Body and carcass measurements, carcass conformation and tissue distribution of high dairy genetic merit Holstein, standard dairy genetic merit Friesian and Charolais × Holstein-Friesian male cattle

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The increased proportion of Holstein genes in the dairy herd may have undesirable consequences for beef production in Ireland. A total of 72 spring-born calves, (24 Holstein (HO), 24 Friesian (FR) and 24 Charolais × Holstein-Friesian (CH)) were reared from calfhood to slaughter. Calves were artificially reared indoors and spent their first summer at pasture following which they were assigned to a 3 breeds (HO, FR and CH) × 2 production systems (intensive 19-month bull beef and extensive 25-month steer beef) × 2 slaughter weights (560 and 650 kg) factorial experiment. Body measurements of all animals were recorded at the same time before the earliest slaughter date. After slaughter, carcasses were graded and measured and the pistola hind-quarter was separated into fat, bone and muscle. HO had significantly higher values for withers height, pelvic height and chest depth than FR, which in turn had higher values than CH. HO had a longer back and a narrower chest than either FR or CH, which were not significantly different. Carcass length and depth, pistola length, and leg length were 139.2, 134.4 and 132.0 (s.e. 0.81), 52.1, 51.3 and 47.7 (s.e. 0.38), 114.4, 109.0 and 107.0 (s.e. 0.65) and 76.7, 71.9 and 71.4 (s.e. 0.44) cm for HO, FR and CH, respectively. Breed differences in pistola tissue distribution between the joints were small and confined to the distal pelvic limb and ribs. There were relatively small breed differences in the distribution of pistola muscle weight between individual muscles. Body measurements were significantly greater for animals on the intensive system (bulls) than the extensive system (steers) in absolute

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terms, but the opposite was so when they were expressed relative to live weight. The only significant difference in relative carcass measurements between the production systems was for carcass depth, which was lower for the intensive compared with the extensive system. Increasing slaughter weight significantly increased all carcass measurements in absolute terms but reduced them relative to weight. It is concluded that there were large differences between the breed types in body and carcass measurements, and hence in carcass shape and compactness but differences in tissue distribution were small.

Keywords: beef; bulls; cattle; steers

Introduction

Within the meat industry, carcass conformation assessed by the EU Beef Carcass Classification Scheme (Commission of the European Communities, 1982), is considered important and carcasses with superior conformation attract higher prices. The importance of conformation as an indicator of commercial value is based on the assumption that carcasses with better conformation have advantages in terms of lean meat content, proportion of higher-priced cuts and possibly greater muscle size or area (Kempster, Cuthbertson and Harrington, 1982).

In Ireland, the importation of North American and European Holstein-Friesian genetic material has changed the genetic composition of the dairy herd, from predominantly British Friesian to North American and European Holstein-Friesian (Buckley *et al.*, 2000). The ramifications of this breed substitution is of interest to Irish beef producers as almost half of the calves born to dairy cows and over 0.2 of the national calf crop are sired by Holstein-Friesian bulls (Irish Cattle Breeding Federation (ICBF), 2002). The replacement of Friesian by Holstein is perceived to be undesirable from a beef production viewpoint.

In previous experiments at this centre, Friesian and Holstein × (Holstein × Friesian) steers (Keane and More O'Ferrall, 1988), and Friesian and Charolais × Friesian steers (More O'Ferrall and Keane, 1990; Keane *et al.*, 1990) were compared but the dairy animals used in those experiments were of lower dairy genetic merit than present day animals.

There is a renewed interest in young bull beef production in Ireland (Keane and Fallon, 2001; Fallon, Drennan and Keane, 2001) and beef breed comparisons should be undertaken within the type of production systems to which the results are intended to apply (Keane and Allen, 2002). Due to the possibility of genotype × slaughter weight interactions animals must be slaughtered at more than one end point to obtain commercially useful estimates of growth patterns (Keane and Allen, 1998).

The objectives of the present study were: (i) to compare various measurements of body and carcass size and shape, and tissue distribution for Holstein, Friesian and Charolais × Holstein-Friesian male cattle, (ii) to compare these variables under two production systems (intensively reared as bulls or extensively reared as steers), and (iii) to examine the effects of two slaughter ages on the measured variables. Because systems rather than discrete treatments were compared, there was inevitable confounding of some production variables such as gender and feeding level or management.

Materials and Methods

Animals and management

The source of the calves and their rearing and management were described previously (McGee *et al.,* 2005). Briefly, a total of 72 spring-born male calves (24 Holstein (HO), 24 Friesian (FR) and 24 Charolais × Holstein-Friesian (CH)) were reared from calfhood to slaughter. The HO group were the male progeny of high genetic merit (0.92 Holstein) dairy heifers imported from France and the Netherlands as part of the programme to evaluate various dairy cattle strains at the Dairy Research Centre, Moorepark (O'Connell *et al.*, 2000). The average pedigree index (RBI 95) of the imported heifers was 134 compared with a value of 104 for Irish heifers born in the same year (Buckley and Dillon, 1998). The FR animals were sourced from commercial farms with the assistance of the South-Eastern Cattle Breeding Society (Dovea AI). These calves were the progeny of bulls with less than 0.13 Holstein genes, which had been mated to cows of similar genotype. It is assumed that not more than proportionately 0.20 were from heifers. Mean birth and arrival dates at Grange Research Centre for HO and FR calves were 2 February and 8 March, and 3 February and 25 March, respectively. The CH calves were purchased at a number of commercial livestock marts so as to be representative of the commercial population of CH calves generally. It was assumed that the CH calves were the progeny of mature Holstein-Friesian cows as due to their relatively high level of calving difficulty, Charolais bulls are rarely used on dairy heifers. The sires and birth dates of these calves were not known. Their mean arrival date at Grange Research Centre was 23 March.

Calf rearing was as outlined by Fallon (1992). Calves were turned out to pasture together after a mean rearing period of 57 days and continued to receive barley-based concentrate at 1 kg per head daily for the following 4 weeks. Calves remained at pasture together until 25 October. They were then blocked on live weight, within breed type, and from within block were assigned to a 3 breeds (HO, FR and CH) × 2 production systems (intensive bull beef and extensive steer beef) × 2 slaughter weights (560 and 650 kg) factorial experiment.

The animals assigned to the intensive system were immediately housed in pens of 6 in a slatted floor shed. They were offered grass silage *ad libitum* plus barley-based concentrate increasing gradually from 2.5 to 6.0 kg daily per head over the feeding period. Concentrate levels greater than 5 kg per day were offered twice daily. They were slaughtered when they reached the target mean group slaughter weight.

