SEX DIFFERENCES IN CARCASS COMPOSITION AND TISSUE DISTRIBUTION IN MATURE DOUBLE MUSCLED CATTLE

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Nineteen mature Double Muscled (DM) cattle consisting of 11 cows and eight bulls were slaughtered between 470 and 710 kg to determine the influence of sex on carcass composition and muscle, bone and fat in DM cattle. Expressed as a percentage of the total side weight, DM bull carcasses had 15% more muscle and 55% less total fat. When sides were compared DM bulls showed a 17% increase in the muscle:bone ratio compared with DM cows. In bull carcasses, there were shifts in muscle weight distribution towards the forequarter. The ratio of hindquarter muscle:forequarter muscle was greater in cows than in bulls. Expressed as a percentage of the total side muscle, significant differences between sexes were found in 48 of the 95 muscles. The most striking sexual dimorphism was found in the neck region, particularly among the muscles responsible for secondary sexual features and those which act to elevate and extend the head. Sexual dimorphism was less pronounced in the distal parts of the both limbs. The cervical vertebrae and scapula made up a greater proportion of total side bone in DM bulls than in DM cows. There was a consistent but nonsignificant trend for the cows to have more of their bone caudally and less anteriorly compared with the bulls.

Key words: Carcass composition, muscle distribution, bone distribution, mature Double Muscled cattle, double muscling

[Différences dues au sexe dans la composition des carcasses et la répartition des tissus chez les culards matures.]
Titre abrégé: Répartition des tissus chez les culards matures.
Dix-neuf culards matures, 11 femelles et 8 mâles, ont été abattus à un poids variant de 470 à 710 kg en vue de la détermination des différences dues au sexe dans la composition de la carcasse et la répartition des muscles, des os et de la matière grasse chez les culards. En pourcentages du poids total de la demi-carcasse, les maîes contenaient 15% de plus de muscles et 55% de moins de gras. Par ailleurs, le rapport muscles:os chez les culards mâles étaient supérieur de 17% à celui obtenu pour les femelles. Dans les carcasses des sujets mâles, nous avons observé un déplacement de la répartition du poids des muscles vers le quartier avant. Le rapport du poids des muscles du quartier arrière sur celui des muscles du quartier avant était supérieur chez les femelles. En pourcentages du poids total des muscles de la demi-carcasse, 48 des 95 muscles étudiés présentent des différences significatives entre les deux sexes. Le dimorphisme sexuel le plus frappant a été observé dans la région du cou, en particulier chez les muscles responsables des caractères sexuels secondaires et ceux qui font lever et avancer la tête. Le dimorphisme sexuel était moins prononcé dans les parties distales des membres avant et arrière. Les vertèbres cervicales et la ceinture scapulaire comptaient pour une partie plus importante du poids total des os de la demi-carcasse chez les mâles, comparativement aux femelles. Nous avons observé une tendance constante mais non significative, chez les car-

casses des femelles, à contenir plus de tissus osseux vers l'arrière et moins vers l'avant, comparativement aux mâles.

Mots clés: Composition de la carcasse, répartition des tissus musculaires, répartition des tissus osseux, culards matures

Double muscling (DM) or muscular hypertrophy is manifest by extremely heavy muscling and less bone leading to higher muscle:bone ratios than normal. Its expression varies depending upon the genetic background, environment, sex and stage of maturity of the particular animal.

An earlier series of papers from the University of Alberta (Shahin and Berg 1985a–e) compared young growing DM bulls to more normal genotypes with respect to the growth patterns and distribution of major tissues. Lauvergne et al. (1963) pointed out that the effects of Double Muscling were more marked in males than in females. Furthermore, the DM condition in females became less pronounced at puberty and calving whereas it was maintained prominently in the males. It would therefore appear that the differences in musculature between sexes became more pronounced with the advance in age. Sex differences in carcass composition and tissue distribution in normal cattle are well documented, but little is known about these criteria in mature DM cattle. Therefore the objective of this study was to investigate the influence of sex on carcass composition and tissue distribution in mature Double Muscled cattle.

