The relationship of live animal muscular and skeletal scores, ultrasound measurements and carcass classification scores to carcass composition and value in cattle

by

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Declaration

I declare that this thesis, has not previously been submitted as an exercise for a degree at the National University of Ireland or any other university and I further declare that the work embodied in this thesis is my own.

Stephen Conroy, B.Agr.Sc. 30th December 2011

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Thesis abstract

The objectives of the research reported in this thesis were to (i) determine the relationship, in beef cattle, of live animal muscular and skeletal scores measurements, ultrasonically scanned muscle and fat depth measurements of *M. longissimus dorsi*, and carcass conformation and fat scores with kill-out proportion, carcass composition and carcass value in steers (**Chapter 3**) and bulls (**Chapter 4**); (ii) develop and test the accuracy of prediction equations for carcass meat, fat and bone proportions derived from carcass conformation and fat scores; (iii) develop prediction equations for total carcass composition from hind quarter composition (**Chapter 5**); (iv) to determine the relationship of live animal muscular scores in bulls and steers at two distinct phases during their productive life (*viz.* 8 to 12 months of age and pre-slaughter), in predicting carcass traits and (v) to examine this relationship across suckler-bred and artificially reared dairy-bred steers (**Chapter 6**).

Results from the first two experiments (**Chapters 3 and 4**) showed that pre-slaughter, live animal scores, ultrasonically scanned muscle and fat depth measurements of the *M. longissimus dorsi* and carcass classification scores, explained an appreciable amount of the total variation (R^2 ranged from 0.48 to 0.81) in carcass meat, fat and bone proportions and carcass value, and a moderate amount of the variation (R^2 ranged from 0.28 to 0.42) in proportion of high-value meat cuts in the carcass, while the live animal measures explained a relatively poor amount of the variation in high value cuts as a proportion of meat and perinephric plus retroperitional fat (R^2 ranged from 0.01 to 0.23).

Results from the third experiment (**Chapter 5**) showed that carcass classification scores and hind-quarter composition were accurate and efficient predictors of carcass meat, fat and bone proportions. The bias of the prediction equations when applied across all animals was not different from zero, but there was some evidence for bias amongst some of the genotypes within the dataset. Findings from the fourth experiment **(Chapter 6)** showed that live animal visual muscular scoring systems can be simplified, to focus on development of hind-quarter, when predicting carcass traits. Muscular scores obtained pre-slaughter explained more variation (R^2 ranged from 0.25 to 0.58) in carcass traits than those obtained at 8 to 12 months of age (R^2 ranged from 0.02 to 0.19) across both dairy and suckler-bred systems. The relationship between muscular scores obtained pre-slaughter and carcass traits was relatively similar for both suckler-bred and artificially reared dairy-bred steers.

Chapter 1

Introduction

1.1 Beef production in Ireland

In Ireland, the national cow herd totalled 2.097 million in 2010 of which, 1.07 million or 51 percent, were suckler cows (Central Statistics Office, 2010). The average beef herd size in Ireland is 55 animals (Bord Bia, 2010). Cattle are produced mainly on grass-based systems and due to the seasonality of grass growth, most cows are calved in Spring. For a spring-calving beef herd, calves are reared on their dams at pasture for about 8 months following which, they are weaned and housed indoors. Steers and heifers are generally offered grass silage plus supplementary concentrates and then grazed for a second season. They are then usually finished indoors on diets that vary from *ad-libitum* grass silage or maize silage and supplementary concentrates to high concentrate diets with a small quantity of roughage. Bulls are reared in a similar fashion to steers up to weaning. However, post-weaning, bulls are generally kept indoors until slaughter and usually finished on *ad-libitum* concentrate-based diets. In contrast dairy-bred male calves are reared indoors on milk replacer, concentrates and hay as described by Fallon and Harte (1987) before being turned out to pasture, where they follow a similar post-weaning management to that outlined above. Steers, heifers and bulls are usually slaughtered between 24 and 30 months, 20 and 24 months, and 15 and 18 months of age, respectively, although in practice many different production systems are employed.

The annual output of beef in Ireland in 2010 was approximately 559,000 tonnes of carcass weight equivalent, of which 97% was marketed through export licensed meat plants (Bord Bia, 2010). Total cattle disposals in 2010 was 2.1 million head, made up of animals slaughtered in export licensed meat plants (1.643 million) and local abattoirs (0.072 million) as well as live exports (0.339 million). Live exports vary considerably from year to year and in recent years ranged from 218,000 head in 2003, increasing to

250,000 head in 2006, declining again to 207,000 head in 2007 and 147,000 in 2008, increasing then to 286,000 and 339,000 head in 2009 and 2010, respectively (Bord Bia, 2010). Live exports mainly consist of calf and weanling shipments to continental EU countries.

The average carcass weight for steers, heifers, cows and young bulls was 357 kg, 289 kg, 298 kg and 360 kg, respectively, for 2010 (Bord Bia, 2010). In 2010, the main destination of meat exports was to EU markets with the UK accounting for 51.5% of exports and continental EU, 47%, while the remaining 1.5% was sold to other international markets, including Russia and Turkey. The continental EU market has increased substantially in relative importance as a destination for Irish beef exports, in recent years.

Due to Ireland’s reliance on beef exports and especially the higher-priced EU markets, where premiums are paid for lean carcasses with good conformation, it is important that Ireland have a carcass payment system that rewards farmers for producing cattle with high quality carcasses. Drennan (2006) reported that although conformation score has a major effect on carcass price, there was considerable variation between EU countries in the price differential between different conformation classes. Throughout the EU, carcasses are classified according to their conformation and fat cover, the so called EUROP system (Commissions of the European Communities 1982). In 2004 Ireland replaced visual grading of carcasses with mechanical grading, with 24 systems in operation in factories in 2005, which is consistent with the number in operation in 2011. Additionally, live animal scores/measurements could be used to further assist the breeding and production of animals that meet market requirements through identification or screening earlier in life provided that there is a good relationship between these live animal records and the carcass traits of interest. Live animal records collected at present by breed societies and the Irish Cattle Breeding Federation (ICBF), include muscular and skeletal scores, and scanned *M. longissimus* muscle size or depth and fat cover. Some studies (Perry *et al.*, 1993; MacAodhain, 2004; Drennan *et al.*, 2008) have shown live animal muscular scores to be useful in predicting meat yield, while other studies (Faulkner *et al.*, 1990; Greiner *et al.* 2003; Tait *et al.*, 2005) have shown live animal ultrasound measurements to have a good relationship with carcass meat proportion.

Therefore, any live-animal indicators which could be used by farmers to make better breeding decisions would be very useful in improving the quality of beef produced, and in turn more animals would be suitable for the high-priced EU markets.

1.2 Introduction to thesis experiments

In the EU, beef carcasses are classified according to the official beef carcass classification scheme (Commissions of the European Communities, 1982) for conformation and fatness. In 2004, Ireland became the first country to have mechanical grading authorised to replace the previous visual assessment based system in factories (Allen, 2005). The conformation classes are denoted using the EUROP acronym with E representing highly muscled carcasses with best conformation. There is also an ‘S’ class, which represents exceptionally well-muscled carcasses and is usually only relevant to animals exhibiting muscular hypertrophy or ‘double muscling’ (Allen, 2007). Fat cover is also assessed on a 5 point scale (1-5), with 1 being the leanest. By attaching a pricing scheme to the various classes, producers are incentivised to supply the type of carcass required by the market (Allen, 2007). Beef carcass classification plays an important role in Europe, as a marketing aid within and between countries and as a means of increasing the precision of price reporting for administrative purposes

(Fisher, 2007). The price paid to producers is an important determinant of profitability with carcass conformation score having a major effect on the value of a carcass. However, the price differential among conformation classes varies considerably between countries. The usefulness of carcass classification information for conformation and fatness is dependent on their relationship to economically important traits such as meat yield, meat distribution in the carcass and ultimately carcass value (Drennan, 2006).