The animals assigned to the extensive system were castrated at the time of allocation to treatment. They were subsequently housed, primarily in individual tie-up stalls, where they remained for the duration of the winter period (156 days). For the first 55 days and final 45 days of the winter they were offered grass silage *ad libitum* only, whereas in the intervening 56 days the silage was supplemented with a barley-based concentrate (3 kg per head daily) in two equal feeds. Following the winter period, animals were turned out to pasture for a second grazing season of 203 days. At the end of this grazing season they were housed for the second winter (161 days mean duration) and finished on grass silage *ad libitum* plus 6 kg/day of a barley-based concentrate following gradual introduction. They were also slaughtered when they reached the target mean group slaughter weight.

Body measurements and fleshiness

Body measurements were taken on all animals immediately prior to the earliest slaughter date which was the light slaughter weight for the intensive system animals (bulls). Measurements taken were height at withers, height at pelvis, width of chest, depth of chest, chest girth and width of pelvis (De Boer *et al.*, 1974). In addition, length of back (from the mid-point of the shoulder blades to the junction of the coccygeal and sacral vertebrae) was measured. Measurements were expressed relative to live weight on the day of measurement. Fleshiness (scale 1–5) (an agreed score by two trained individuals) was assessed at the same time (De Boer *et al.*, 1974).

Carcass measurements and dissection

After slaughter in a commercial meat plant, carcasses were graded for conformation (EUROP - scale 1 (P = poorest) to 5 (E = best)) according to the EU Beef Carcass Classification Scheme (Commission of the European Communities, 1982) - and carcass measurements were made as outlined by De Boer *et al.* (1974). These included carcass length and depth, and leg length, width and thickness. The length of the pistola was obtained following quartering of the carcass side (see below). After a 24-h chilling period (4 °C), the right side of each carcass was cut through the spinal column between the 5th and 6th thoracic vertebrae. The abdominal muscles were freed where they join the pelvic limb and the side was cut along the edge of *m. iliocostalis lumborum* through the ribs to the earlier cut between the 5th and 6th thoracic vertebrae (Williams and Bergstrom, 1980) and then the cut was continued along the caudal edge of the 5th rib. This divided the side into a pistola hind-quarter (i.e., the hind-quarter to the 5th thoracic vertebra without the area on the abdominal side of *m. iliocostalis lumborum*) and a fore-quarter, which included the afore-mentioned area. The hind-quarters were then transported in a refrigerated truck to the meat laboratory and placed in a chill room (4 °C) for a further 24 h.

At ~48 h post slaughter, the pistola was divided into four joints – distal pelvic limb, proximal pelvic limb, lumbar and ribs (Williams and Bergstrom, 1980). Subcutaneous fat depth and *m. longissimus* area were measured at the cut surface between the 10th and 11th ribs where the lumbar and rib joints were separated. Each joint was weighed and separated into subcutaneous fat, intermuscular fat, individual muscles or muscle groups, bone and other tissue (large blood vessels, tendons, fascia and *ligamentum nuchae*). The other tissue was included with bone in the final statistical analyses. The length, circumference and weight of *biceps femoris*, *semimembranosus*, *semitendinosus*, *quadriceps*, *psoas major* and *longissimus lumborum*, and weight of *gastrocnemius*, *gluteus*, *adductor*, *psoas minor* and *longissimus thoracis* muscles were recorded as were the length and weight of the tibia and femur.

Statistical analyses

Data were statistically analysed using the general linear models procedure of the Statistical Analysis System Institute (SAS, 1996). Body measurements and fleshiness scores were analysed using a model with terms for block, breed, production system, breed × production system effects and error. Carcass, bone and muscle measurements and pistola muscle distribution data were analysed as a 3 × 2 × 2 factorial (n = 6 per treatment group) with terms for block, breed, production system, slaughter weight, breed × slaughter weight, breed × production system, production system × slaughter weight, breed × slaughter weight × production system and error. Logarithmic regressions (Berg, Andersen, and Liboriussen, 1978a), with a model consisting of a common regression coefficient and a separate intercept for each breed and production system, were used to relate joint bone, muscle and fat weights to total pistola bone, muscle and fat weights. The regression parameters are presented as a common regression coefficient (b) and the intercept value (a) for HO intensive system animals (bulls) and the deviations from this intercept value for FR and CH and for extensive system animals (steers). The significance of the intercept differences for FR v. HO, CH v. HO, FR v. CH and extensive system v. intensive system animals are shown.

Results

Results pertaining to intake, growth and conventional slaughter and carcass traits were published previously (McGee *et al.*, 2005). This paper contains the results on body and carcass measurements, carcass conformation and tissue distribution.

Body measurements

Body measurements are shown in Table 1. HO had significantly higher values than FR for withers height, pelvic height and chest depth and values for FR were greater than CH. HO had a significantly longer back and a narrower chest than FR and CH, which were not different ($P > 0.05$). When expressed relative to live weight, HO and CH differed significantly for all values, whereas FR had significantly higher values for withers height, pelvic height, chest depth and back length than CH, and a higher value for chest width than HO. In terms of fleshiness, CH was significantly higher than FR, which in turn was higher

Table 1. Body measurements and fleshiness scores of male cattle of three breeds prior to slaughter of the intensive system animals (bulls) at the light slaughter weight

	Breed[1] (B)			System (S)		s.e.[2]	Significance	
	HO	FR	CH	Intensive	Extensive		B	S
Live weight (kg)	511	501	515	555	463	0.64		***
Measurements (cm)								
Withers height	132.3[a]	127.4[b]	122.5[c]	128.4	124.7	0.60	***	**
Pelvic height	137.5[a]	131.6[b]	129.6[c]	136.3	131.1	0.64	***	*
Chest width	44.0[a]	45.7[b]	47.0[b]	48.2	42.9	0.47	***	***
Chest depth	71.4[a]	69.4[b]	67.5[c]	70.6	68.0	0.45	***	***
Back length	128.6[a]	123.9[b]	123.4[b]	127.9	122.8	0.87	***	***
Measurements relative to live weight (cm/100 kg)								
Withers height	26.2[a]	25.8[a]	24.0[b]	23.3	27.4	0.30	***	***
Pelvic height	27.2[a]	26.7[a]	25.4[b]	24.2	28.7	0.30	***	***
Chest width	8.7[a]	9.2[b]	9.2[b]	8.7	9.3	0.12	**	***
Chest depth	14.1[a]	14.0[a]	13.2[b]	12.8	14.8	0.15	***	***
Back length	25.4[a]	25.0[a]	24.2[b]	23.2	26.6	0.26	**	***
Fleshiness (5 point scale)	1.83[a]	2.50[b]	3.08[c]	2.89	2.05	0.082	***	***

[1] HO = Holstein, FR = Friesian, CH = Charolais × Holstein-Friesian.
[2] In this and subsequent tables s.e. for $n = 24$ (Breed).
[abc] In this and subsequent tables breed means, within a row, without a common superscript are significantly different ($P < 0.05$).

than HO. Body measurements were significantly greater for animals in the intensive system (bulls) than those in the extensive system (steers) in absolute terms but the opposite was so when expressed relative to live weight.