MATERIALS AND METHODS

Dissection data from 11 DM cows and eight DM bulls were available for this study. These animals were from the University of Alberta's beef research herd at Kinsella, Alberta. The DM cattle were derived from a combination of Angus, Galloway, Limousin, Charolais and Hereford breeding selected for manifestation of the DM condition.

The management and breeding plan of the Kinsella beef breeding project were reported in detail by Berg (1978) and the DM population was described by Shahin and Berg (1985a). Both cows and bulls in this study were part of the DM breeding population. Within the double muscled population, animals were classified as on a visual basis and scored on a scale of 1 to 5 where 1 and 2 were normal and 3 to 5 moderate to extreme double muscled. All cows showed moderate to extreme Double Muscling while bulls were all classified as showing extreme manifestation of the condition. Both sexes were maintained on native short grass range throughout the year with supplementary feed provided during the winter when the snow cover prevented normal grazing. The cows used were culled for reproductive failure and varied in age from 838 to 4255 d. Bulls were culled as they were replaced by younger bulls and their age at slaughter varied from 905 to 2035 d.

Before slaughter, all animals were fed ad libitum a high energy diet of rolled barley, oats and alfalfa pellets for a variable period of time, the minimum being 140 d until they were subjectively judged to have an A1 carcass grade. Slaughter weight varied from 470 to 620 kg for cows and from 612 to 710 kg for bulls.

After normal slaughter procedures, the left side of each carcass was removed to the University of Alberta Meats Laboratory and dissected into major carcass tissues using the procedure of Butterfield and May (1966). The sum of the dissected muscle, fat, bone and "other tissue" was used as dissected side weight (DSW). The total side muscle (TSM) contained the sum of all muscles on the side. Individual muscles were removed from each side and means of the total side muscle and individual muscles derived separately for sexes. An estimate of total side fat was obtained by dissecting out the subcutaneous intermuscular and carcass cavity fat seperately for each animal within sex and grouping them to compute the mean and SD. Similar procedures were followed to compare total side bone. All percentages were calculated on a within-animal, within-sex basis, so that means and SD could be derived. The proportion of individual muscle groups were derived by expressing it as a percentage of the total side muscle for each animal. The percent means were calculated on a within-sex basis. The muscular tissue was dissected into 95 individual muscles, and after dissection the individual muscles were grouped into nine "anatomical groups" based on their anatomical location (Butterfield 1963): G_1, proximal hindlimb; G_2, distal hindlimb; G_3, muscles surrounding the spinal column; G_4, abdominal wall; G_5, proximal forelimb; G_6, distal forelimb; G_7, thorax to thoracic limb; G_8, neck and forelimb; and G_9, intrinsic muscles of the neck and thorax. The weight of individual and groups of bones in the axial skeleton, forelimb and hindlimb were recorded. The sum of the individual bones was used as total side bone (TSB).

The significance between means was tested applying methods outlined by Harvey (1975). All means reported represent actual values and no adjustments have been made to account for differences between years.

RESULTS

Bulls had a greater proportion of total side muscle (51.3%) and a higher muscle:bone ratio (17.2%) than cows (Table 1). Expressed as a percentage of the total side weight, bulls had 15% more muscle, 55% less total side fat, 65% less subcutaneous fat and 48% less intermuscular fat compared with cows. The muscle:bone ratio in bull carcasses ranged from 6.2 to 8.9 with a mean of 7.5, while in cow carcasses it ranged from 5.3 to 8.0 with a mean of 6.4.

The mean distribution of muscle for entire muscle groups G_1–G_9 expressed as a percentage of the total side muscle in the carcass for cows and bulls is shown in Table 2. Significant sex differences were observed for all but G_6 muscles of the distal forelimb. Cows showed significantly more muscle in five of the groups while bulls had more muscle in three groups.