As a large and increasing proportion of Irish beef is exported to continental EU markets which yield higher prices for lean carcases of superior conformation, the main aim of Irish beef cattle producers should thus be to meet the requirements of that market. The identification and propagation of animals with superior carcass traits can be aided through appropriate breed and progeny testing programmes and further augmented through the use of live animal scores/measurements as indicators of carcass composition and value. Furthermore, the earlier in the animal’s life that this information can be accurately obtained the greater the potential for reducing the generation interval and increasing the rate of genetic progress.

Chapter 2 of this thesis reviews the published literature to-date on live animal muscular and skeletal scores, live animal ultrasonic muscle and fat depth measurements and carcass conformation and fat scores.

The first two experiments **(Chapter 3 and 4)** using 336 steers and 74 bulls, respectively, investigated live animal indicators of various carcass traits at both weaning and pre-slaughter. These two studies also examined the relationship between carcass conformation and fat scores with carcass composition and value. The Irish Cattle Breeding Federation (ICBF) uses a linear scoring system, across all breeds, to assess muscular and skeletal characteristics of individual animals (ICBF, 2002). Linear scoring by trained ICBF assessors involves assigning muscular scores on a scale of 1 (poor) to 15 (excellent), at six locations (width at withers, width behind withers, loin development, development of hind-quarters, width of hind-quarters and development of the inner thigh) and skeletal scores (scale of 1 to 10) at three locations (length of back, pelvic length and height at withers) (ICBF, 2002). Other core traits scored by ICBF include depth of chest, width of chest, fore legs, hind legs (side view), hind legs (rear view), level of back, width at hips, width at pins, thickness of bone, locomotion and docility. Previous studies (Perry *et al.*, 1993; MacAodhain, 2004; Drennan *et al.*, 2008) have shown that live animal muscular scores were useful in predicting meat yield.

Few studies have examined the relationship between carcass conformation and fat scores as measured under the EU beef carcass classification scheme with carcass traits and value. Breeders are always striving to select the type of animal that will produce the most profitable carcass for specific markets, therefore any live animal indicators that can help improve selection of animals and thus, increase profit and production is welcome.

The objective of the third experiment (**Chapter 5)** was to develop and test the accuracy of prediction equations for carcass meat, fat and bone proportions, derived from carcass conformation and fat scores, and also develop prediction equations for total carcass composition from hind-quarter composition. Previous studies have examined the relationship between EU carcass classification scores and carcass composition (Drennan *et al.*, 2008). Johnson and Chant (1998) noted that research has used very expensive technologies such as velocity of sound and bioelectrical impedance to improve the accuracy of carcass composition prediction, while Shackelford *et al.* (1995) and Muldowney *et al.* (1997) reported that, to their knowledge, equations to predict boneless and totally trimmed retail cut yields have not been published. In an industry that is seeking increasingly detailed data on carcass composition, an accurate and rapid technique to estimate carcass composition would be invaluable. Furthermore, a long-term objective of carcass dissection studies should be the development of accurate part-to-whole carcass composition relationships that would reduce the resource requirement that is now an integral part of detailed carcass dissection (Johnson and Charles, 1981).

The objective of the fourth experiment (**Chapter 6)** was to determine the relationship of live animal muscular scores at two distinct phases during their productive life, 8 to 12 months of age and pre-slaughter, in predicting carcass traits in both bulls and steers and also to examine this robustness of this relationship across both suckler-bred and artificially reared dairy-bred steers. A more simplified muscular scoring system, using fewer locations, without any deterioration in accuracy of evaluations, would result in a greater throughput at a lower cost per animal. This would facilitate improved accuracy of genetic evaluations that assist farmers in making the best breeding decisions for their herd. Currently, little information is available on the usefulness of live animal muscular scores as predictors of carcass traits in either suckler-bred or artificially reared dairy-bred beef cattle.

In **Chapter 7** a summary of the main outcomes and conclusions as well as the implications of the work conducted for this thesis are presented.

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Chapter 2

Literature review

2.1 Live animal muscular and skeletal scores

2.1.1 Muscular and skeletal scoring systems

Muscular and skeletal scoring is becoming widely used as a tool in the evaluation of beef breeding animals. Muscle scoring is a subjective skill which needs to be perfected by continual practice and evaluation against an experienced assessor (McKiernan, 2001). The Irish Cattle Breeding Federation (ICBF) use a linear scoring system which is used across all breeds and allows for a muscular and skeletal assessment of individual animals in order to evaluate each animal for the different traits. Linear scoring by trained ICBF assessors involves assigning subjective muscular scores on a scale of 1 (poor) to 15 (excellent), at six locations (width at withers, width behind withers, loin development, development of hind-quarters, width of hind-quarters and development of the inner thigh) and subjective skeletal scores (scale of 1 to 10) at three locations (length of back, pelvic length and height at withers) (ICBF, 2002). The 6 muscular scores are then averaged to give one score per animal for each assessor, while skeletal scores are also averaged in a similar manner. Linear scoring is not an evaluation as to the quality of the animal, it is an objective observation of clearly defined aspects of the morphology of the animal at a given age (Doorley, 2001). It is a relatively inexpensive approach to evaluate animals for muscle and skeletal traits (Doorley, 2001).

As part of genetic evaluations for cattle in the UK, Signet Breeding services also uses a muscular scoring system for three locations on an animal and is based on a scale of 1 to 15 extending to 18 for double-muscled animals (Collins, 1998). The three scoring locations are roundness of hind-quarters, width of hind-quarters and, depth and width of loin, and these scores are averaged to give a mean score per animal.

2.1.2 Errors involved in obtaining live animal scores

Perry *et al.* (1993b) stated that "as with any subjective scoring system, accuracy and consistency is dependent on the experience of the assessors". Furthermore, Perry *et al.* (1993a) stated that "visual scoring is difficult to standardise and because of its subjectivity is open to dispute and is easily criticised". Perry *et al.* (1993b) found differences in fatness between carcasses of the same weight and P8 fat depth, but different muscle scores suggesting that the distribution of subcutaneous fat cover over the carcass may change as muscle score increases and any such changes may partly reflect differences in fat distribution between breeds, where breeds tend also to differ in muscularity. Fisher (1975) concluded that there were three forms of measurement error in live animal scoring, namely; (a) correct identification of end reference points (in many ways circumferences and special measurements); (b) anatomical distortion produced by changes in the animal's posture or muscular tone which actually alters the distance between the end points when measuring with a tape and (c) error involved in measuring the actual located difference which is minimal for calliper measurements, involves a constancy of tension in the measuring tape used over convex surfaces.

Taylor (1963) (cited by Fisher 1975) found that estimates of observer variance in the same measurement of muscular score over a number of trials differed up to 12 fold. Touchberry and Lush (1950) concluded that caution must be employed when using live animal measurements when applied to a homogeneous sample of animals, while Fisher (1975) stated that "clearly errors are to be expected when measuring cattle due to animal movement". Afolyan *et al.* (2002) using live animal scores reported that breed differences had a significant effect in evaluating carcass traits.

2.1.3 Correlations between muscular and skeletal scores with carcass traits

Studies have generally shown moderate to strong positive correlations between live animal muscular scores with carcass meat proportion, proportion of high-value cuts in the carcass and carcass conformation score, while weak to moderate negative correlations have been observed with carcass fat proportion, fat score and carcass bone proportion (Table 2.1). In some instances where a negative relationship was obtained between live animal muscular scores and carcass meat proportion and conformation score this was as a result of the scoring system giving 1 to the best muscle score rather than the poorest and thus, having the opposite scaling effect (Table 2.1).

Correlations of live animal skeletal scores with carcass traits were negative, weak and generally not significant (Table 2.2).

