissance semblables pour tous les os autres que les vertèbres cervicales, les côtes, le tibia, le péroné et le tarse. Après ajustement à un même poids total d'os, on observe des différences significatives interraces dans la distribution du poids des os, mais les différences sont très faibles et probablement de faible importance économique. La castration stimule la croissance des vertèbres lombaires, des os des membres postérieurs, de la rotule et de l'arrière-train, mais inhibe la croissance des côtes, de l'omoplate, du carpe, des os des membres antérieurs et de l'avant-train. Pour le même poids total osseux, les bœufs montrent un changement dans la distribution osseuse pour ce qui est du train arrière, des os du bassin et des os longs par rapport aux taureaux. Des interactions race x sexe, faibles mais significatives, sont observées dans la distribution de quelques os.*

croissance osseuse / distribution osseuse / race / sexe / castration / interaction / bovin

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INTRODUCTION

It is well established that sex differences in bone growth and distribution are more pronounced than breed differences (Berg and Walters, 1983; Jones *et al*, 1984; Shahin *et al*, 1986). Studies have shown that castration results in a relative decrease in the weight of bone in the proximal part of the fore and hind limbs and the ribs and a relative increase in the height at withers, depth of chest, length of bones, particularly in the distal parts of the limbs (Geddes, 1910–1911; Hammond, 1932; Robertson *et al*, 1970; Brannang, 1971; Kay and Houseman, 1974). These castration effects are due to reduction in androgen secretion with an accompanying effect on metabolism and growth (Dauzier, 1980; Galbraith and Topps, 1981; Davis *et al*, 1984; Hock *et al*, 1988).

In spite of the existence of an extensive body of information on the effect of castration on daily gain, feed conversion, carcass composition, and meat quality, little is known about its effect on the growth of individual bones or bone groups and whether this is influenced by breed type.

To test the hypothesis that gender dimorphism in relation to bone structure of the carcass is similar among breeds, this study was designed to characterize the influence of breed-type, gender and breed type x gender interactions on bone growth and distribution.

MATERIALS AND METHODS

The study contained dissection data on 210 cattle, *ie* 119 bulls and 91 steers; from 56 (45 bulls, 11 steers) straightbred Hereford (HE); 52 (30,22) Beef Synthetic (SY); 59 (24,35) Hereford crossbred (HC) and 43 (20,23) Shorthorn crosbreed (SC) cattle. They were from The University of Alberta's beef research herd at Kinsella, Alberta. The HE were purebred, and the SY a composite line containing approximately 33% Charolais and Angus and 21% Galloway breeds. HC were from crosses among British beef breeds mainly sired by Hereford bulls, and containing > 50% HE breeding; SC were crosses of Shorthorn sires on HE, Sy and crossbred dams. All animals were born in April–May, nursed on their dams without creep feed and weaned in October at an average age of 5–6 months. Castration was carried out either prior to or at weaning. After weaning, animals were adjusted to an *ad libitum* high concentrate diet on which they remained until slaughter. The animals were serially slaughtered from 268–785 kg liveweight for HE, 322–821 kg for SY, 209–600 kg for HC and 191–531 for SC. Bulls and steers were of similar average age at slaughter.

The left side of each carcass was dissected into muscle, bone and fat. The weight of bones in the axial skeleton, forelimb and hindlimb were recorded. The sum of the weights of the humerus, radius and ulna, femur, tibia and fibula was used as "total long bone weight" and the sum of the lumbar, thoracic and cervical vertebrae was used as "total vertebral weight". The sum of the weight of hindlimb bone, lumber and thoracic vertebrae was used as "pistol bone". The sum of the weight of the hindlimb bones, lumber vertebrae, the last 2 thoracic vertebrae, and the last 2 ribs was used as "commercial hindquarter bone" and the sum of the weight of the forelimb bones, sternum, cervical vertebrae, the first 11 thoracic vertebrae and the first 11 ribs was used as "commercial forequarter bone". The bones of the pelvis, were not separated from the sacral and first 2 caudal vertebrae. The entire structure was treated as a single entity called the os coxa. The sum of the weight of individual bones and tendon was used as the weight of "total side bone".