Sexes differed significantly in the proportions of 48 of the 95 muscles (Tables 3.1 to 3.9). Bulls had significantly greater proportions for 17 muscles (constituting approximately 21.3% of TSM), but they had significantly smaller proportions for 31

Table 1. Unadjusted means and standard deviations (SD) of side weight, and major carcass tissues by sex

	Cows		Bulls		Significance of difference	Ratio Bull/cow
	Mean	SD	Mean	SD		
Age (d)	1844		1252			
Side weight† (kg)	160	28.0	213	28.2	$P<0.01$	1.331
Total side muscle (kg)	111.9	24.5	169.3	20.3	$P<0.01$	1.513
Total side fat (kg)	30.4	6.1	18.8	9.8	$P<0.01$	0.618
Total side bone (kg)	17.4	2.6	22.8	3.9	$P<0.01$	1.310
Subcutaneous fat (kg)	12.2	2.5	5.9	4.0	$P<0.01$	0.484
Intermuscular fat (kg)	13.6	3.6	9.6	3.9	$P<0.05$	0.706
Carcass cavity fat (kg)	4.7	0.9	3.4	1.9	$P<0.05$	0.723
Muscle:bone ratio	6.4	1.0	7.5	0.9	$P<0.05$	1.172
Muscle in side (%)	69.4	4.5	79.8	3.2	$P<0.01$	1.150
Fat in side (%)	19.2	4.2	8.7	3.9	$P<0.01$	0.453
Bone in side (%)	10.9	1.1	10.7	1.3	NS	0.982
SCF in side (%)‡	7.8	1.9	2.7	1.8	$P<0.01$	0.346
IMF in side (%)‡	8.5	2.3	4.4	1.4	$P<0.01$	0.518
CCF in side (%)‡	2.9	0.6	1.6	0.8	$P<0.01$	0.552
Fat depots as % of total side fat						
SCF%	40.5	5.2	29.0	6.7	$P<0.01$	0.716
IMF%	44.1	5.4	53.7	7.5	$P<0.01$	1.218
CCF%	15.5	1.6	17.4	3.1	$P<0.05$	1.122

†Excluding kidney knob and channel fat.
‡SCF, subcutaneous fat; IMF, intermuscular fat; CCF, carcass cavity fat.

Table 2. Mean distribution of muscle for entire muscle groups in Double Muscled cow and bull carcasses

Group	Cows % of total side muscle in carcass	Bulls % of total side muscle in carcass	Significance of difference	Ratio Bull/Cow
1. Muscles of the proximal hindlimb	32.1	28.7	$P<0.01$	0.894
2. Muscles of the distal hindlimb	3.9	3.4	$P<0.01$	0.874
3. Muscles surrounding the spinal column	12.8	11.5	$P<0.05$	0.898
4. Muscles of the abdominal wall	9.9	9.5	$P<0.05$	0.960
5. Muscles of the proximal forelimb	10.6	10.7	NS	1.009
6. Muscles of the distal forelimb	2.1	1.9	$P<0.05$	0.905
7. Muscles connecting the thorax to the forelimb	10.3	11.0	$P<0.05$	1.068
8. Muscles connecting the neck to the forelimb	6.8	8.7	$P<0.01$	1.279
9. Intrinsic muscles of the neck and thorax	9.2	12.4	$P<0.01$	1.343

muscles (constituting approximately 29.7% of TSM) than cows. The remaining 47 muscles were similar in both sexes. The muscles which showed significant differences between sexes were located in all muscle groups.

The muscles of G_1, G_2 and G_3 in cows comprised a greater proportion of total

Table 3.1. Distribution of total muscle weight (means) in Double Muscled cow and bull carcasses, Group 1 muscles