Carcass and bone measurements

Carcass and bone measurements are presented in Table 2. The proportion of conformation classes R, O and P were zero, 0.33 and 0.67, 0.21, 0.75 and 0.04, and 0.79, 0.13 and zero for HO, FR and CH, respectively. Carcass conformation score was significantly higher for CH than FR and for FR compared with HO. Carcass and pistola length were significantly greater for HO than FR, which in turn was greater than CH. Carcass depth was similar ($P > 0.05$) for the dairy breeds and less ($P < 0.001$) for CH. HO had greater ($P < 0.001$) leg length than both CH and FR, which did not differ ($P > 0.05$). Leg width and thickness were significantly greater for CH than for the dairy breeds, which were similar ($P > 0.05$). When expressed relative to carcass weight, carcass length and depth, pistola length and leg width did not differ ($P > 0.05$) between the dairy breeds but were lower ($P < 0.001$) for CH. All three breeds differed significantly for leg length relative to carcass weight, which was greatest for HO and least for CH. Relative leg thickness was lower ($P < 0.05$) for CH than FR, with HO being intermediate ($P > 0.05$).

Production system significantly affected all absolute carcass measurements other than pistola length, with animals on the extensive system having higher values for all traits except carcass length, which was lower than for animals on the intensive system. When the measurements were expressed relative to carcass weight, however, the only significant difference was for carcass depth, which was greater for animals on the extensive system. Compared to the lighter slaughter weight, all carcass measurements were significantly higher for the heavier slaughter weight in absolute terms and lower when expressed relative to carcass weight.

Tibia length was significantly greater for HO than FR and for FR than CH, whereas tibia weight was significantly greater for HO than CH, which in turn was greater than FR. Femur length and weight were significantly greater for HO than FR and CH, which did not differ ($P > 0.05$). When scaled for weight, tibia length was significantly greater for FR than HO and CH, which did not differ ($P > 0.05$), whereas relative femur length was greater for FR than HO with CH being intermediate ($P > 0.05$). Tibia and femur length was significantly greater both on an absolute basis and relative to carcass weight for animals on the intensive compared to the extensive system. However, tibia weight was greater ($P < 0.001$) for animals on the extensive than intensive system, whereas femur weight did not differ ($P > 0.05$) between the systems. Both tibia ($P < 0.001$) and femur ($P < 0.01$) weight were greater at the heavy slaughter weight. Increasing slaughter weight reduced ($P < 0.01$) tibia length, whereas femur length was unaffected ($P > 0.05$) but when scaled for weight, both were lower ($P < 0.001$) at the heavy slaughter weight.

There were breed × system and system × slaughter weight interactions for carcass and bone measurements. Compared to the intensive system, on the extensive system absolute carcass depth increased for the two dairy breeds, relative carcass depth increased for FR and leg width increased for HO with no effect of production system on these variables for the other breeds. There was no difference in absolute or relative femur length between the production systems for the two dairy

Table 2. Carcass conformation and carcass, and bone measurements of male cattle from three breeds in intensive and extensive production systems and slaughtered at light or heavy weights

	Breed[1] (B)			System (S)		Slaughter weight (w)		s.e.[2]	Significance			
	HO	FR	CH	Intensive	Extensive	Light	Heavy		B	S	W	Interactions
Carcass conformation[3]	1.51^{a}	2.18^{b}	2.96^{c}	2.25	2.18	2.17	2.26	0.085	***			
Carcass measurements (cm)												
Carcass length	139.2^{a}	134.4^{b}	132.0^{c}	136.2	134.2	133.8	136.6	0.81	***	*	***	S × W^{4*}
Carcass depth	52.1^{a}	51.3^{a}	47.7^{b}	48.8	51.9	49.4	51.3	0.38	***	***	***	B × S^{5**} S × W^{6***}
Pistola length	114.4^{a}	109.0^{b}	107.0^{c}	110.1	110.2	108.4	111.9	0.65	***		***	S × W^{7**}
Leg length	76.7^{a}	71.9^{b}	71.4^{b}	72.5	74.1	72.6	74.0	0.44	***	**	**	
Leg width	45.6^{a}	45.1^{a}	46.7^{b}	45.2	46.4	45.2	46.4	0.51	**	***	**	B × S^{8*}
Leg thickness	28.0^{a}	28.1^{a}	29.5^{b}	28.0	29.0	27.6	29.5	0.29	***	**	***	S × W^{9**}
Carcass measurements (cm/kg carcass)												
Carcass length	0.431^{a}	0.423^{a}	0.376^{b}	0.415	0.405	0.436	0.384	0.0089	***		***	
Carcass depth	0.161^{a}	0.161^{a}	0.136^{b}	0.149	0.157	0.161	0.144	0.0025	***	**	***	B × S^{10*}
Pistola length	0.354^{a}	0.343^{a}	0.304^{b}	0.335	0.332	0.353	0.314	0.0041	***		***	
Leg length	0.237^{a}	0.226^{b}	0.203^{c}	0.221	0.223	0.237	0.208	0.0028	***		***	
Leg width	0.141^{a}	0.141^{a}	0.133^{b}	0.137	0.140	0.146	0.130	0.0023	***		***	
Leg thickness	0.086^{ab}	0.088^{a}	0.084^{b}	0.085	0.087	0.090	0.083	0.0010	*		***	S × W^{11***}
Bone measurements												
Tibia length (cm)	41.2^{a}	39.6^{b}	38.3^{c}	40.9	38.5	40.4	38.9	0.38	***	***	**	S × W^{12***}
Tibia weight (g)	3069^{a}	2686^{b}	2849^{c}	2629	3107	2626	3110	49.0	***	***	***	S × W^{13***}
Femur length (cm)	41.5^{a}	38.9^{b}	39.4^{b}	40.7	39.1	40.3	39.5	0.49	**	**		B × S^{14*}
Femur weight (g)	3196^{a}	2826^{b}	2930^{b}	2955	3013	2893	3075	50.3	***		**	
Tibia length (cm/kg tibia)	14.0^{a}	15.2^{b}	14.0^{a}	16.4	12.5	16.2	12.6	0.20	***	***	***	B × S^{15**} S × W^{16***}
Femur length (cm/kg femur)	13.1^{a}	13.8^{b}	13.5^{ab}	13.9	13.1	14.0	12.9	0.20	*	**	***	B × S^{17*}