In conclusion, muscular scores are useful in the prediction of carcass traits which concurs with the more recent findings of Drennan *et al.* (2008). However, live animal skeletal scores were poor predictors of carcass traits. This is also in agreement with Drennan *et al.* (2008) in a study using bulls and heifers who found correlations between skeletal scores (length of back, length of pelvis, and height at withers) and carcass traits to be low and generally non-statistically significant (r ranged from -0.41 to 0.38).

Table 2.1 Correlation coefficients between live animal muscular scores with carcass traits

Author	Type of animal	Description of comments	Meat%	Fat %	Bone%	Carcass value	Conformation score	Carcass fat score
Perry *et al.* (1993a)	Steers		0.70	-0.46		0.64	0.84	
Herring *et al.* (1994a)	Steers	Visual muscle score (scale 1 to 10)	-0.24	0.16				
May *et al.* (2000)	Steers and Heifers	Visual muscular scores (1=thick 2= average 3=thin)	-0.35***	0.16***				
MacAodhain (2004)	Bulls	Weaning muscular scores	0.47*** to 0.64***	-0.40** to -0.50**	-0.36* to -0.48***		0.54*** to 0.70***	-0.29 to -0.40**
MacAodhain (2004)	Bulls	Slaughter muscular scores	0.39*** to 0.57***	-0.21 to -0.42**	-0.58*** to -0.64***		0.63*** to 0.77***	-0.09 to -0.12
MacAodhain (2004)	Bulls	Weight of cube roll						
Doorley (2001)	Bulls	Experiment 1 and 2 (Five locations)	0.87***				0.62***	

Table 2.2 Correlation coefficients between live animal skeletal scores with carcass traits

Author	Type of animal	Description of comments	Meat%	Fat %	Bone%	[1]K + C%	Conformation score	Carcass fat score
Cook *et al.* (1951)	Steers	Length of body					-0.21**	
Cook *et al.* (1951)	Steers	Height at withers					0.42**	
Busch *et al.* (1969)	Steers	Length of body	0.62**					
Busch *et al.* (1969)	Steers	Height of withers	0.60**					
Bailey *et al.* (1986)	Bulls	Withers height (340 kg)	-0.40*	0.21	0.41*		-0.40*	
Bailey *et al.* (1986)	Bulls	Withers height (470 kg)	-0.40*	0.30	0.33*		-0.11	
Bailey *et al.* (1986)	Bulls	Withers height (600 kg)	-0.19	0.05	0.43		-0.49*	
Faulkner *et al.* (1990)	Cows	Hip height	0.45	0.04	-0.12			
Herring *et al.* (1994a)	Steers	Hip height	-0.14	0.091				
Herring *et al.* (1994a)	Steers	Frame size	-0.033	0.013				
Hassen *et al.* (1999)	Steers and bulls	Age end points = 365 days (hip height)	-.06					
Hassen *et al.* (1999)	Steers and bulls	Age end points = 382days (hip height)	-0.04					
Hassen *et al.* (1999)	Steers and bulls	Age end points = 414days (hip height)	-0.02n.s					
Hassen *et al.* (1999)	Steers and bulls	Age end points = 448days (hip height)	-0.00n.s					
May *et al.* (2000)	Steers and heifers	Frame size	-0.26***	0.31***				
Doorley (2001)	Bulls	Experiment 1 and 2 (5 skeletal locations)		-0.12	-0.82***	0.06	0.10	-0.01
MacAodhain (2004)	Bulls	Weaning scores (5 locations)	-0.03 to -0.09	0.00 to -0.08	0.25		-0.15 to -0.17	-0.03 to -0.12
MacAodhain (2004)	Bulls	Slaughter scores (8 locations)	0.00 to 0.03	-0.03 to 0.04	-0.08 to -0.22		-0.02 to 0.20	0.02 to 0.05

[1] Perinephric and retroperitoneal fat

2.1.4 Variation explained using live animal muscular and skeletal scores/measurements with carcass traits

Perry *et al.* (1993a) reported that live-weight and P8 fat depth measured using a Hennessy probe on the hot carcass explained 25.5 and 41.0% of the total variation in lean and total fat percentage, respectively. They also found that when live muscle score was added to a regression model incorporating live-weight and P8 fat depth, the corresponding values were 46.3 and 48.8 %, respectively. Zgur *et al.* (2006) found that objective measurements of various cuts from the carcass explained moderate to high amounts of the variation (R^2 ranged from 0.58 to 0.80) in meat, fat and bone percentages. May *et al.* (2000) found that including frame size, muscle score, live and hot carcass weight and fat thickness in a multiple regression model for predicting yield of boneless subprimal trimmed to 0.64 cm of fat cover explained from 43 to 66 % of variation. Herring *et al.* (1994a) reported that a visual muscular score and ultrasound live animal measurements explained 24 to 48 % of total variation in various retail cuts.

Hassen *et al.* (1999) found hip height to be useful in a multiple regression equation model with three other traits (real time ultrasound predicted percentage of intramuscular fat, longissimus muscle area and pre-slaughter live-weights), which explained 30% of variation in retail product percentage early in the animal's life, but as the animal approached slaughter its influence diminished and it explained little or none of the variation. Afolynan *et al.* (2002) reported that height (measured as the distance from the top of the midline between the hips to the ground), hip width, stifle width and girth (measured as the body circumference immediately posterior to the front leg) combined explained 52% of total variation in meat yield percentage and when length of animal was added instead of girth, 31% of total variation in bone percentage was accounted for.

Afolynan *et al.* (2002) also explained 42% of total variation in fat percent using the measurements combined of height, hip width, stifle width and girth.

2.2 Live animal ultrasonic muscle and fat depth measurements

2.2.1 Principles of ultrasound

Ultrasound has been used to estimate carcass composition in cattle since the 1950s (Houghton and Turlington, 1992). It has emerged as a technology of choice for determining carcass value quantitatively, in addition to predicting heritable muscling and quality attributes (Whittaker *et al.,* 1992). Ultrasound is capable of travelling through solids, liquids and tissues. This is achieved as a result of ultrasonic waves been generated by the ultrasound transducer. Piezoelectric crystals in the transducer convert electrical energy into ultrasound waves. This ultrasound is then emitted from the transducer in short pulses and these pulses are then reflected and scattered by tissue and tissue interfaces. The sound waves then penetrate the tissue whilst also reflecting back to the transducer and the echoes that return from the sound source (transducer) are detected and displayed on the ultrasound unit screen in a cross-sectional anatomical format (Whittaker *et al.,* 1992). This then allows the characteristics of the image to be visually interpreted.

There are three basic display modes of ultrasound which are A-mode, B-mode and real time ultrasonic imaging. The A-mode is the first display mode and refers to amplitude modulation which is a one dimensional display of ultrasonic imaging. It works through echoes from the transducer that appear as spikes on the display and these spikes can be related to the distance between successive interfaces with the height of the spike corresponding to the sound amplitude at that tissue depth (Houghton and Turlington, 1992). A-mode is only capable of measuring depths in the live animal and not the measurement of area.

A-mode uses 16 shades of grey whereas the next display format, B-mode or brightness mode (a modified version of A-mode) uses 64 shades of grey. This latter mode does not distinguish between red and fat tissue except by texture where dense tissue give white pixels and medium tissues give grey pixels on the scanner screen. B-mode is a two dimensional display of dots or pixels with the brightness of each dot being determined by the amplitude of the echo. Thus, the final image can be interpreted from the shades of grey. Bergen *et al.* (2005) stated "that B-mode ultrasound technology has become a major component of genetic improvement programmes in north American beef cattle".