Statistical analyses

To assess breed type and gender influences on bone growth and distribution, the data were analyzed by least squares analysis of data with unequal subclass numbers (Harvey, 1975). The allometric equation: $Y = AX^b$ after transformation to common logarithms ($\log_{10}$) formed the basis for the model which was :

$$\log Y_{ijk} = A + G_i + S_j + (GS)_{ij} + b \log X_{ijk} + (Gb)_i \log X_{ijk} + (Sb)_j \log X_{ijk} + e_{ijk}$$

where :

Y_{ijk} = weight (g) of bone or bone groups for the *ijk* th animal;

A = the intercept;

G_i = fixed effect of the ith breed group (i = 1, ..., 4);

S_j = fixed effect of the ith gender (j = 1,2);

$(GS)_{ij}$ = the interactions between breed and gender;

X_{ijk} = weight (kg) of TSB for the *ijk* th animal;

b = regression coefficient of Y on X;

$(Gb)_i$ = interaction effect (breed x regression coefficient);

$(Sb)_j$ = interaction effect (gender x regression coefficient);

e_{ijk} = error assumed to be NID (0, $\sigma^2 e$).

Individual breed group or gender regression coefficients were computed and compared and in cases where the regressions were homogeneous ($P > 0.05$) the common regression coefficient was used for adjustment. However, if the regressions were significantly different ($P < 0.01$) adjusted means were computed using the appropriate breed group or gender regression but they were not statistically tested for significance. Duncan's multiple range test as modified by Kramer (1957) was used to test for significant differences between pairs of adjusted means.

RESULTS

Bone percent in the side ranged from ≈ 11.7% for HE to ≈ 13% for SC and from 12% for steers to 12.7% for bulls (table I). Pistol bone accounted for 45–46% of total side bone (TSB) weight, the forequarter bone accounted for 52–54% of TSB weight and the hindquarter bone accounted for 40% of TSB weight. The remainder was tendon. In bulls, pistol bone formed a slightly lower proportion of the total bone than it did in steers, but the proportion of forequarter bone was similar in the 2 genders (table I).

There were significant breed type differences in the growth rate of the cervical vertebrae, ribs, tibia and fibula and tarsus relative to TSB (table II). HE had a higher relative growth rate fo the cervical vertebrae and a lower relative growth rate for the ribs, tibia and fibula than other breed types. SY had a significantly lower relative growth rate for the tarsus than the other breed types.

As TSB increased the proportion of bone in the scapula, ribs and os coxa increased ($b > 1$; $P < 0.05$), the proportion of bone in the cervical vertebrae, humerus, radius and ulna, carpus, femur, patella, tibia and fibula decreased ($b < 1$; $P < 0.005$), and the proportion of bones in the lumber vertebrae, thoracic vertebrae and sternum remained relatively constant ($b = 1$; $P > 0.05$).

As TSB increased, the proportion of bone in the forequarter ($b > 1$; $P < 0.05$), while that in the pistol and hindquarter decreased ($b < 1$; $P < 0.05$) (table II).

The effect of castration on bone growth is shown in table II and figure 1. Bulls had 38% higher relative growth for carpus, and 14% each for the scapula, ribs, thoracic

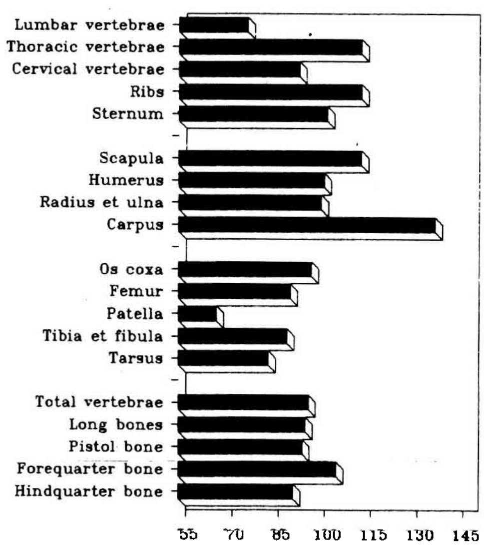

Fig 1. Relative growth rate of individual bones and bone groups in bulls expressed as a percentage of those in steers.

Table I. Unadjusted means and standard deviations (SD) of side bone as a percentage of total side weight and various bones and groups of bones as percentages of total side bone by breed type and gender.