[1,2] See footnotes to Table 1.
[3] EU Beef Carcass Classification Scheme scale 1 (poorest) to 5 (best).
[4] Values of 133.5 v 139.0 and 134.2 v 134.2 for Light v Heavy for Intensive (bulls) and Extensive (steers) systems, respectively.
[5] Values of 50.8 v 53.4, 48.7 v 53.8 and 47.0 v 48.5 for Intensive v Extensive system for HO, FR and CH, respectively.
[6] Values of 46.9 v 50.7 and 51.9 v 51.9 for Light v Heavy for Intensive and Extensive systems, respectively.
[7] Values of 107.3 v 112.9 and 109.4 v 110.9 for Light v Heavy for Intensive and Extensive systems, respectively.
[8] Values of 44.2 v 47.0, 44.9 v 45.2 and 46.4 v 47.0 for Intensive v Extensive systems for HO, FR and CH, respectively.
[9] Values of 27.6 v 28.5 and 27.7 v 30.4 for Light v Heavy for Intensive and Extensive system, respectively.

(Table 2 Continued)

[10] Values of 0.159 v 0.163, 0.151 v 0.171 and 0.135 v 0.136 for Intensive v Extensive system for HO, FR and CH, respectively.
[11] Values of 0.091 v 0.079 and 0.088 v 0.086 for Light v Heavy for Intensive and Extensive systems, respectively.
[12] Values of 42.9 v 38.8 and 37.9 v 39.1 for Light v Heavy for Intensive and Extensive systems, respectively.
[13] Values of 2139 v 3118 and 3113 v 3101 for Light v Heavy for Intensive and Extensive systems, respectively.
[14] Values of 42.4 v 40.5, 38.8 v 39.1 and 40.9 v 37.8 for Intensive v Extensive system for HO, FR and CH, respectively.
[15] Values of 16.1 v 11.9, 16.4 v 14.0 and 16.1 v 12.0 for Intensive v Extensive system for HO, FR and CH, respectively.
[16] Values of 20.1 v 12.6 and 12.3 v 12.7 for Light v Heavy for Intensive and Extensive systems, respectively.
[17] Values of 13.2 v 12.9, 14.0 v 13.7 and 14.4 v 12.7 for Intensive v Extensive system for HO, FR and CH, respectively.

breeds, whereas values were lower for CH on the extensive than the intensive system. With increasing slaughter weight, absolute carcass length and depth, pistola length and tibia weight increased significantly, whereas relative leg thickness and tibia length, both on an absolute and relative basis, decreased on the intensive system with no change on the extensive system.

Muscle measurements

Carcass muscle dimensions are shown in Table 3. Length of the *biceps femoris* was significantly lower for FR than HO and CH, which did not differ (P > 0.05), whereas length of *semimembranosus* and *semitendinosus* were significantly lower for FR than HO with CH being intermediate (P > 0.05). The length of *longissimus lumborum* was lower for CH than for the dairy breeds, which were similar (P > 0.05), whereas the *psoas major* was longer for HO than for FR and CH, which did not differ (P > 0.05). Compared to the dairy breeds, which were similar (P > 0.05), the circumference of the *semimembranosus*, *quadriceps*, *psoas major* and *longissimus lumborum* were significantly greater for CH, whereas that of the *semitendinosus* was significantly lower for HO than FR, and for FR than CH. Scaled for weight, the lengths of *biceps femoris*, *semimembranosus*, *quadriceps*, *psoas major* and *longissimus lumborum* were significantly lower for CH than for the dairy breeds, which did not differ (P > 0.05). The relative length of the *semintendinosus* was significantly longer for HO than for FR and for FR than CH. The relative circumference of the *semimembranosus* and *psoas major* was significantly greater for FR than HO and CH, which were similar (P > 0.05), whereas that of the *semitendinosus*, *quadriceps* and *longissimus lumborum* was lower for CH than the dairy breeds, which did not differ (P > 0.05). Scaled for weight the

Table 3. Carcass muscle dimensions of male cattle from three breeds in the intensive and extensive production systems and slaughtered at light or heavy weights

		Breed[1] (B)			System (S)		Slaughter weight (W)		s.e.[2]	Significance			
		HO	FR	CH	Intensive	Extensive	Light	Heavy		B	S	W	Interactions
Muscle measurements (cm)													
Biceps femoris	Length	70.1^{a}	65.9^{b}	68.6^{a}	66.5	69.9	68.4	68.0	0.76	**	***		
	Circumference	44.8^{a}	46.5^{b}	48.8^{c}	46.9	46.5	46.0	47.4	0.49	***		*	
Semimembranosus	Length	42.1^{a}	40.8^{b}	41.6^{ab}	40.8	42.2	40.7	42.2	0.39	*	**	**	
	Circumference	48.6^{a}	49.5^{a}	52.8^{b}	50.7	50.0	49.7	51.0	0.58	***			
Semitendinosus	Length	42.6^{a}	40.5^{b}	41.7^{ab}	40.7	42.5	41.5	41.7	0.44	**	**		
	Circumference	30.5^{a}	31.8^{b}	34.1^{c}	33.3	31.0	31.6	32.7	0.37	***	***	*	
Quadriceps	Length	34.5	34.0	34.2	34.0	34.5	33.5	35.0	0.45			**	
	Circumference	60.7^{a}	59.6^{a}	62.5^{b}	60.6	61.2	59.9	62.0	0.54	**		**	
Psoas major	Length	67.7^{a}	64.1^{b}	63.6^{b}	64.9	65.4	64.0	66.2	0.67	***		**	
	Circumference	24.7^{a}	24.8^{a}	26.6^{b}	25.4	25.3	24.7	26.0	0.47	**		*	
Longissimus lumborum	Length	57.2^{a}	55.8^{a}	53.6^{b}	54.4	56.7	55.7	55.3	0.57	***	**		B × W[3]**
	Circumference	35.6^{a}	35.2^{a}	39.1^{b}	36.7	36.5	35.9	37.3	0.58	***		*	
Muscle measurements (cm/kg weight)													
Biceps femoris	Length	10.6^{a}	10.1^{a}	8.9^{b}	9.5	10.2	10.2	9.5	0.20	***	*	**	
	Circumference	6.7^{a}	7.1^{b}	6.3^{c}	6.6	6.8	6.8	6.6	0.09	***		*	
Semimembranosus	Length	9.1^{a}	9.1^{a}	7.0^{b}	8.5	8.9	9.0	8.5	0.19	***		*	
	Circumference	10.5^{a}	11.0^{b}	10.1^{a}	10.6	10.5	10.9	10.2	0.16	**		***	
Semitendinosus	Length	19.0^{a}	17.6^{b}	15.1^{c}	15.9	18.5	17.9	16.6	0.38	***	***	**	B × W[4]*
	Circumference	13.5^{a}	13.8^{a}	12.2^{b}	12.9	13.4	13.4	12.9	0.20	***	*	*	S × W[5]*
Quadriceps	Length	6.0^{a}	6.1^{a}	5.5^{b}	5.8	5.9	6.0	5.7	0.14	**		*	
	Circumference	10.6^{a}	10.7^{a}	10.1^{b}	10.4	10.5	10.7	10.1	0.18	*		***	
Psoas major	Length	29.4^{a}	30.5^{a}	25.4^{b}	29.1	27.8	29.2	27.7	1.07	**			
	Circumference	10.6^{a}	11.7^{b}	10.6^{a}	11.3	10.7	11.1	10.8	0.35	*			
Longissimus lumborum	Length	14.2^{a}	14.2^{a}	11.0^{b}	12.8	13.5	13.7	12.6	0.30	***		*	B × W[6]*
	Circumference	8.8^{a}	8.9^{a}	8.0^{b}	8.5	8.6	8.7	8.4	0.18	**			