The third display format is real time ultrasonic imaging which is a form of B-mode, where it creates images, which can be seen instantaneously. It occurs as a result of ultrasound pulses being produced by applying a very short electrical voltage impulse to the transducer. The sound field resulting from ultrasonic pulses is called a 'beam' and the beam is divided into two regions called the near and far field. The sound beams that pass through the tissues are displayed as an echo on the ultrasound screen, where the image can then be interpreted. The echo is displayed as grey, extending to black and white.

2.2.2 General scanning procedure

A common cause of poor quality ultrasonic images is failure in the appropriate preparation of the animal to be scanned (Doorley, 2001). In order to ascertain the level of image required certain factors need to be taken into account:

2.2.2.1 Animal restraint

In order to reduce animal stress and the chance of injury to the animal and operator, animals should be restrained in a squeeze chute or crush with the option of the animals head being safely secured in a head gate. Perkins *et al.* (1992a) waited until the animals weight was spread evenly on all four feet before the scan was taken. Faulkner *et al.* (1990) restrained animals in a squeeze chute before ultrasonic measurements were carried out. Animal movement during scanning can contract muscles, distorting the ultrasonic measurements (Mersmann, 1982).

2.2.2.2 Scanning site/position

It is important to use a site that is easy to locate on the animal and provides little difficulty and maximises safety to the operator when working with that particular anatomical location (Doorley, 2001).

Determination of ultrasonic *longissimus* muscle area is two-dimensional in nature (length and depth). Therefore, it is more difficult to get an accurate estimate for *longissimus* muscle area than for backfat area (Williams, 2002). Bergen *et al*. (2003) showed that ultrasound measurements of *longissimus* muscle depth and width were as valuable in predicting carcass composition as traced *longissimus* muscle area in young bulls. *Longissimus* muscle area represents a cross sectional area of the *longissimus* muscle at a point between the 12th and 13th rib. It is the most common estimator of carcass muscle and is used in yield grade estimation in the U.S. (Williams, 2002).

Many researchers have reported fat thickness over the 12th rib to be most accurate indicator of carcass composition and therefore, it is one of the most widely used measurements (Crouse *et al.,* 1975; Faulkner *et al*., 1990). Two sites commonly used for predicting carcass composition in beef cattle are the 12th or 13th rib and the rump or

Australian P8 site (Perry *et al.*, 1993b; Reverter *et al.*, 2000). The P8 site is located over the gluteus muscle on the rump, at the intersection of a line through the pin bone parallel to the chine and its perpendicular through the third sacral crest (Reverter *et al.*, 2000). In most studies animals have been scanned along the loin area over the *longissimus dorsi* muscle between the 10th rib and the 5th lumbar vertebra (Simm *et al.*, 1983). The main reason for this is that the *longissimus dorsi* is a well-defined muscle and in addition, skeletal features in that area are easy to locate (Anderson, 1975).

2.2.2.3 Clipping and coupling agent

The use of electric clippers is the most effective way to ensure that hair, dirt and debris on the hide are removed and no air bubbles can interfere with contact between the sound waves emitted by the transducer and the animal's body (MacAodhain, 2004). Robinson *et al.* (1992) found that adequate images could be obtained without clipping if the hair was combed to free it of debris and enough corn oil was used. In contrast, Hassen *et al.* (1998) found that animals needed to be clipped in order to establish good transducer-animal contact. Furthermore, these authors found it necessary to apply vegetable oil to the clipped area, then curry comb it until free from dirt and then re-oil the animals in order to obtain optimum image quality.

Sound waves will not travel through air therefore a couplant must be used to obtain good acoustical contact between the probe and the skin surface. Some operators used a scanning gel in the past, however it proved too expensive and impractical since it caused air pockets if hair was not clipped (Williams, 2002). Various oils were used to obtain images including motor oil (Stouffer *et al.*, 1961), liquid paraffin (Fursey *et al.*, 1991) but now, most operators use vegetable or corn oil (Robinson *et al.*, 1992; Hamlin *et al.*, 1995).

2.2.2.4 Scanning procedure

In summary, in order to obtain a high quality scan the typical steps involved as used by Doorley (2001) are:

> (1) Clipping hair from the area to be scanned and adding corn oil to the animals hide in order to promote good acoustical contact between the animal and the transducer.
>
> (2) Placing the transducer between the ribs in question following physical palpation to acquire the scanning site.
>
> (3) Moving the transducer at right angles to the animal's backbone until the *longissimus dorsi* muscle comes into view on the monitor.

2.2.3 Factors affecting the accuracy of ultrasound measurements

2.2.3.1 Differences between operator and interpretation

Accuracy is highly dependent on the technician and level of experience that the person requires (McLaren *et al.,* 1991). Technician training and experience is needed for accurate image collection and interpretation (Herring, 1994a). Moody *et al.* (1965) found that as a technician becomes more experienced the accuracy of images improves. Perkins *et al.* (1992a) found no significant difference using ultrasound between technicians and also accuracy of ultrasound measurements did not improve as level of technician experience increased during the study. Miles *et al.* (1972) reported that individuals interpret the same ultrasonic images differently, and that there are differences in the accuracy of anatomical locations, thus making the technique highly technician dependent. Herring *et al.* (1994a) reported that the two main sources of error in ultrasound data collection were image acquisition and image interpretation. Waldner *et al.* (1992) concluded that increased level of operator skill obtaining the images did not improve the accuracy of fat and *longissimus* muscle area measurements, however increased level of skill of the interpreter in assessing the scanned images did improve the accuracy of *longissimus* muscle area estimations. Robinson *et al.* (1992) found that slight movements of the transducer helped aid image interpretation when measuring rib fat using ultrasound. Miles *et al.* (1972) found that inaccurate interpretation of the image produced, contributes to low values. McLaren *et al.* (1991) also reported variation among operators in interpreting scans for *longissimus* muscle area. Renand and Fisher (1997) obtained correlations of 0.83 to 0.90 for interpretation of the same scan for fat and stated that the interpretation of the scans for measuring fat thickness could be considered to be satisfactory. Temple *et al.* (1965) found that errors using ultrasound in cattle to be a result of poor interpretation and machine manipulation by the operator.

Perkins *et al.* (1992a) and Recio *et al.* (1986) found that under-prediction occurred more often than over-prediction for *longissimus* muscle area and fat. Perkins *et al.* (1992b) found that technicians more often over-estimated for fat and underestimated for *longissimus* muscle area.

2.2.3.2 Repeatability of operators

Hassen *et al.* (1998) used two certified scanning technicians to collect and interpret images from steers on feeding trials prior to slaughter found repeatability of ultrasound back-fat was similar for both technicians (0.96 v. 0.97), however one technician exhibited better repeatability of *longissimus* muscle area than the other (0.92 v. 0.79). Perkins *et al.* (1992b) found repeatability estimates for *longissimus* muscle area interpretation of scans from video tape were 0.87 and 0.84 within technician and 0.81

and 0.71 between technicians. Perkins *et al.* (1992b) reported using two technicians, repeatability of measurements for scanned fat was 0.88 and 0.93 for technicians 1 and 2 and *longissimus* muscle area repeatabilities were approximately 0.81 for both technicians for images repeated over two days. Brethour (1992) obtained correlations of 0.98 between consecutive ultrasound back-fat measurements. Herring *et al.* (1994b) reported repeatability between three technicians over two days ranged from 0.36 to 0.90 and 0.69 to 0.90 for ultrasound *longissimus* muscle area and fat depth, respectively. Renand and Fisher (1997) using two interpreters achieved repeatability of 0.61 and 0.90 for scanned fat thickness at 3 different locations (10th rib, 13th rib and 3rd lumbar) on the animal. Robinson *et al.* (1992) found that operator experience (accredited technicians compared to non-accredited technicians) improved the repeatability and accuracy of scanning fat but had little effect on scanning *longissimus* muscle area when related to carcass measurements.