	Cows	Bulls		
Muscles of the proximal hindlimb	Percentage of total muscle	Percentage of total muscle	Significance of difference	Ratio bull/cow
M. tensor fasciae latae	1.54	1.43	$P<0.05$	0.929
M. biceps femoris	7.27	6.87	NS	0.945
M. gluteus medius	3.71	3.24	NS	0.873
M. vastus lateralis	2.50	2.07	$P<0.05$	0.828
M. gluteus accessorius	0.25	0.23	NS	0.920
M. rectus femoris	2.01	1.83	NS	0.915
M. semitendinosus	2.94	2.80	NS	0.952
M. gracilis	1.25	1.29	NS	1.032
M. semimembranosus	5.39	4.55	$P<0.01$	0.844
M. adductor femoris	1.65	1.41	$P<0.01$	0.855
M. pectineus	0.59	0.50	$P<0.01$	0.847
M. sartorius	0.35	0.36	NS	1.029
M. quadratus femoris	0.05	0.05	NS	1.000
Mm. obturatorii externus et internus	0.48	0.41	$P<0.01$	0.854
M. vastus medialis	0.61	0.42	$P<0.01$	0.694
M. articularis genu	0.03	0.02	$P<0.05$	0.667
M. iliacus	0.66	0.54	$P<0.01$	0.818
M. gluteus profundus	0.27	0.20	$P<0.01$	0.741
M. gemellus	0.05	0.04	$P<0.05$	0.771
M. vastus intermedius	0.53	0.46	NS	0.864

Table 3.2. Distribution of total muscle weight (means) in Double Muscled cow and bull carcasses, Group 2 muscles

Muscles of the distal hindlimb	Cows: Percentage of total muscle	Bulls: Percentage of total muscle	Significance of difference	Ratio bull/cow
M. gastrocnemius	1.76	1.52	$P<0.01$	0.864
Mm. extensores	0.53	0.47	$P<0.01$	0.887
M. peroneus longus	0.08	0.07	$P<0.05$	0.875
M. extensor digitorum lateralis	0.09	0.09	NS	1.000
M. tibialis cranialis	0.13	0.14	NS	1.077
M. tibialis caudalis	0.11	0.09	NS	0.815
M. popliteus	0.20	0.17	$P<0.05$	0.850
M. flexor digitorum longus	0.20	0.21	NS	1.050
M. flexor digitorum superficialis	0.32	0.25	$P<0.01$	0.781
M. flexor hallucis longus	0.47	0.39	NS	0.830

Table 3.3. Distribution of total muscle weight (means) in Double Muscled cow and bull carcasses, Group 3 muscles

Muscles surrounding the spinal column	Cows: Percentage of total muscle	Bulls: Percentage of total muscle	Significance of difference	Ratio bull/cow
M. psoas major	1.68	1.43	$P<0.01$	0.851
M. quadratus lumborum	0.12	0.11	NS	0.917
M. iliocostalis thoracis	0.42	0.38	NS	0.905
M. longissimus thoracis et lumborum	7.26	6.15	$P<0.01$	0.847
M. multifidus thoracis et lumborum	1.13	1.03	NS	0.912
M. longissimus cervicis	0.29	0.38	NS	1.287
M. spinalis cervicis et thoracis	1.66	1.79	NS	1.078
M. psoas minor	0.27	0.26	NS	0.963

Table 3.4. Distribution of total muscle weight (means) in Double Muscled cow and bull carcasses, Group 4 muscles

Muscles of the abdominal wall	Cows: Percentage of total muscle	Bulls: Percentage of total muscle	Significance of difference	Ratio bull/cow
M. cutaneus trunci	1.86	2.09	NS	1.125
M. serratus dorsalis caudalis	0.17	0.20	NS	1.176
M. obliquus externus abdominis	2.69	2.44	$P<0.05$	0.907
M. retractor costae	0.08	0.09	NS	1.125
M. obliquus internus abdominis	1.75	1.54	$P<0.05$	0.880
M. transversus abdominis	1.30	1.00	$P<0.05$	0.768
M. rectus abdominis	2.09	2.11	NS	1.010

Table 3.5. Distribution of total muscle weight (means) in Double Muscled cow and bull carcasses, Group 5 muscles