	Hereford		*Shorthorn cross*		*Hereford cross*		*Beef synthetic*		*Bulls*		*Steers*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Bone % in the side	11.7	1.2	13.0	2.1	12.5	1.6	12.7	2.1	12.7	2.1	12.1	1.2
Axial skeleton												
Lumbar vertebrae	4.9	1.1	4.6	0.8	4.6	0.9	4.8	0.9	4.7	1.0	4.8	0.9
Thoracic vertebrae	8.4	1.0	8.3	1.0	8.3	1.0	8.4	1.3	8.2	1.1	8.5	1.1
Cervical vertebrae	6.4	0.9	6.8	0.7	6.7	0.8	6.6	1.0	6.6	0.9	6.6	0.8
Ribs	15.6	1.1	13.8	1.9	14.7	1.4	15.4	1.6	15.0	1.8	14.8	1.4
Sternum	5.6	0.8	6.0	0.8	5.9	0.8	6.1	1.1	5.8	0.8	6.0	1.0
Forelimb												
Scapula	5.5	0.4	4.9	0.4	5.3	0.4	5.2	0.5	5.3	0.5	5.1	0.4
Humerus	8.2	0.5	8.2	0.4	8.4	0.4	8.3	0.5	8.2	0.5	8.4	0.4
Radius and ulna	6.0	0.3	6.0	0.3	6.2	0.3	6.1	0.3	6.0	0.3	6.2	0.3
Carpus	1.2	0.1	1.5	0.2	1.3	0.2	1.3	0.2	1.3	0.2	1.4	0.2
Hindlimb												
Os coxa [1]	11.3	0.7	10.4	0.8	10.7	0.7	11.0	1.2	10.9	0.9	10.8	1.0
Femur	10.0	1.4	10.9	0.8	11.1	0.7	10.7	0.8	10.4	1.3	11.0	0.6
Tibia and fibula	7.0	1.3	6.8	0.6	7.0	0.5	7.0	0.8	6.9	1.1	7.0	0.4
Tarsus	3.6	0.4	4.1	0.6	3.8	0.5	3.6	0.5	3.7	0.6	3.8	0.4
Totals												
Vertebrae [2]	19.7	2.1	19.6	1.5	19.6	1.8	19.7	2.0	19.5	1.9	19.9	1.8
Long bones	31.0	1.7	32.0	1.8	32.7	1.6	32.1	1.6	31.6	1.9	32.5	1.3
Pistol bone [3]	45.1	2.2	45.1	2.0	45.5	1.7	45.5	2.1	44.9	2.2	45.9	1.7
Forequarter bone	53.6	1.7	52.7	1.6	53.7	1.7	54.1	53.4	2.0	53.7	1.5	
Hindquarter bone	40.0	2.0	39.7	1.6	40.2	1.5	40.4	1.6	39.7	1.7	40.6	1.5
Tendon	5.8	1.7	6.9	1.4	5.4	2.0	4.8	2.1	6.2	1.9	4.9	1.8

[1] Split pelvis + sacrum + 2 caudal vertebrae. [2] Excluding sacral–caudal; see text.

vertebrae. They had 33% lower relative growth rate in the patella, 23% lower in the lumbar vertebrae, 16% lower in the tarsus and 10% and 6% lower in the tibia and fibula and cervical vertebrae, respectively. However, bulls and steers tended to have similar relative growth rates for the rest of the skeleton.

Along the vertebral column, in steers the growth coefficient for the lumbar vertebrae (1.26) was higher than that of the cervical vertebrae (1.01), which in turn was higher than that of the thoracic vertebrae (0.88), while in bulls the growth coefficients for all 3 vertebral regions were similar (table II).

Table II. Growth coefficients (b) and standard errors (SE) of bones and groups of bones relative to total side bone.