2.2.3.3 Differences between machines

The ultrasound system used to capture and interpret images can have a significant impact on the accuracy and repeatability of ultrasound-based carcass measurement estimates (Williams, 2002). Charagu *et al.* (2000) evaluated the Aloka SSD-1100 (AL) and Tokyo CS 3000 (TK) ultrasound machines and found both machines to have similar accuracy in cattle with larger *longissimus* muscle area, but differed significantly in lighter muscled animals. They reported that the AL under-predicted rib-eye area (REA) and fat in steers, heifers and bulls and that the TK under-predicted fat for heifers and had a very small bias for bulls and steers. Herring *et al.* (1994b) found that the estimation of *longissimus* muscle area with ultrasound was more difficult with machines requiring split-screen images compared to machines that allow for complete *longissimus* muscle imaging on a single screen and concluded that machine differences do exist. Herring *et al.* (1998) found the Aloka 500v to be superior in accuracy and repeatability to the Aloka 210DX, for measurements of *longissimus* muscle area. In contrast, Waldner *et al.* (1992) obtained no difference between Aloka Technicare 210DX and Equisonics LS-300A real time, B-mode ultrasonic scanners in the accuracy of estimating fat and *longissimus* muscle area. Similarly, Hassen *et al.* (2001) reported that the Aloka 500V (AL-500) and Classic Scanner 200 (CS-200) machines had similar accuracy in predicting intramuscular fat in live cattle.

2.2.3.4 Time of scanning

If valuable carcass information could be accurately obtained (predicted) earlier in the animals life using scanning, this information could be used in breed improvement and progeny testing programmes. Williams (2002) stated “that there is a need to select replacement seedstock at one year of age, rather than waiting to obtain actual progeny carcass data, which can significantly impact the rate of genetic progress”. He also stated that to “evaluate for carcass merit before one year old is not recommended as a certain level of physiological maturity is necessary to allow adequate evaluation”. Waldner *et al.* (1992) concluded that scanning of *longissimus* muscle area at 12 months of age and of fat at 12 to 16 months of age were sufficiently accurate to characterise groups of bulls, although some individual measurements were quite inaccurate. Suguisawa *et al.* (2003) reported that carcass fat could be predicted with a higher degree of accuracy the nearer animals approached slaughter using ultrasound, which agrees with the conclusions of Bergen *et al.* (1996). Wollcott *et al.* (2001) using scanned P8 site for fat and eye muscle area in addition to live-weight to predict retail product at three different stages of the animals growth (weaning, entry to finishing and pre-slaughter) obtained R^2

of 0.06, 0.38 and 0.56, respectively. Also Hamlin *et al.* (1995) found that accuracy and predictability increased gradually over-time for scanned *longissimus* muscle area and fat in animals that were scanned seven times over a 263 day feeding period. Similarly, Hassen *et al.* (1999) scanned animals at 365, 382, 414 and 448 days of age for *longissimus* muscle area and fat and found that although correlations were weak the relationship between scanned measurements and retail beef yield to increase the nearer animals were to slaughter. The literature would suggest that the nearer an animal is to slaughter the more accurate ultrasound can predict carcass traits.

2.2.3.5 Effect of breed on accuracy

Crouse *et al.* (1975) in a study that looked at 786 steers from Hereford or Angus cows bred to Hereford, Simmental, Charolais, Limousin, Angus, South Devon and Jersey, found fat thickness at 12th rib to be a useful predictor ($r = -0.73$) of cutability within and across all breed groups evaluated. Faulkner *et al.* (1990) found that breeds which ranged from early to late maturing animals did not significantly ($P > 0.15$) affect the accuracy of ultrasonic measurements of fat in slaughtered animals using three groups of cattle that consisted of various breeds, sexes and weights. Oltjen *et al.* (1989) reported that ultrasonic fat depth was measured accurately across various breeds but *longissimus* muscle area was significantly over-predicted in British × Exotic crosses than breed crosses having greater than 3/8 Zebu breeding. Suguisawa *et al.* (2003) found ultrasonic measurements of rib-eye area (REA) and fat were significantly affected both by genetic group and interaction of genetic group × period, as a result of different patterns in muscular growth and back-fat accretion among genetic groups. Suguisawa *et al.* (2003) found that when breed was included in a regression model, the R^2 value increased for fat prediction. Perkins *et al.* (1992b) in a study comprising of 3 technicians found accuracy differences in fat and *longissimus* muscle area between breed types but found no technician × breed-type interactions.

2.2.3.6 Animal gender

Faulkner *et al.* (1990) found sex of the animal to have no influence on accuracy of ultrasound measurements. Perkins *et al.* (1992a) using steers and heifers found that fat thickness for steers and *longissimus* muscle area for both sexes were underestimated more often than not and that steers had higher levels of fat thickness and smaller *longissimus* muscle area than did heifers.

2.2.3.7 Ribbing and fat removal

Excessive fat removal was observed during the hide removal process, especially at the 12th to 13th rib site which can be the cause of error when relating live ultrasound measurements to the carcass (Herring *et al.*, 1994b). Robinson *et al.* (1992) found differences between the right and left side of the carcass resulting from handling and dressing procedures. Faulkner *et al.* (1990) reported that the relationship between carcass and ultrasound fat may be influenced by slaughtering technique. Hendrick *et al*. (1965) reported that considerable variation in area of muscle of the right and left sides can occur if the sides are not ribbed at the same anatomical location and at the same angle. Hendrick *et al*. (1965) also found subcutaneous fat to vary significantly between the 11th thoracic vertebra, 13th thoracic vertebra and 1st lumbar and concluded that the differences that occur between the right and left *longissimus dorsi* muscle and subcutaneous fat thickness measurements are due principally to errors in ribbing.

2.2.3.8 Extremes in muscle and fat

Bergen *et al.* (1996) concluded that accuracy of ultrasound measurements decreases in heavily muscled animals with excessively large *longissimus dorsi* muscles. Waldner *et al.* (1992) found that there was a tendency to over-estimate thin cattle and under-estimate fat cattle especially as fat increased above 1.0 cm. Ultrasound accuracy decreases where fat is higher than 10 mm (Faulkner *et al.* 1990., Bergen *et al.,* 1996). Suguisawa *et al.* (2003) found that ultrasound under-estimated ribeye area (REA) in heavier muscled animals. Smith *et al.* (1992) concluded that fat thickness was under-estimated on fatter cattle and muscle area was under-predicted in more heavily muscled animals. Charagu *et al.* (2000) using two different machines found REA to be under-predicted in larger muscled cattle and over-predicted in smaller muscled cattle. Also both machines were found to under-predict fat in fatter cattle and over-predict fat in leaner cattle. Perkins *et al.* (1997) also found that ultrasound under-estimated actual back-fat in fatter cattle and over-estimated back-fat in leaner cattle. Wollcott *et al.* (2001) reported that it was difficult to obtain quality images of eye muscle area in large, fatter Japanese animals.

Overall, the literature above would suggest that there is a tendency for ultrasound to under-estimate extreme muscled animals while, fat can be over-predicted in thin cattle and under-predicted in fat cattle.

2.2.4 Heritability of eye muscle area and fat

Moderate heritability estimates (0.29 to 0.40) of *longissimus* muscle area have been obtained (Johnson *et al.,* 1993; Moser *et al.,* 1998; Stelzleni *et al.,* 2002). Heritability varied greatly for fat in beef cattle with values using ultrasound measurements ranging from 0.04 to 0.52 (Benyshek, 1981; Lamb *et al.,* 1990; Turner *et al.,* 1990; Johnson *et* *al.*, 1993; Robinson *et al.*, 1993; Moser *et al.*, 1998; Stelzleni *et al.*, 2002). Shephard *et al.* (1996) reported the highest heritability for *longissimus* muscle area at 0.56 and also obtained a heritability of 0.11 for back-fat thickness. Using six breeds DeRose *et al.* (1988) obtained heritability for back-fat thickness which ranged from 0.25 to 0.76. Hassen *et al.* (1998) reported heritability estimates of *longissimus* muscle area and fat thickness in bulls to be 0.21 and 0.05, respectively, whereas the corresponding values in steers were 0.07 and 0.42.