Muscles of the proximal forelimb	Cows Percentage of total muscle	Bulls Percentage of total muscle	Significance of difference	Ratio bull/cow
M. deltoideus	0.51	0.54	NS	1.051
M. infraspinatus	1.95	1.75	$P<0.01$	0.901
M. triceps brachii (Caput laterale)	0.60	0.55	$P<0.05$	0.931
M. teres minor	0.17	0.14	$P<0.01$	0.820
M. triceps brachii (Caput longum)	3.18	3.56	$P<0.01$	1.119
M. tensor fasciae antebrachii	0.17	0.22	$P<0.01$	1.315
M. supraspinatus	1.44	1.29	$P<0.01$	0.894
M. biceps brachii	0.53	0.49	$P<0.05$	0.914
M. teres major	0.47	0.47	NS	1.000
M. brachialis	0.35	0.33	NS	0.943
M. coracobrachialis	0.11	0.08	$P<0.05$	0.727
M. subscapularis	1.00	1.21	$P<0.05$	1.210
M. triceps brachii (Caput mediale)	0.08	0.09	NS	1.119

Table 3.6. Distribution of total muscle weight (means) in Double Muscled cow and bull carcasses, Group 6 muscles

Muscles of the distal forelimb	Cows Percentage of total muscle	Bulls Percentage of total muscle	Significance of difference	Ratio bull/cow
M. extensor carpi radialis	0.66	0.66	NS	1.000
M. extensor digitorum tertii	0.10	0.08	$P<0.01$	0.806
M. extensor digitorum communis	0.07	0.05	$P<0.05$	0.774
M. extensor digitorum lateralis	0.09	0.08	NS	0.923
M. ulnaris lateralis	0.21	0.18	$P<0.05$	0.889
M. abductor pollicis longus	0.02	0.02	NS	1.000
M. flexor carpi radialis	0.09	0.08	NS	0.852
M. flexor carpi ulnaris	0.08	0.10	NS	1.264
M. flexor digitorum profundus	0.34	0.28	$P<0.01$	0.804
M. anconeus	0.06	0.06	NS	1.000
M. flexor digitorum sublimis	0.37	0.29	$P<0.01$	0.779

muscle than they did in bulls, while the muscles of the cranial end (G_7, G_8 and G_9) formed a greater proportion of total muscle in bulls than they did in cows. The proportion of muscle in G_5 (the proximal forelimb) was similar in bulls and cows and the proportions of muscle in G_6 (the distal forelimb) and G_4 (the abdominal wall) were higher in cows than in bulls. Compared with cows, bulls had significantly higher proportions of the skeleton in the cervical vertebrae and scapula but a lower proportion in the tarsus than cows (Table 4).

Table 3.7. Distribution of total muscle weight (means) in Double Muscled cow and bull carcasses, Group 7 muscles

	Cows	Bulls		
Muscles connecting the thorax to the forelimb	Percentage of total muscle	Percentage of total muscle	Significance of difference	Ratio bull/cow
M. trapezius thoracis	0.89	1.12	$P<0.01$	1.258
M. latissimus dorsi	2.48	2.53	NS	1.019
M. serratus ventralis thoracis	1.61	1.41	NS	0.878
M. pectoralis profundus	4.05	4.25	NS	1.049
M. pectoralis superficialis	1.48	1.71	$P<0.05$	1.155

Table 3.8. Distribution of total muscle weight (means) in Double Muscled cow and bull carcasses, Group 8 muscles

	Cows	Bulls		
Muscles connecting the neck to the forelimb	Percentage of total muscle	Percentage of total muscle	Significance of difference	Ratio bull/cow
M. trapezius cervicalis	0.57	0.85	$P<0.01$	1.491
M. omotransversarius	0.68	0.86	$P<0.05$	1.253
M. rhomboideus	1.19	2.34	$P<0.01$	1.885
M. serratus ventralis cervicis	2.82	2.80	NS	0.993
M. brachiocephalicus	1.53	1.83	$P<0.01$	1.203

Table 3.9. Distribution of total muscle weight (means) in Double Muscled cow and bull carcasses, Group 9 muscles