	Hereford		*Shorthorn cross*		*Hereford cross*		*Beef synthetic*		*Bulls*		*Steers*		*Common*		*Significance of differences*	
	b+	*SE*	b	*SE*	b	*SE*	b	*SE*	b	*SE*	b	*SE*	b	*SE*	*Breed*	*Gender*
Axial skeleton																
Lumber vertebrae	1.19	0.20	1.11	0.11	1.11	0.15	1.07	0.13	0.97	0.07	1.26	0.13	0.99	0.06	NS	*
Thoracic vertebrae	0.94	0.12	0.91	0.07	0.97	0.09	0.82	0.08	0.97	0.04	0.85	0.11	0.95	0.04	NS	NS
Cervical vertebrae	1.24	0.12	0.89	0.07	0.87	0.09	0.92	0.08	0.95	0.04	1.01	0.11	0.91	0.04	*	NS
Ribs	0.98	0.08	1.36	0.05	1.23	0.06	1.16	0.05	1.26	0.03	0.10	1.10	1.29	0.02	**	*
Sternum	0.87	0.01	1.06	0.08	1.16	0.10	1.01	0.09	1.04	0.05	1.01	0.13	1.06	0.04	NS	NS
Forelimb																
Scapula	1.01	0.07	1.14	0.04	1.09	0.05	1.09	0.05	1.15	0.02	1.01	0.07	1.15	0.02	NS	*
Humerus	0.85	0.05	0.91	0.03	0.93	0.03	0.93	0.03	0.91	0.02	0.89	0.04	0.92	0.01	NS	NS
Radius and ulna	0.84	0.04	0.92	0.02	0.91	0.03	0.92	0.03	0.90	0.01	0.89	0.04	0.91	0.01	NS	NS
Carpus	0.83	0.12	0.72	0.07	0.84	0.09	0.93	0.08	0.96	0.04	0.70	0.11	0.93	0.03	NS	*
Hindlimb																
Os coxa	1.07	0.07	1.11	0.04	1.11	0.05	1.11	0.05	1.09	0.02	1.11	0.05	1.10	0.02	NS	NS
Femur	0.99	0.09	0.87	0.05	0.90	0.07	0.92	0.06	0.88	0.03	0.96	0.08	0.87	0.03	NS	NS
Patella	0.92	0.10	1.06	0.06	1.07	0.08	1.11	0.07	0.83	0.04	1.24	0.09	0.89	0.03	NS	*
Tibia and fibula	0.61	0.10	0.90	0.06	0.88	0.07	0.90	0.07	0.78	0.03	0.87	0.09	0.84	0.03	*	NS
Tarsus	0.94	0.30	0.81	0.17	0.97	0.22	0.19	0.20	0.66	0.10	0.79	0.27	0.61	0.09	**	NS
Totals																
Vertebrae	1.09	0.09	0.95	0.05	0.96	0.07	0.91	0.06	0.96	0.03	0.99	0.08	0.94	0.03	NS	NS
Long bones	0.83	0.04	0.89	0.02	0.91	0.03	0.92	0.03	0.87	0.01	0.91	0.04	0.88	0.01	NS	NS
Pistol bone	0.95	0.02	0.95	0.02	0.98	0.03	0.96	0.02	0.93	0.01	0.98	0.04	0.94	0.01	NS	NS
Forequarter bone	0.96	0.02	1.03	0.02	1.02	0.02	0.98	0.02	1.03	0.01	0.97	0.03	1.03	0.01	*	*
Hindquarter bone	0.96	0.02	0.97	0.02	0.99	0.03	1.00	0.02	0.94	0.01	1.02	0.03	0.95	0.01	NS	*
Tendon	1.84	0.32	1.08	0.19	0.97	0.24	1.45	0.22	1.18	0.11	1.49	0.30	1.12	0.10	*	NS

+ Growth coefficients underlined are significantly different from 1 at $P < 0.05$. NS, $P > 0.05$; * $P < 0.05$; ** $P < 0.01$.

Castration caused a small but significant reduction in the relative growth of the forequarter bones and an increase in the relative growth of the hindquarter bones (table II).

Adjustment to a common side bone weight resulted in a number of significant breed type differences in bone weights (table III). However, no clear pattern was evident and the differences themselves were quite small.

Adjusted to the same TSB, bulls had significantly lighter thoracic vertebrae, radius and ulna, femur, total long bones, and pistol bones than steers (table III).

The results of interaction analyses for regression of individual bones or bone groups on TSB indicated that the effect of breed was similar in both genders for most of the skeleton; however, the breed x gender interaction was a significant source of variation for the cervical vertebrae, ster-

Table III. Weight (g) of individual bones and bone groups adjusted to the geometric mean of total side bone (15.6 kg).