2.2.5 Correlations between ultrasonic measurements of muscle and fat with carcass traits

2.2.5.1 Carcass meat proportion

Studies have shown variation in the association between ultrasound *longissimus* muscle area (or depth) and meat or retail yield percentage (Table 2.3). MacAodhain (2004) and Doorley (2001) obtained moderate to strong correlations (0.36 to 0.80) between *longissimus* muscle area and carcass meat proportion, whereas weaker correlations (-0.06 to 0.28) between these two traits have been obtained in other studies.

Scanned fat depth (Table 2.4) also shows varying correlations (r = -0.74 to -0.44) with meat yield percentage. Bailey *et al.* (1986) obtained considerably lower correlations ranging from (-0.28 to -0.16) between these traits using animals scanned at 3 different weights (340 kg, 450 kg and 600 kg). While, Griffin *et al.* (1999) reported that as fat trim level increased the relationship between ultrasound fat depth and percentage retail product increased.

2.2.5.2 Carcass fat proportion

Numerous studies have shown ultrasound fat measurement to have moderate to high correlations (r = 0.31 to 0.81) with carcass fat percentage (Table 2.4). Correlations of ultrasound *longissimus* muscle area or depth were found to be generally poorly correlated (r = -0.35 to 0.14) with fat percentage in the carcass (Table 2.3).

2.2.5.3 Carcass bone proportion

Bailey *et al.* (1986) obtained correlations between ultrasound *longissimus* muscle area and bone percentage to range from -0.46 to 0.05 (Table 2.3). Correlations between ultrasound fat and bone percentage were reported (Table 2.4) to range from -0.70 to -0.01 (Bailey *et al.*, 1986; Faulkner *et al.*, 1990).

2.2.5.4 Proportion of high-value cuts in the carcass

Tait *et al.* (2005) obtained a positive correlation (0.30) between ultrasound *longissimus* muscle area and the proportion of high-value cuts in the carcass (Table 2.3), whereas the corresponding correlation (Table 2.4) with ultrasound fat depth was negative (-0.58)

2.2.5.5 Perinephric and retroperitoneal fat

Perinephric and retroperitoneal fat weight was shown to be positively related (r = 0.26 to 0.56) to ultrasound fat depth and negatively related to *longissimus* muscle area (-0.11 to -0.31) (Table 2.3 and 2.4).

2.2.5.6 Carcass conformation score

Bailey *et al.* (1986) obtained correlations ranging from -0.16 to 0.57 between ultrasound *longissimus* muscle area and conformation score and weak correlations between ultrasound fat and conformation score with Holstein-Friesian scanned at light, medium and heavy weights (Table 2.3). Bailey *et al.* (1986) also found that the relationship between scanned muscle score measurements and conformation score improved as the animals approached slaughter. Doorley (2001) and MacAodhain (2004) obtained positive correlations (0.40 to 0.60) between ultrasound *longissimus* muscle depth and conformation score, whereas MacAodhain (2004) obtained negative correlations (-0.17 to -0.37) between ultrasound fat depth and conformation score (Table 2.4). So in conclusion, there is the potential to predict carcass conformation score using ultrasound measurements of longissimus muscle depth or area.

2.2.5.7 Carcass fat score

Previous studies (Table 2.4) have found positive correlations (0.57 to 0.73) between ultrasound fat depth and fat score, indicating that ultrasound fat is a potential predictor of carcass fat. MacAodhain (2004) obtained correlations ranging between -0.06 and -0.20 with carcass fat score using scanned muscle depth at the 3rd lumbar vertebra.

Table 2.3 Correlation coefficients of ultrasonic scanned muscle depth (or area) measurements with carcass traits

Author	Position	Type of animal	Description/comments	Meat %	Fat %	Bone %	^{1}HVC %	^{2}K+C %	Conformation score	Fat score
Crouse *et al.* (1975)		Steers	*Longissimus* muscle area (carcass measurement)	0.47						
Bailey *et al.* (1986)		Bulls	Ultrasound *longissimus* muscle area (340-600 kg)	0.17 to 0.28	-0.01 to -0.23	0.05 to -0.46				
Faulkner *et al.* (1990)	12th rib	Cows	Carcass ribeye area cm^2	0.75		-0.67				
Herring *et al.* (1994a)		Steers	Ultrasound *longissimus* muscle area	0.095	0.14	0.06			-0.16 to 0.57*	
Hamlin *et al.* (1995)		Steers	Ultrasound *longissimus* muscle area (60 day intervals)	-0.06 to -0.36						
Shalkelford *et al*. (1995)		Steers	*Longissimus* muscle area (carcass measurement)	0.44	-0.39					
Griffen *et al.* (1999)		Steers	Ultrasound ribeye area cm^2 (Fat trim level 2.54)	0.002						
Griffen *et al*. (1999)		Steers	Ultrasound ribeye area cm^2 (Fat trim level 1.27)	0.06						
Griffen *et al.* (1999)		Steers	Ultrasound ribeye area cm^2 (Fat trim level 0.62)	0.07						
Hassen *et al*. (1999)	Between 12th and 13th rib	Steers and bulls	Age end points=365 days (ultrasound *dorsi* area only)	0.01 n.s						
Hassen *et al.* (1999)	Between 12th and 13th rib	Steers and bulls	Age end points=382 days (ultrasound *dorsi* area only)	0.05*						
Hassen *et al.* (1999)	Between 12th and 13th rib	Steers and bulls	Age end points=414 days (ultrasound *dorsi* area only)	0.11**						
Hassen *et al.* (1999)	Between 12th and 13th rib	Steers and bulls	Age end points=448 days (ultrasound *dorsi* area only)	0.15**						
Doorley (2001)	3rd lumbar	Bulls	Ultrasound maximum muscle depth	0.80***					0.60***	
May *et al.* (2000)		Steers and heifers	Ultrasound *longissimus* muscle area cm^2	0.07	0.07					
Greiner *et al*. (2003)		Steers	Ultrasound *longissimus* area	0.17						
MacAodhain (2004)	3rd lumbar	Bulls	Ultrasound maximum muscle depth	0.36* to 0.47***	-0.25 to -0.35*			-0.11 to -0.13	0.40** to 0.55***	-0.06 to 0.20
Tait *et al.* (2005)		Bulls and steers	*Longissimus* muscle area		-0.12**		0.30***			

[1] High-value cuts in the carcass; [2] Perinephric and retroperitoneal fat weight

Table 2.4 Correlation coefficients of ultrasonic scanned fat depth measurements with carcass traits