	Cows	Bulls		
Intrinsic muscles of the neck and thorax	Percentage of total muscle	Percentage of total muscle	Significance of difference	Ratio bull/cow
M. intercostales (externi et interni)	2.58	2.43	NS	0.942
M. serratus dorsalis cranialis	0.20	0.26	NS	1.346
M. scalenus dorsalis	0.22	0.40	$P<0.01$	1.856
M. splenius	0.74	1.92	$P<0.01$	2.607
M. intertransversarius longus	0.27	0.55	$P<0.01$	2.061
M. longus capitis	0.16	0.30	$P<0.01$	1.823
M. longissimus capitis et atlantis	0.42	0.66	$P<0.01$	1.578
M. intertransversarius cervicis (dorsalis et ventralis)	0.72	0.95	$P<0.05$	1.318
M. complexus	1.44	2.41	$P<0.01$	1.668
M. obliquus capitis caudalis	0.55	0.57	NS	1.048
M. rectus thoracis	0.13	0.13	NS	1.000
M. transversus thoracis	0.22	0.19	NS	0.837
M. cervicohyoideus	0.05	0.05	NS	1.000
M. scalenus ventralis	0.46	0.48	NS	1.055
M. longus colli	0.67	0.72	NS	1.070
M. multifidus cervicis	0.33	0.34	NS	1.029

Table 4. Distribution of total bone weight in Double Muscled cow and bull carcasses

	Cows	Bulls		
	Percentage of total bone	Percentage of total bone	Significance of difference	Ratio bull/cow
Axial skeleton				
Lumbar vertebrae	5.10	4.93	NS†	0.966
Thoracic vertebrae	8.34	8.74	NS	1.048
Cervical vertebrae	6.18	7.23	$P<0.05$	1.169
Ribs	17.86	17.37	NS	0.972
Sternum	6.47	7.00	NS	1.084
Entire axial skeleton	43.95	45.27	NS	1.034
Forelimb				
Scapula	5.69	6.10	$P<0.01$	1.073
Humerus	7.72	7.89	NS	1.022
Radius et ulna	5.63	5.75	NS	1.022
Carpus	1.12	1.08	NS	0.963
Entire forelimb	20.16	20.83	NS	1.033
Hindlimb				
Os coxa†	12.73	12.11	NS	0.951
Femur	10.15	10.21	NS	1.006
Patella	0.70	0.68	NS	0.971
Tibia et fibula	6.57	6.42	NS	0.977
Tarsus	3.86	3.53	$P<0.05$	0.915
Entire hindlimb	34.01	32.94	NS	0.969

†NS, $P>0.05$.
‡Os coxa, pelvis + sacral + two coccygeal vertebrae.

DISCUSSION

Carcass Composition

Mature bulls in this study had more muscle, higher muscle:bone ratios, less total fat and less fat in all depots than mature cows. Although these results are expected in general terms (Berg and Butterfield 1976), the absolute differences in fatness were undoubtedly influenced by the different feeding and management history for mature bulls and cows in this study. Feeding and management are expected to have less influence on muscle:bone ratios and on muscle and bone distribution than on fat accumulation. The lower percentage of fat in mature bulls was associated with a lower proportion in the SCF depot and a higher proportion in the IMF depot as expected (Berg and Walters 1983).

Muscle Weight Distribution

The hindquarter muscles (G_1, G_2 and G_3) made up a greater proportion of total muscle in mature cows than in mature bulls in the present study (Table 2); conversely the forequarter muscle (G_5 to G_9) constituted a greater proportion of total muscle in bulls than in cows, the differences between sexes became wider in the mature animals. Compared with mature DM cows, mature DM bulls had 10.7% less muscle in the hindquarter and 14.6% more muscle in the forequarter. The ratio of the hindquarter muscle to the forequarter muscle was 1.25 and 0.98 in the cows and mature bulls, respectively. These results are in general accord with reports of Butterfield and Berg (1972) who have shown that in normal cattle the proportion of muscle in the forequarter increased from heifers to steers to young bulls to mature bulls.