[1,2] See footnotes to Table 1.
[3] Values of 58.5 v 55.8, 54.6 v 57.1 and 54.0 v 53.2 for Light v Heavy for HO, FR and CH, respectively.
[4] Values of 20.6 v 17.4, 17.9 v 17.3 and 15.1 v 15.0 for Light v Heavy for HO, FR and CH, respectively.
[5] Values of 13.4 v 12.4 and 13.4 v 13.5 for Light v Heavy for Intensive (bulls) and Extensive (steers) systems, respectively.
[6] Values of 15.5 v 12.9, 14.2 v 14.2 and 11.4 v 10.6 for Light v Heavy for HO, FR and CH, respectively.

circumference of the *biceps femoris* was significantly greater for FR than HO and for HO than CH.

Compared to the intensive system, animals on the extensive system had a significantly greater length of *biceps femoris* and *semitendinosus* both absolutely and scaled for weight, and significantly greater absolute values for length of *semimembranosus* and *longissimus lumborum*. The circumference of the *semitendinosus* was lower ($P < 0.001$) but relative to weight was higher ($P < 0.05$), for animals on the extensive than on the intensive system. With increasing slaughter weight, absolute muscle length increased significantly for *semimembranosus*, *quadriceps* and *psoas major*, whereas circumference increased for *biceps femoris*, *semitendinosus*, *quadriceps*, *psoas major* and *longissimus lumborum*. All relative measurements decreased significantly at the heavy slaughter weight except for length and circumference of *psoas major* and circumference of *longissimus lumborum*, which did not differ ($P > 0.05$) between the slaughter weights.

There were breed × slaughter weight interactions and a system × slaughter weight interaction for carcass muscle measurements. With increasing slaughter weight, *longissimus lumborum* length decreased for HO, increased for FR and did not change for CH, whereas relative *longissimus lumborum* and *semitendinosus* length decreased for HO but not for FR or CH. The *semitendinosus* circumference scaled for carcass weight decreased between the two slaughter weights for animals on the intensive but not for those on the extensive system.

Tissue distribution

Distribution of pistola tissue between the joints is shown in Table 4. Breeds CH and HO had significantly more of the pistola fat in the distal pelvic limb than FR, whereas FR had more in the ribs than CH, with HO being intermediate ($P > 0.05$). The proportion of pistola bone in the distal pelvic limb was significantly greater for CH than for HO and for HO than for FR. HO had a significantly greater proportion of pistola muscle in the distal pelvic limb than FR and CH, which were similar ($P > 0.05$), whereas CH had a lower proportion in the ribs than the dairy breeds, which did not differ ($P > 0.05$). Compared to the intensive system, animals on the extensive system had a lower ($P < 0.001$) proportion of their pistola fat in the distal pelvic limb and higher proportions in both the loin ($P < 0.05$) and ribs ($P < 0.001$). They also had a higher ($P < 0.01$) proportion of pistola bone and muscle in the distal pelvic limb and a lower ($P < 0.05$) proportion of pistola bone in the ribs. Increasing slaughter weight reduced ($P < 0.05$) the proportion of the pistola fat in the proximal pelvic limb and increased ($P < 0.05$) the proportion in the loin. It also reduced ($P < 0.001$) the proportion of pistola bone in the distal pelvic limb and increased ($P < 0.01$) the proportion in the loin and ribs. Slaughter weight had no effect ($P > 0.05$) on pistola muscle distribution between the joints.

There were breed × slaughter weight, system × slaughter weight and a breed × system interaction for pistola tissue distribution. Increasing slaughter weight increased the proportion of pistola fat in the distal pelvic limb in HO and decreased the proportion of pistola bone in the distal pelvic limb of both HO and FR but had no effect on the other breeds. The proportion of pistola bone in the distal pelvic limb did not differ between systems for HO and CH but was higher for the extensively reared than intensively reared FR. With increasing slaughter weight, the proportion of pistola fat, bone and muscle in the ribs increased for animals on the intensive

Table 4. Distribution of total pistola fat, bone and muscle between joints of male cattle from three breeds in the intensive and extensive production systems and slaughtered at light or heavy weights

	Breed[1] (B)			System (S)		Slaughter weight (W)		s.e.[2]	Significance			
	HO	FR	CH	Intensive	Extensive	Light	Heavy		B	S	W	Interactions
Fat distribution (g/kg)												
Distal Pelvic Limb	97^{a}	83^{b}	106^{a}	106	85	92	98	4.0	***	***		$B \times W^{3*}$
Proximal Pelvic Limb	565	562	565	572	557	575	553	7.7			*	$S \times W^{4***}$
Loin	169	174	169	163	178	165	177	5.3		*	*	$S \times W^{5**}$
Ribs	169^{ab}	181^{a}	159^{b}	159	180	168	172	4.6	**	***		$S \times W^{6***}$
Bone distribution (g/kg)												
Distal Pelvic Limb	231^{a}	226^{b}	238^{c}	228	235	238	225	1.7	***	**	***	$B \times S^{7*}$ $B \times W^{8*}$ $S \times W^{9***}$
Proximal Pelvic Limb	452	452	449	449	453	454	449	3.0				$S \times W^{10**}$
Loin	191	192	190	194	188	186	196	2.6			**	
Ribs	122	126	120	125	120	118	128	2.2		*	**	$S \times W^{11***}$
Muscle distribution (g/kg)												
Distal Pelvic Limb	92^{a}	88^{b}	90^{b}	89	91	91	89	0.7	***	**		$S \times W^{12***}$
Proximal Pelvic Limb	622	626	627	625	625	624	626	2.4				$S \times W^{13**}$
Loin	172	170	176	173	173	173	173	1.6				$S \times W^{14*}$
Ribs	113^{a}	115^{a}	108^{b}	113	110	112	112	1.8	*			$S \times W^{15***}$