Author	Position	Type of animal	Description/comments	Meat%	Fat%	Bone%	[1]HVC%	[2]K+C%	Conformation score	Fat score
Crouse *et al.* (1975)		Steers	Fat thickness (carcass measurement)	-0.76						
Simm *et al*. (1983)		Bulls	Scanned fat area	-0.58						
Simm *et al*. (1983)		Bulls	Dannscanner fat area	-0.6						
Bailey *et al.* (1986)		Bulls	Ultrasound fat (340-600 kg)	-0.16 to -0.28	0.31 to 0.36*	-0.01 to -0.15				
Faulkner *et al.* (1990)	12th to 13th rib	Cows	Ultrasound fat cm	0.51	0.81	0.7				
Herring *et al*. (1994a)			Ultrasound fat thickness	-0.49**	0.61**					
Hamlin *et al.* (1995)		Steers	Ultrasound fat (60 day intervals)		0.62 to 0.86				0.0 to -0.07	
Renand and Fisher (1997)	10th rib	Young bulls	Ultrasound fat depth		0.49					
Renand and Fisher (1997)	13th rib	Young bulls	Ultrasound fat depth		0.43					
Renand and Fisher (1997)	3rd lumbar	Young bulls	Ultrasound fat depth		0.48					
Griffen *et al.* (1999)		Steers	Ultrasound fat thickness cm^2 (Fat trim level 2.54)	-0.21						
Griffen *et al.* (1999)		Steers	Ultrasound fat thickness cm^2 (Fat trim level 1.27)	-0.36						
Griffen *et al.* (1999)		Steers	Ultrasound fat thickness cm^2 (Fat trim level 0.62)	-0.4						
Hassen *et al.* (1999)	Between 12th and 13th rib	Steers and bulls	Age end points=365 days (ultrasound fat only)	-0.57						
Hassen *et al.* (1999)	Between 12th and 13th rib	Steers and bulls	Age end points=382 days (ultrasound fat only)	-0.62**						
Hassen *et al.* (1999)	Between 12th and 13th rib	Steers and bulls	Age end points=414 days (ultrasound fat only)	-0.64**						
Hassen *et al.* (1999)	Between 12th and 13th rib	Steers and bulls	Age end points=448 days (ultrasound fat only)	-0.63**						
Doorley (2001)	3rd lumbar	Bulls	Ultrasound fat depth		0.61**			0.56***		0.73***
Doorley (2001)	12th to 13th rib	Bulls	Scanned back fat depth					0.45*		0.63***
May *et al.* (2000)		Steers and heifers	Ultrasound fat thickness cm	-0.73***	0.78***					
Greiner *et al*. (2003)		Steers	Ultrasound fat	-0.74						
MacAodhain (2004)	3rd lumbar	Bulls	Ultrasound fat depth	-0.44** to -0.60***	0.48*** to 0.63***			0.26 to 0.30*	-0.17 to -0.37*	0.57*** to 0.61***
Tait *et al.* (2005)		Bulls and steers	Scanned area of gluteous medius anterior		-0.03		0.02			
Tait et al. (2005)		Bulls and steers	Fat thickness		0.39***		-0.58			

[1] High-value cuts in the carcass; [2] Perinephric and retroperitoneal fat weight

2.2.6 Variation in carcass traits explained using live animal ultrasound measurements.

Lambe *et al.* (2010) obtained an adjusted R^2 of 0.69 in predicting carcass meat percentage using scanned muscle depth (3rd lumbar vertebra) and scanned fat depth (8 locations) and live-weight, with all measurements taken 1 day prior to slaughter. Using the same measurements taken at the start of the finishing period to predict meat yield percent, they found the adjusted R^2 decreased to 0.65. Tait *et al.* (2005) in predicting percentage of retail product of four primal cuts found that ultrasound fat explained 32% of the total variation, and addition of ultrasound *longissimus* muscle area increased the amount of variation explained to 41%. They also found that ultrasound fat accounted for 0.12 of the total variation in carcass fat percentage and the addition of *longissimus* muscle area increased the amount of variation explained to 0.16. Faulkner *et al.* (1990) found that using liveweight and ultrasound fat depth measurements taken at the 12th rib accounted for 0.85, 0.59 and 0.79 in carcass fat percentage, fat-free lean percentage, and bone percentage, respectively. In a multiple regression equation, Griffin *et al.* (1999) in predicting yield of boneless subprimals trimmed to 3 different levels of 2.54cm, 1.27 cm and 0.67 cm explained 33, 38 and 38 % respectively, of total variation in retail product from percentage kidney, pelvic and heart fat along with scanned backfat thickness. They also found that in a stepwise regression model which included seven carcass measurements taken after slaughter, scanned ribeye area was omitted from the model as it explained no further variation in predicting boneless subprimals. Greiner *et al.* (2003) reported that 78% of total variation in percentage retail product was explained by using live-weight and ultrasound fat in a multiple regression equation and that addition of ultrasound *longissimus* muscle area increased the proportion of total variation explained to 83%. Hamlin *et al.* (1995) concluded that ultrasound *longissimus* muscle area was not an accurate predictor of percentage retail product ($R^2 < 15\%$) but that fat thickness was a good predictor especially with animals near a finished condition (R^2 = 58% to 64%). Tarouco *et al.* (2007) explained 78% of retail product weight in the hind-quarter, although predictions of the percentage of retail product in the hind-quarter were a lot weaker (R^2 = 18%). Wollcott *et al.* (2001) using scanned P8 fat depth, scanned eye muscle area and live-weight of steers at weaning, entry to finishing and pre-slaughter to predict percentage retail beef yield (RBY) obtained R^2 values of 0.06, 0.38 and 0.56, respectively. Herring *et al.* (1994a) found that ultrasound *longissimus* muscle area explained little or no variation in percentage retail product, whereas ultrasound fat alone explained 24 to 27% of the total variation. Bergen *et al.* (2003) reported in one study that ultrasonic fat depth measurements were the most important, *longissimus dorsi* measurements (area, width and depth) were moderately important and live-weight was the least important predictor of carcass lean meat yield. In a second experiment, Bergen *et al.* (2003) found that multiple regression equations based on ultrasonic fat and *longissimus* muscle area measurements, predicted carcass lean meat yield (R^2 =0.82 to 0.85) as accurately as carcass-based equations (R^2 =0.81). Hassen *et al.* (1999) found ultrasound fat to account for the largest proportion of total variation in percentage retail yield with *longissimus* muscle area only having a marginal contribution with animal scanned at 4 age end points.

2.3 Carcass conformation and fat scores

2.3.1 Carcass grading system

Carcass muscularity is defined as the thickness of the muscle relative to skeletal dimensions and carcass conformation is a visual assessment of the thickness of fat and muscle in relation to skeletal measures (Charteris and Garrick, 1997). Carcass classification is an important tool for ensuring fair payment to the producer, as well as contributing to transparency of the market. By identifying the various qualities of carcasses, classification identifies more valuable carcasses and accordingly, should encourage the breeding and production of better quality animals (Department of Agriculture and Food, 2010).

In Ireland, a national beef carcass classification scheme was introduced in August 1979. It was based on a seven point scale for conformation using the letters I, R, E, L, A, N, D and for fat the numbers 1-7. Due to European Council and Commission regulations, the national scheme was superseded by a standard European-wide classification scheme on October 1st 1982 (Department of Agriculture and Food, 2010).

Allen (2007) stated that "the classification scheme is used by the EU for price reporting and market intervention purposes and by the industry for quality based payments to producers and for carcass trading". The system describes four carcass characteristics; weight, gender, conformation and fatness. The council regulation set down the five gender categories Y, B, S, C and H (later revised to A, B, C, D and E) and conformation (E, U, R, O, P with E best) on a five point scale with fat also on a scale of 1-5 (5 fattest). There is a conformation class 'S' for carcasses better than 'E' conformation. The use of conformation class 'S' is authorised in some member states, but it is not used in Ireland. In Ireland (Table 2.5) conformation class P is subdivided into three subdivisions represented by P^+, P and P^-, describing declining conformation. Fat class 4 in Ireland is also subdivided into low (4L) and high fat (4H).

However, since December 2009 slaughtering plants in Ireland have expanded the 5 point scale to a 15 point scale for carcass conformation and fatness. For carcass conformation E^+, E and E^- denotes animals of high conformation and P^+, P and P^- representing animals of poor conformation. Since the introduction of the 15 point scale for conformation and fatness animals receive a higher price per kilo carcass weight for each increase in conformation on the 15 point scale with a small deduction for over-fat animals.