In normal young cattle, Mukhoty and Berg (1973) found that the proportion of G_1 muscles in females was proportionately larger than in males and the same was found in the present study with mature DM cattle. Also, in the present study, 17 muscles within this anatomical region were relatively larger in cows than corresponding muscles in bulls (Table 3.1). The presence of the 'DM gene' seems to magnify sex differences in the relative development of muscle in this anatomical region. The anterior thigh muscles showed a lower proportion in bulls than in cows. Shahin and Berg (1985e) found that, compared with normal young bulls, DM bulls had a lower proportion of these muscles. Also, Shahin et al. (1985a) working with the same DM cows as in the present study found that DM cows had a significantly lower proportion of the anterior thigh muscles than normal cows.

In normal young cattle, Mukhoty and Berg (1973) found the proportion of muscle in the distal hindlimb to be similar in males and females, but Shahin et al. (unpublished) have found that young bulls had a significantly lower proportion of this muscle group than steers. In the present study, mature bulls had a significantly lower proportion of muscle in the distal hindlimb than cows.

Muscles around the spinal column constituted a greater proportion of total muscle in mature cows than in mature bulls (Table 2). Mukhoty and Berg (1973) found no significant difference between young males and females in this muscle group. Shahin et al. (unpublished) found that muscles around the spinal column in young growing bulls were relatively heavier than in young growing steers. The magnitude of the gender difference in this muscle group seems to vary with maturity. It is worth mentioning that of the spinal muscles, m. longissimus thoracis et lumborum in the young, growing DM bulls of Shahin and Berg (1985e) comprised a relatively higher proportion of total muscle than it did in mature DM bulls in this study (6.54 vs. 6.15).

The individual muscles within G_3 and G_4 (Tables 3.3 and 3.4) showed that the muscles which are responsible for straightening the vertebral column (i.e., m. longissimus thoracis et lumborum), and those which are responsible for flexing it and stabilizing its curvature in the lumbar, sacral and thoracolumbar regions (i.e., m. psoas major, m. obliquus externus abdominis, m. obliquus internus abdominis and m. transversus abdominis) of mature cows, tended to be relatively larger than the corresponding muscles in mature bulls. It can be argued that the differences between sexes in the relative development of the abdominal muscle is due to the construction of the body axis (Badoux 1975); this is because one of the functions of these muscles is to pull the pelvis dorsally, thereby flattening the lumbar curve of the spine. Pregnancy and the weight of the gravid uterus may alter the weight of the muscles in the abdomen as in the case of sows (Berg and Butterfield 1976), but little is documented about its more permanent effects on mature cows.

Mature cows had significantly more muscle in the abdominal wall than bulls, which is a situation similar to that found for sex differences in younger animals (Mukhoty and Berg 1973; Bergstrom 1978). In the mature females, abdominal wall muscles G4 (Table 3.4) formed a relatively greater proportion of total muscle than they did in the males. This is partly in response to the functional demand of pregnancy as all cows had completed at least one pregnancy. The proportion of G_4 muscles in cows was 9.9% of total muscle, similar to that reported by Johnson (1981) in DM Santa Gertrudis steers. In young growing DM bulls, Shahin and Berg (1985c) found G_4 to be 10.1% of total muscle weight.

The percentage of total muscle found in the proximal forelimb was similar in mature bulls and cows (Table 2), which was similar to results with young bulls and heifers obtained by Mukhoty and Berg (1973). Although there was no significant difference between mature bulls and cows in the proportion of muscle in the proximal forelimb, there were a number of significant differences in individual muscles (Table 3.5). However, the overall magnitude of the sex difference was small. Of the proximal forelimb muscles m. triceps brachii (caput longum), which acts as the flexor of the shoulder joint, formed a greater proportion of total muscle in bulls than it did in cows, while m. supraspinatus, which acts as an extensor of the shoulder joint, was better developed in cows than in bulls (Table 3.5).

Papanicolaous and Falk (1938) reported that androgens stimulate certain muscles more than others. They found that in guinea pigs, the mastication muscles undergo the greatest atrophy after castration and these muscles are the ones that increase most after androgen injection. However, Scow and Hagan (1965) reported differences between species in the responsiveness of specific muscles to androgens and suggested that in a given species the muscles most responsive to testosterone are those which are important for the sexual activity of the male.