[1,2] See footnotes to Table 1.
[3] Values of 86 v 108, 78 v 89 and 113 v 100 for Light v Heavy for HO, FR and CH, respectively.
[4] Values of 602 v 542 and 549 v 564 for Light v Heavy Intensive (bulls) and Extensive (steers) systems, respectively.
[5] Values of 147 v 180 and 182 v 174 for Light v Heavy for Intensive and Extensive systems, respectively.
[6] Values of 146 v 173 and 190 v 171 for Light v Heavy for Intensive and Extensive systems, respectively.
[7] Values of 230 v 232, 219 v 233 and 235 v 240 for Intensive v Extensive system for HO, FR and CH, respectively.
[8] Values of 238 v 223, 234 v 217 and 240 v 235 for Light v Heavy for HO, FR and CH, respectively.
[9] Values of 239 v 217 and 237 v 233 for Light v Heavy for Intensive and Extensive systems, respectively.
[10] Values of 457 v 442 and 450 v 457 for Light v Heavy for Intensive and Extensive systems, respectively.
[11] Values of 115 v 142 and 129 v 118 for Light v Heavy for Intensive and Extensive systems, respectively.
[12] Values of 92 v 86 and 90 v 93 for Light v Heavy for Intensive and Extensive systems, respectively.
[13] Values of 628 v 622 and 621 v 630 for Light v Heavy for Intensive and Extensive systems, respectively.
[14] Values of 175 v 170 and 171 v 175 for Light v Heavy for Intensive and Extensive systems, respectively.
[15] Values of 105 v 122 and 119 v 102 for Light v Heavy for Intensive and Extensive systems, respectively.

system and decreased for those on the extensive system, whereas the opposite occurred for the proportion of pistola muscle in the distal pelvic limb and loin. In intensively reared animals, the proportion of pistola fat and bone in the proximal pelvic limb and the proportion of pistola bone in the distal pelvic limb decreased with increasing slaughter weight, whereas there was no change in extensively reared animals. The proportion of pistola fat in the loin increased with increasing slaughter weight in intensively reared animals but did not change in extensively reared animals, whereas the opposite occurred for the proportion of pistola muscle in the proximal pelvic limb.

Muscle distribution

The distribution of total pistola muscle weight between the various muscles and muscle groups is shown in Table 5. HO had significantly lower proportions of *biceps femoris* and *semitendinosus* and a higher proportion of *adductor* than FR and CH, which did not differ ($P > 0.05$). CH had a significantly lower proportion of *quadriceps* and a higher proportion of *longissimus thoracis et lumborum* than the dairy breeds, which were similar. Animals on the extensive system had significantly higher proportions of *gastrocnemius* and *adductor*, and lower proportions of *semitendinosus* and other muscle than those on the intensive system. There were no effects of slaughter weight on muscle weight distribution.

There were breed × slaughter weight, breed × system and system × slaughter weight interactions for pistola muscle distribution. Slaughter weight had no effect on the *semitendinosus* proportion of the pistola in the dairy breeds, whereas it decreased at the heavy slaughter weight in CH. Production system had no effect on *quadriceps* proportion of the pistola in HO and CH, whereas it was greater for extensively than intensively reared FR. With increasing slaughter weight the *gastrocnemius* and *longissimus thoracis et lumborum* proportion of the pistola decreased in intensively reared, and increased in extensively reared, animals, whereas the opposite occurred with the proportion of other muscle. The *semimembranosus* proportion increased in animals on the extensive but not in the intensive system with increasing slaughter weight.

Allometric regressions

The allometric regressions relating bone, muscle and fat weights in the joints to total pistola bone, muscle and fat weights are shown in Table 6. Distal pelvic limb bone grew relatively more slowly and lumbar and rib joint bone grew relatively more rapidly than total pistola bone, whereas proximal pelvic limb bone changed relatively little. The muscle in the individual joints had similar growth rates to total pistola muscle. Of the individual muscles, the *gluteus*, *quadriceps*, *adductor* and *longisssimus lumborum* grew relatively more slowly, whereas the *gastrocnemius*, *biceps femoris*, *semimembranosus*, *semitendinosus*, *psoas* and *longissimus thoracis* grew relatively more quickly than total pistola muscle. Fat in the distal pelvic limb, lumbar area and ribs joint had a higher relative growth, whereas fat in the proximal pelvic limb had a lower relative growth rate than total pistola fat.

Discussion

The production system, management practices and slaughter weights in the present study were designed to reflect commercial on-farm practices in Ireland and to maintain good comparability with other breed comparison studies at this centre (Keane *et al.*, 1990; More O'Ferrall

Table 5. Distribution (g/kg) of pistola muscle weight between individual muscles and muscle groups for male cattle from three breeds in intensive and extensive production systems and slaughtered at light and heavy weights

Muscle	Breed[1] (B)			System (S)		Slaughter weight (W)		s.e.[2]	Significance			
	HO	FR	CH	Intensive	Extensive	Light	Heavy		B	S	W	Interactions
Gastrocnemius	45.3	43.8	44.8	43.8	45.5	44.9	44.4	0.46		**		S × W[3]***
Biceps femoris	137.3[a]	141.7[b]	142.4[b]	140.0	140.2	140.9	139.3	1.13	**			
Semimembranosus	96.4	96.6	96.2	95.3	97.6	95.9	97.0	1.04				S × W[4]**
Semitendinosus	46.7[a]	49.8[b]	51.4[b]	51.2	47.4	49.5	49.1	0.68	***	***		B × W[5]*
Gluteus	85.4	83.6	84.7	82.9	86.3	85.3	83.9	1.77				
Quadriceps	119.9[a]	120.1[a]	114.4[b]	116.6	119.7	117.1	119.1	1.71	**			B × S[6]*
Adductor	35.9[a]	34.3[b]	33.5[b]	33.8	35.3	34.4	34.7	0.49	**	*		
Psoas	53.6	51.4	51.7	51.2	53.3	52.6	51.8	1.01				
Longissimus thoracis et lumborum	117.3[a]	119.3[a]	124.0[b]	119.2	121.1	120.3	120.1	1.35	**			S × W[7]**
Other muscle	262.2	260.5	256.9	265.9	253.8	258.9	260.7	3.01		**		S × W[8]***