	Breed type				*Gender*		*Significance of difference*		
	Hereford	*Shorthorn cross*	*Hereford cross*	*Beef synthetic*	*Bulls*	*Steers*	*Breed (G)*	*Gender (S)*	*G x S*
Axial skeleton									
Lumbar vertebrae	758	696	697	736	707	736	NS	TNL	NS
Thoracic vertebrae	1337	1266	1276	1300	1266	1323	NS	*	NS
Cervical vertebrae	999	1034	1020	1014	1029	1005	TNL	NS	*
Ribs	2397	2261	2290	2301	2284	2340	TNL	TNL	NS
Sternum	866[a]	932[b]	916[b]	944[b]	900	929	*	NS	*
Forelimb									
Scapula	842[a]	786[b]	818[a]	786[b]	811	804	**	TNL	NS
Humerus	1278[a]	1253[a]	1308[b]	1304[b]	1280	1291	**	NS	NS
Radius and ulna	944[a]	919[b]	952[a]	962[a]	932	957	**	**	NS
Carpus	182[a]	227[b]	200[b]	207[b]	205	202	**	TNL	*
Hindlimb									
Os coxa	1727[a]	1648[b]	1667[b]	1689[b]	1681	1684	*	NS	NS
Femur	1605[a]	1647[a]	1720[b]	1693[b]	1635	1697	**	**	*
Patella	118[a]	117[b]	113[b]	110[b]	110	119	*	TNL	NS
Tibia and fibula	1076	1021	1070	1100	1058	1075	TNL	NS	NS
Tarsus	545	576	569	526	542	566	TNL	NS	*
Totals									
Vertebrae	3111	3014	3015	3076	3010	3026	NS	NS	NS
Long bones	4923[a]	4841[a]	5052[b]	5067[b]	4920	5021	**	**	NS
Pistol bone	7094[a]	6911[a]	7038[a]	7133[b]	6970	7117	**	**	NS
Forequarter bone	8327	8245	8342	8386	8332	8328	TNL	TNL	*
Hindquarter bone	6421[a]	6215[b]	6339[ab]	6438[a]	6270	6448	**	TNL	NS
Tendon	754	1085	806	648	925	707	TNL	*	NS

[a,b] Means in a row bearing superscripts differ significantly at $P < 0.05$. NS, $P > 0.05$; * $P < 0.05$; ** $P < 0.01$. TNL, test not legitimate (slopes differed significantly).

num, femur, carpus and tarsus (tables III, IV; fig 2).

DISCUSSION

Bone growth patterns

Breed effects

Relative to total bone weight, breed types tended to have similar growth rates for all bones other than the cervical vertebrae, ribs, tibia and fibula and tarsus. HE cervical vertebrae grew more rapidly, while HE ribs and tibia and fibula grew more slowly than other breed types. In HE, the cervical vertebrae were late maturing ($b > 1$) while in the other breed types they grew at the same rate as total bone. HE have a smaller mature body size than the other breed types and would, therefore, be more mature at a common side bone weight. Hammond (1932) reported that the earlier maturing breeds (HE in the present study) have relatively shorter and thicker neck bones than later maturing breeds. This is confirmed at constant skeletal weight in the present study.

The homogeneity of the growth coefficients of some individual bone and bone

Table IV. Breed by gender least squares means for bones adjusted to equal total side bone of 15.6 kg.

	Hereford	*Shorthorn cross*	*Hereford cross*	*Beef synthetic*
Cervical vertebrae				
Bulls	1004	1047	1000	1066
Steers	995	1022	1041	964
Bulls/steers	1.01	1.03	0.96	1.11
Sternum				
Bulls	867	943	936	894
Steers	862	923	905	1007
Bulls/steers	1.01	1.02	1.03	0.89
Carpus				
Bulls	196	220	200	205
Steers	169	233	200	209
Bulls/steers	1.16	0.94	1.00	0.98
Femur				
Bulls	1520	1627	1729	1671
Steers	1694	1668	1711	1715
Bulls/steers	0.90	0.98	1.01	0.97
Tarsus				
Bulls	593	567	545	471
Steers	502	586	593	587
Bulls/steers	1.18	0.97	0.92	0.80