In the present study, muscles and muscle groups connecting the forelimb to the thorax (G_7) and neck (G_8) were relatively larger in mature bulls than the corresponding muscles in mature cows (Table 2). Shahin et al. (unpublished), working with the same cows as in the present study, found that G_7 formed a relatively greater proportion of total muscle in DM than in normal cows. Mukhoty and Berg (1973) found that in normal cattle sex had no significant effect on the proportion of muscle in either G_7 or G_8. It seems that Double Muscling had a greater hypertrophic effect on G_7 muscles in mature bulls than in mature cows and the presence of the DM gene along with maturity tends to magnify sex differences. Bulls exceeded cows for the proportions of m. trapezius cervicalis, m. omotransversarius and m. rhomboideus (Table 3.8). The chief action of these muscles is to pull the scapula upward or forward and to extend the head and neck. Thus, the higher proportions of these muscles in bulls could be related to these functions or to their heavier cranial end as a whole. M. rhomboideus is thought to undergo greater hypertrophy in sexually mature animals (Berg and Butterfield 1976).

In the present study, the most striking sexual dimorphism of muscles was found in the neck region, which contains muscles responsible for secondary sexual features and those which act to elevate and extend the head, which is much more massive in bulls than cows (Berg and Butterfield 1976). Within the neck region, (Table 3.9) m. splenius (crest formation) of the bull weighed 2.6 times as much as that of the cow, whereas m. intertransversarius longus weighed twice as much and m. complexus (m. semispinalis capitis) weighed 1.7 times as much as those of the cow. The proportion of m. splenius in mature DM bulls in this study was much higher than that in young, growing bulls of Shahin and Berg (1985e) (1.9 vs. 1.3%). M. splenius was shown by Brannang (1971) to be the muscle most inhibited by castration.

Bone Weight Distribution

Selection for heavy muscling, of which DM is an extreme example, results in a relative decrease in the skeleton. Generally the distal parts of the limbs are less affected than the proximal (Dumont 1982). Shahin and Berg (1985b) showed that young DM bulls had less weight in the total long bones and in the os coxa and femur than normal cattle. In the present study mature bulls and cows tended to have quite similar bone distribution for all bones other than cervical vertebrae, scapula and tarsus (Table 4). The former two bones formed a greater proportion of the total bone in bulls than they did in cows while the latter formed a greater proportion of total bone in cows than in bulls. The muscles in the neck region which surround the cervical vertebrae were better developed in bulls than in cows; thus, the differences between sexes in the proportion of bone in the neck region could be a response to the greater muscle mass in this region.

Brannang (1971) reported that the scapula was lighter in steers than in bulls. Cows had nonsignificantly heavier os coxae than bulls. Hammond (1932) pointed out that the os coxa in the female was better developed in linear dimension than in the male, but the weight was not. There was a consistent but nonsignificant trend for cows in the present study to have more of their bone in the hindlimb and less in the forelimb than bulls. Jones et al. (1978) found that at the same total bone weight, heifers had significantly more bone weight in both fore- and hindlimbs than young bulls. Cows had nonsignificantly higher proportion of bone in the ribs than bulls in the present study, which might reflect increased weight support requirement of the thoracic and abdominal regions. Jones et al. (1978) found heifers had significantly higher proportion of bone in the ribs than young bulls. Along the vertebral column, bulls had a significantly higher proportion of the cervical vertebrae, the most anterior of the vertebral column, and nonsignificantly higher proportion of the thoracic vertebrae, but they had a nonsignificantly lower proportion of the lumbar vertebrae. The differences between sexes in bone weight distribution between the various regions of the vertebral column could be related to differences in the way the weight is distributed over the body. In bulls there was a shift in muscle weight towards the forequarter and consequently the center of gravity of the bulls would shift cranially, while in cows the center of gravity remained more caudal.

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