[1,2] See footnotes to Table 1.
[3] Values of 45.3 v 42.4 and 44.6 v 46.3 for Light v Heavy for Intensive (bulls) and Extensive (steers) systems, respectively.
[4] Values of 96.4 v 94.1 and 95.3 v 99.9 for Light v Heavy for Intensive and Extensive systems, respectively.
[5] Values of 45.7 v 47.8, 50.1 v 49.5 and 52.9 v 49.9 for Light v Heavy for HO, FR and CH, respectively.
[6] Values of 121.5 v 118.2, 114.3 v 125.8 and 113.9 v 115.0 for Intensive v Extensive system for HO, FR and CH, respectively.
[7] Values of 121.8 v 116.6 and 118.8 v 123.5 for Light v Heavy for Intensive and Extensive systems, respectively.
[8] Values of 256.5 v 275.2 and 261.3 v 246.2 for Light v Heavy for Intensive and Extensive systems, respectively.

Table 6. Allometric regressions ($\log_{10} Y = a + b \log_{10} X$) of joint bone, muscle and fat weights (Y in g) on total pistola bone, muscle and fat weights (X in g), respectively, for male cattle from three breeds in intensive and extensive production systems and slaughtered at light and heavy weights

Component	Regression coefficient		Intercept[1]		Intercept adjustment for			s.e.	Significance of intercept differences			
	b	s.e.	a	s.e.	FR[2]	CH[2]	Extensive		FR	CH	FR v. CH	Extensive
			Total bone = X									
Distal pelvic limb bone	0.731	0.0676	0.492	0.2820	–0.020	0.005	0.015	0.007	**		***	**
Proximal pelvic limb bone	0.970	0.0527	–0.207	0.2198	0.001	–0.003	0.007	0.005				
Lumbar bone	1.333	0.1005	–2.088	0.4191	0.017	0.011	–0.007	0.010				
Rib bone	1.212	0.1524	–1.767	0.6357	0.027	–0.001	–0.011	0.015			*	
			Total muscle = X									
Distal pelvic limb muscle	0.976	0.0625	–0.930	0.2932	–0.023	–0.012	0.012	0.007	***			*
Proximal pelvic limb muscle	1.014	0.0249	–0.271	0.1168	0.003	0.002	0.000	0.003				
Lumbar muscle	0.910	0.0613	–0.340	0.2876	–0.006	0.013	–0.000	0.007			**	
Rib muscle	1.072	0.1361	–1.280	0.6386	0.010	–0.024	–0.011	0.015			*	
Gastrocnemius	1.043	0.0722	–1.556	0.3389	–0.015	–0.008	0.017	0.008	*			**
Biceps femoris	1.088	0.0494	–1.277	0.2317	0.012	0.011	0.002	0.005	*	*		
Semimembranosus	1.055	0.0733	–1.279	0.3440	0.001	–0.004	0.011	0.008				
Semitendinosus	1.102	0.0980	–1.795	0.4598	0.029	0.036	–0.033	0.010	**	**		***
Gluteus	0.961	0.1106	–0.895	0.5189	–0.008	0.000	0.016	0.012				
Quadriceps	0.860	0.0989	–0.273	0.4642	–0.000	–0.012	0.009	0.011				
Adductor	0.873	0.0862	–0.859	0.4044	–0.023	–0.024	0.017	0.010	*	*		*
Psoas	1.032	0.1355	–1.431	0.6359	–0.019	–0.018	0.020	0.012		**	*	
Longissimus lumborum	0.844	0.1050	–0.350	0.4929	0.005	0.038	0.005	0.012				
Longissimus thoracis	1.339	0.1029	–3.074	0.4828	0.009	–0.008	0.014	0.011				
			Total fat = X									
Distal pelvic limb fat	1.097	0.1160	–1.363	0.4535	–0.068	0.044	–0.113	0.030	*		***	***
Proximal pelvic limb fat	0.950	0.0387	–0.048	0.1512	0.001	0.003	–0.003	0.010				
Lumbar fat	1.080	0.0894	–1.109	0.3497	0.004	–0.009	0.030	0.023				
Rib fat	1.075	0.0884	–1.105	0.3456	0.030	–0.030	0.050	0.023			**	*

[1] For Holstein intensive (bulls) system animals.
[2] FR = Friesian, CH = Charolais × Holstein-Friesian.

and Keane, 1990; Keane and Allen, 2002; Keane, 2003).

Body, carcass, bone and muscle measurements

The greater carcass conformation score of CH over FR and of FR over HO is in agreement with the findings of Kempster Cook and Southgate (1988) and confirms that beef breeds have a superior conformation score compared with dairy breeds (Keane and More O'Ferrall, 1992; Keane, 1994; Keane and Allen, 2002; Keane, 2003). Although body measurements were only carried out prior to slaughter of the intensive system animals (bulls) at the light slaughter weight, carcass measurements broadly reflected those body measurements for the three breeds. In accord with the present findings, Cook and Newton (1979) found that purebred Holstein had longer carcasses and legs than purebred Friesian steers. Similarly, Baber *et al.* (1984) reported that Canadian Holstein × British Friesian steers had longer carcass sides and legs and similar leg thickness but a greater fore-quarter depth than British Friesian steers finished at the same level of fatness. However, in contrast, previous studies at this centre have shown that Friesian steers had similar carcass length, leg length and leg width to Holstein × (Holstein × Friesian) steers (Keane and More O'Ferrall, 1988) and Charolais × Friesian steers (More O'Ferrall and Keane, 1990), but carcass depth was greater for the Holstein crosses than for the Charolais crosses and Friesians, which were similar. The greater breed differential in the present results may be attributed to the much higher proportion of Holstein genes and higher dairy genetic merit of the dairy breeds than in the earlier studies. Unlike the study of Keane and More O'Ferrall (1988) where conformation score and most carcass measurements did not differ significantly between the Holstein crosses and Friesians, the poorer conformation of the HO in the present study can be associated with its greater skeletal size. Despite the generally longer muscles of the HO compared to FR there were few differences in muscle circumference. This is surprising considering the differences in fleshiness and carcass conformation scores between the dairy breeds. The greater muscle circumference of CH compared to the dairy breeds reflected the greater fleshiness and carcass conformation of CH.

There were few differences between the production systems in carcass measurements relative to weight, which is consistent with the absence of differences in conformation score. Using similar production systems to this study, Keane and Allen (1998) and Keane (2003) found that relative pistola and leg lengths were lower for animals on the intensive system (bulls) than for those on the extensive system (steers) but carcass conformation was better on the intensive system in those studies.