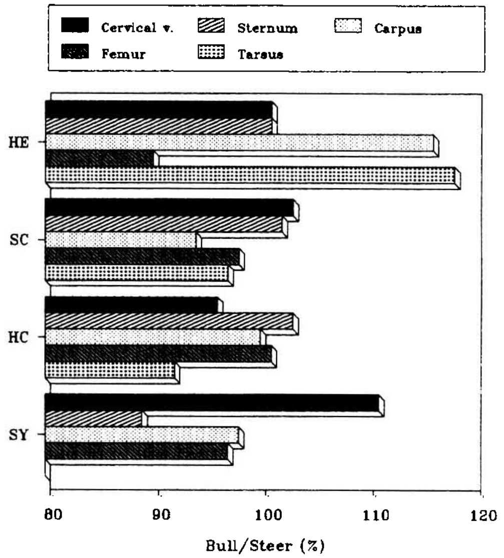

Fig 2. Relative development (% ratio) of bones in bulls compared with steers at constant total side bone weight of 15.6 kg.

groups in the present study implies that there is no differential effect of genotype on the relative growth of these bones. Thus any differences among adjusted means would reflect breed type differences established earlier in development than the start of the present experiment.

Hammond (1932) suggested the centripetal theory of growth gradients which states that the growth of the vertebral column follows as anterio-posterior gradient while that of the limbs follows a disto-proximal gradient. In the present study the growth coefficients of the bones in the limbs revealed an increasing disto-proximal gradient, while that of the vertebral column was dependent upon the breed type and there was no clear pattern of growth gradient. This agrees with the results of Jones *et al* (1978). In HE, the earliest maturing breed type, the growth coefficient for the cervical vertebrae, the most anterior of the vertebral column was higher ($b > 1$) than that of the thoracic and lumbar vertebrae. Similarly, Kempster *et al* (1977) found that the cervical vertebrae and humerus tended to grow at a faster relative rate than total bone weight.

Gender effects

The effect of castration on bone growth and development may depend upon the age at castration. Hammond (1932) claimed that in sheep if castration is performed at an early age (*ie* before puberty) its effect can be seen in the upper and lower parts of the limbs, but if castration is carried out late (*ie* after puberty) its effect can be seen only in the upper parts of the limbs and more particularly those parts associated with secondary sexual characteristics. Jones *et al* (1983) reported that castration before puberty in cattle may increase skeletal size and consequently steers would have larger ultimate skeletal size than bulls.

In the present study castration promoted relative growth of the lumbar vertebrae, patella bone and hindquarter bone but inhibited relative growth of the ribs, scapula, carpus and forequarter bone. In bulls the highest relative growth rate was found in the ribs, while in steers it was found in the lumbar vertebrae. The relatively lower growth rate of the flat bones of the scapula and ribs in steers may reflect altered response to levels of circulating male hormones which are thought to stimulate flat bone development and inhibit long bone development (Silberberg and Silberberg, 1971). Hammond (1932) reported that the ribs in bulls were more strongly developed and more markedly curved than those of steers. Brannang (1971) found that castration resulted in a relative decrease in the ribs and scapula. Jones *et al* (1978) found no significant differences between sexes in the relative growth rates of each bone relative to total side bone.

Bone weight distribution

Breed effects

Comparisons of bone weight distribution have been made at the same weight of TSB. However, it is necessary to consider possible differences in maturity and mature weight of different breed types at the same TSB. The breed type which has reached the greatest degree of maturity at a standard TSB will have the relatively highest proportion of late developing bones or bone groups. Compared with other breed types, HE had proportionately more of their bone in the os coxa. Assuming that the os coxa is a late developing part, the differences between HE and other breed types would reflect differences in the stage of maturity, HE being of smaller mature size would be more mature when compared at the same total bone weight. Seebeck (1973) found that Africaner cross steers had relatively heavier ribs than Brahman crosses. Truscott *et al* (1976) found that Friesians had less bone in the thoracic region than Angus crosses. Berg *et al* (1978) found that at same total bone weight, small Herefored-sired bulls tended to have more of their bone weight in the thoracic and lumbar vertebrae whereas the larger Chianina, Charolais or Romagnola sired bulls were heavier in the hind shank. Differences in bone mineral concentration (bone density) could be another factor which is responsible for differences among breeds in bone distribution. Nour and Thonney (1988) reported significant differences between breeds in the concentrations of K, Ca and Na in bone. Though there were significant differences among breed types in bone weight distribution, the differences were very small and probably of little economic importance.

HE had a proportionately smaller sternum than other breed types (table III). The reason for this is not clear. Jones *et al* (1978) found that at the same total bone weight, later maturing Charolais crossbreds had 8% heavier sternum than earlier maturing British beef types ($P > 0.05$). Shahin and Berg (1985) found that at the same TSB, double muscled bulls had a proportionately larger sternum than HE bulls. Hammond (1932) reported that later maturing breeds of sheep had longer sternums than earlier maturing breeds.

Gender effects

Castration leads to prologation of the process of epiphysial growth and to a disproportionate increase in the length of long bones (Hammond, 1932; Bradfield, 1967; Brannang, 1971; Silberberg and Silberberg, 1971; Kay and Houseman, 1974). In the present study castration increased the development of the bones of the radius and ulna, femur and total long bones. Brannang (1971) found that the effect of castration on the length of bones was clearer than its effect on weights. He found that the length of the long bones was increased by castration but that their weight was decreased. It can be argued that most if not all of the differences between genders in these bones are directly due to testosterone production which is known to cause the epiphyses to unite with the diaphyses. Short (1980) pointed out that in cases of reduced testosterone secretion, epiphyseal fusion is delayed and consequently limb growth would eventually outstrip vertebral growth. Differences in bone shape, dimensions, marrow content, protein matrix and density could be other factors responsible for the differences in bone weight distribution reported in this study. In young growing castrated male rabbits, testosterone treatment significantly increased bone density (Gilsanz *et al,* 1988).

In steers, the growth coefficient of the patella was higher than that of any other bones in the hindlimb. The relatively higher growth coefficient of the patella in steers could be related to their heavier m quadriceps femoris (Shahin *et al,* unpublished observations) since the main function of the patella is to give increased lever power to this muscle. Seebeck and Tulloh (1968) reported somewhat similar findings in steers with normal growth followed by a period of weight loss before slaughter. They pointed out that this bone formed a higher proportion of TSB at the end of the weight loss phase in the larger than in the smaller animals.

The thoracic vertebrae were relatively better developed in steers than in bulls. The reason for this is not clear. Geddes (1910–1911) found that in mature human eunuchs, ossification of the cervical and lumbar vertebrae was complete, whereas that of the thoracic vertebrae was not. Jones *et al* (1978) found no significant differences between bulls and steers in the weight of the thoracic vertebrae.

Bulls and steers in the present study tended to have similar proportions of bone in the os coxae, which agrees with the findings of Jones *et al* (1978). Hammond (1932) pointed out that in sheep, if lambs are castrated soon after birth the pelvis of both the castrated male and the female was very similar at maturity. In cattle, Brannang (1971) found that the effect of castration was greatest in the pelvic bones. It seems more likely that the occurrence of gender differences in this bone depends upon the age at which castration took place and upon the age of the animal at slaughter (*ie* immature *vs* mature). However, Carroll *et al* (1963) castrated cattle at 1 and 7 months of age, and found that age at castration had no effect on the percentage of bone occurring in pelvic limb bones.

Gender differed significantly in the relative growth rate of the lumbar vertebrae, which implies that the adjusted means of this bone group was conditional on the weight of total bone. At lighter weights of total bone, bulls had greater weights of lumbar vertebrae than steers, but at heavier weights of total bone, steers had heavier lumbar vertebrae. These differences between genders may be due to differences in the way the weight is distributed over the body. In bulls there was a shift in muscle weight distribution towards the forequarter and consequently the center of gravity of the bulls would shift cranially. In steers the center of gravity remained more caudal.

Breed–gender interactions

It might be anticipated that when comparisons are made at a common side bone weight, gender dimorphism would be most evident in breed types of smaller mature size, since they (and hence any gender dimorphism) would be more "mature" at any given weight. Such an effect would be manifested in breed–gender interactions. In most cases this was not observed, and even in those where a significant interaction was detected (cervical vertebrae, sternum, feumer, carpus, tarsus and axial skeleton as a unit), no clear pattern of interaction was evident. The reason for this lack of clear effect may be the complex nature of gender dimorphism in skeletal development: while entire males shows faster bone growth than castrates in both length and cross-sectional area following puberty, there is evidence that endochondral growth in the skeleton shows greater persistence in castrated males since they cannot reach puberty (Hutt, 1928; Silberberg and Silberberg, 1971). King and Young (1955) in study of sheep found significant breed–environment interactions for certain skeletal growth measurements and attributed these interactions to the more rapid growth of one breed (Blackface) on the high plane of nutrition.

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