Increasing carcass weight increased the absolute values of all carcass measurements but when expressed relative to carcass weight they were reduced, indicating greater carcass compactness. Although this suggests improved carcass conformation (Keane and Allen, 1999), this was not evident here or in other studies (Keane, 1994, 2003; Keane and Allen, 1998, 2002).

Tissue and muscle distribution

The pistola, although it comprises only about 0.45 of the carcass side weight, accounts for about two-thirds of the side value because it contains all the higher-priced cuts (Keane and Allen, 1998). Whereas there were some significant differences in pistola tissue distribution between the breed types, these were small.

Similarly, Keane and More O'Ferrall (1988) reported no significant difference in side lean distribution between the primal joints of Holstein-cross and Friesian steers although nearly all of the hind-quarter joints had numerically higher proportions of the total muscle for Friesian. Keane *et al.* (1990) also found little difference in the distribution of muscle and bone between the joints for a pre-finishing slaughter group of Friesian and Charolais × Friesian steers. Although there were relatively large differences in carcass conformation score between the breed types in the present study, the relatively small differences in pistola tissue distribution together with the non-significant differences in the proportion of pistola in the side weight (McGee *et al.*, 2005), suggest that carcass conformation score is not a reliable indicator of these traits in these genotypes. Similarly, Keane, Connolly and Muldowney (2000) examined the relationship between carcass grade and carcass composition, using data on 903 carcasses from 11 experiments involving dairy and dairy × beef breed animals, and found no significant relationship between conformation class and muscle proportion within or across the experiments. However, the relationship between conformation and bone proportion was significantly negative. Likewise, Kempster *et al.* (1982) reported that carcass conformation score had little practical value as a predictor of carcass composition or lean meat proportion and distribution within breed. However, in a mixed breed population its value depended on its ability to identify breed (type) differences in carcass characteristics. In agreement, recent results from this centre using genotypes encompassing Holstein-Friesian, beef × Holstein-Friesian and ≥ 0.75 late-maturing continental breed crosses showed correlations of 0.76 and 0.73 between carcass conformation score with meat proportion and proportion of high-value cuts, respectively, indicating its usefulness as a predictor of lean meat yield and carcass value in a mixed breed population (Drennan, Keane and McGee, 2007).

The relatively small breed differences in muscle distribution within the pistola in the present study are in agreement with the findings of Keane and Allen (2002). Somewhat greater differences in muscle distribution between CH and the dairy breeds would be expected if the total carcass side was used, as numerous reports show that late-maturing continental breed cattle have more of their muscle in the pistola (hind-quarter) or higher-priced joints and less in the fore-quarter than dairy breeds (Keane, More O'Ferrall and Connolly, 1989; Keane *et al.*, 1990; Keane and More O'Ferrall, 1992; Keane, 1994). In terms of carcass value, Robelin and Tulloh (1992) pointed out that the most important differences between breeds is in the total amount of muscle as the small differences in the distribution of muscle are relatively unimportant economically.

The lower proportion of pistola fat in the ribs of animals on the intensive system (bulls) compared to those on the extensive system (steers) is also in agreement with the findings of Keane and Allen (1998) although other differences between systems in this study were not consistent with the results reported by these authors. Greater differences between bulls and steers in tissue distribution would be expected if the whole side rather than just the pistola was dissected. Bulls have a higher proportion of their muscle in the neck and shoulder region and a lower proportion in the proximal muscles of hind leg and in the muscles of the abdomen compared to steers (Mukhoty and Berg, 1973). The increase in the proportion of pistola bone in the loin and ribs and decrease in the distal pelvic limb with increasing slaughter weight agrees with the findings of Keane and Allen (1999). Most of the production system × slaughter weight interactions in tissue distribution can be explained by the different growth patterns of bulls and steers. With increasing weight more of the additional weight gain is shifted forward towards the fore-quarter in bulls than steers (Andersen, Ingvartsen and Klastrup, 1984). Additionally, changes in tissue proportion with increasing weight would be expected to be greater for bulls than steers.

Growth patterns

Allometric rather than linear regressions using untransformed data were used as it has been argued that the former are more biologically appropriate for describing the part-whole relationships involved as well as maintaining comparability with previous studies (Keane and Allen, 2002). In accord with the present findings, Berg, Andersen and Liboriussen (1978b) found that bone in the distal and proximal pelvic limb joints grew more slowly and bone in the lumbar and rib joints grew more rapidly relative to total side bone. Relative to total muscle in the pistola, the regression coefficients for proximal pelvic limb, rib joint muscle, *biceps femoris*, *semimembranosus*, *gluteus* and *quadriceps* were comparable with those of Keane and Allen (2002). In contrast, the coefficients for distal pelvic limb, *gastrocnemius*, *semitendinosus*, *adductor* and *psoas* were relatively higher, and the lumbar joint muscle and *longissimus lumborum* were relatively lower in the present study. Within the pelvic limb muscles in the present study, the *semitendinosus*, *biceps femoris* and *semimembranosus* had the highest relative growth, which is similar, although not in the same order, to the values reported by Keane and Allen (2002). Likewise, Keane *et al.* (1990) found that the *semitendinosus* and *biceps femoris* had the highest relative (to total side muscle) growth of the pelvic limb muscles.

In summary, in absolute terms HO were taller, narrower, deeper, longer and had lower fleshiness than either FR or CH, with FR being intermediate for height, depth and fleshiness. Carcass length and pistola length were significantly greater for HO than FR, which in turn were greater than the CH values. Carcass depth was similar for HO and FR and less for CH. HO had greater leg length than both CH and FR, which did not differ. Leg width and leg thickness were greater for CH than for HO and FR, which were similar. In absolute terms, muscle circumference of CH was greater than for the dairy breeds. Breed differences in pistola tissue distribution between the joints were small and confined to the distal pelvic limb and ribs. There were relatively small breed differences in the distribution of pistola muscle weight between individual muscles. Body measurements were significantly greater for animals in the intensive system (bulls) than in the extensive system (steers) in absolute terms but the opposite was so when they were expressed relative to live weight. The only significant difference in relative carcass measurements between the production systems was for carcass depth, which was lower for intensive than extensive animals. Increasing slaughter weight significantly increased all carcass measurements in absolute terms but reduced them when expressed relative to weight.

It is concluded, that the large differences in appearance, shape and conformation between the strains of dairy cattle and between the dairy and beef × dairy cattle were associated with bone length and muscle length and thickness but there were only small differences in tissue distribution in the pistola.

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