There is no uniformity with regard to subdivisions of classes across Europe. France, Netherlands, Denmark, and Sweden subdivide each of the 5 conformation classes into three subclasses, whereas Italy, Spain, and Germany have no subdivisions. The UK and Finland are intermediate with the former subdividing U, O and P into two subclasses and the latter subdividing R, O and P into three. For fat classes, there is no uniformity in the subdivision with the Netherlands and Sweden again having a 15 point scale. France, Denmark, Italy, Spain and Germany have no subdivisions and the UK subdivides both fat classes 4 and 5 into two. In July 2004 mechanical grading of cattle replaced visual grading in Ireland with systems now operating in 24 abattoirs in 2011. Prior to then carcass classification was reliant on human visual judgement using trained classifiers. However, the main problem with visual scoring is that it is subjective, inconsistent and subject to influence (Allen, 2007). The history and origin of the ‘classification movement’ in Europe cannot be identified easily and with certainty. Several countries that later became EU members had developed, and were executing their own systems in the late 1960s/ early 1970s; there were schemes in operation in Germany, France, Ireland, Britain and by the late 1970s there was also Dutch and Danish systems in use (Fisher, 2007). Interestingly these schemes were all also based on the same characteristics: weight, age, gender, fatness and conformation.

2.3.2 Errors in obtaining carcass classification scores

Kempster and Harrington (1980) found that adjusting carcass conformation for percentage subcutaneous fat, improved the accuracy of prediction of meat yield. Similarly, Perry *et al.* (1993b) showed that subjective assessment of carcass muscle scores that were adjusted for subcutaneous fat were positively associated with yield of saleable meat in steers. Perry *et al.* (1993a) stated that "experienced assessors should be able to allocate a live muscle score whilst adjusting for fatness of the animal, although this may be more difficult with very fat animals". Kempster *et al.* (1982) stated "that the relationship between visual conformation assessments with carcass lean content depends on the effectiveness with which variation in fatness is eliminated since fatter carcasses tend to be given higher conformation scores". The latter author also cited Dumont (1977) who suggested that the assessment of carcass composition from conformation would be improved by introducing in the scoring method some additional criteria related to bone development. Kempster (1978) found that Angus crosses have higher meat to bone ratios than would be predicted from their conformation. Kempster and Cuthbertson (1977) reported that breed group differences existed, between groups in both conformation and carcass composition at constant carcass subcutaneous fat percentage.

2.3.3 Relationship of carcass classification with carcass composition and value

2.3.3.1 Carcass conformation score

Carcass conformation scores (shape due to muscle and all the fat layers) have been found in the past to have little value in predicting meat yield (Taylor *et al.* 1990).

However, these authors did explain modest amounts of variation (R^2 = 0.27 to 0.45) between shape score and carcass fat percentage. Boluslavek (2002) using 118 bulls also obtained poor correlation (0.052) between conformation score on a 15 point scale with meat yield percentage and a negative correlation (-0.44) with carcass fat percentage. Perry *et al.* (1993a) using carcass muscle score along with hot carcass weight explained 37.9% of total variation in meat yield and 25.4% of total variation in carcass fat percentage. Perry *et al.* (1993b**)** using carcass muscle score obtained correlations of 0.60, -0.29 and 0.65 with meat and fat percentage and carcass value respectively. Carcass conformation has been found to increase with increased carcass weight (Kempster *et al.,* 1988; More O' Ferrall and Keane, 1990). Ramsey *et al.* (1962) obtained a correlation of 0.70 between visual carcass grades and separable lean yield. Kempster and Harrington (1980) reported correlations between carcass conformation and carcass composition that were moderate to low, with conformation rarely accounting for more than 30% of the total variation. Kempster and Harrington (1980) also reported correlations between conformation and proportion of high-priced cuts in the carcass of 0.32 and 0.15, respectively, they concluded that conformation score provides little information about the proportion of total lean which occurs in the higher-priced joints. Taylor *et al.* (1990) cited studies (Butler *et al*., 1957, Branaman *et al.,* 1962 and Harrington et al., 1971) which showed that carcass conformation had little or no influence on percentage of high-priced cuts in the carcass, whilst others (Martin *et al.,* 1966; Colomer-Rocher *et al.,* 1980) have reported that carcasses with better conformation have higher yields and greater muscle content. Jones *et al.* (1989) using a muscle thickness score on the cold carcass explained 0.20 and 0.24 of total variation in meat and fat percentage, respectively.

2.3.3.2 Carcass fat score

Boluslavek (2002) using carcass fat score on a scale of 1 to 15 obtained correlations of -0.71 and 0.87 with meat and fat percentage, respectively. Ramsey *et al*. (1962) found that fat thickness was significantly negatively related to meat yield, which was in line with similar results obtained by Park *et al*. (2002) using adjusted fat thickness measured on the carcass. Jones *et al*. (1989) found an overall visual score for fat cover on the cold carcass explained 0.42 of the total variation in lean yield percentage and 0.52 of total variation in carcass fat percentage. Cannell *et al.* (2002) obtained strong negative correlations using a computer vision system (csv) grade for fat grade with percentage wholesale cuts.

2.3.4 Beef yield grades

In the USA, as outlined by Hale *et al.* (1998), beef carcasses are graded using the USDA grading system (beef yield and quality grades) which has emphasis on both meat eating quality and carcass quality. Yield grades (YG) estimate the amount of boneless, closely trimmed retail cuts from the high-value parts of the carcass-the round, loin, rib, and chuck. However, they also show differences in the total yield of retail cuts. A YG 1 carcass would be expected to have the highest and YG 5 carcass would have the lowest percentage of boneless, closely trimmed retail cuts, or the lowest cutability. The USDA Yield Grades are rated numerically and are 1, 2, 3, 4, and 5. Yield Grade 1 denotes the highest yielding carcass and Yield Grade 5, the lowest.

Meat graders assign a yield grade to a carcass by evaluating:

1. The amount of external fat;
2. The hot carcass weight;

3. The amount of kidney, pelvic, and heart fat and
4. The area of the rib-eye muscle.

The following descriptions will aid the readers understanding of the differences between carcasses from the five yield grades:

Yield Grade 1

The carcass is covered with a thin layer of external fat over the loin and rib; there are slight deposits of fat in the flank, cod or udder, kidney, pelvic and heart regions. Usually, there is a very thin layer of fat over the outside of the round and over the chuck.

Yield Grade 2

The carcass is almost completely covered with external fat, but lean is very visible through the fat over the outside of the round, chuck, and neck. Usually, there is a slightly thin layer of fat over the inside round, loin, and rib, with a slightly thick layer of fat over the rump and sirloin.

Yield Grade 3

The carcass is usually completely covered with external fat; lean is plainly visible through the fat only on the lower part of the outside of the round and neck. Usually, there is a slightly thick layer of fat over the rump and sirloin. Also, there are usually slightly larger deposits of fat in the flank, cod or udder, kidney, pelvic and heart regions.

Yield Grade 4

The carcass is usually completely covered with external fat, except that muscle is visible in the shank, outside of the flank and plate regions. Usually, there is a moderately thick layer of external fat over the inside of the round, loin, and rib, along with a thick layer of fat over the rump and sirloin. There are usually large deposits of fat in the flank, cod or udder, kidney, pelvic and heart regions.

Yield Grade 5

> Generally, the carcass is covered with a thick layer of fat on all external surfaces. Extensive fat is found in the brisket, cod or udder, kidney, pelvic and heart regions.

Using the USDA beef grading system previous studies (Table 2.6) with beef yield grades, generally show negative correlations with meat and bone percentage and percent high-value cuts in the carcass, whereas correlations with fat percentage are generally positive. The negative relationship with meat yield is due to the scale effect with 1 denoting the best and 5 the poorest. It can also be noted that the USDA grading system places a lot of emphasis on the level of fat on the carcass and could be compared to the fat scoring system used in Ireland.

Table 2.5 Correlation between carcass grades (U.S.D.A standard) with carcass traits

Author	Type of animal	Description and Comments	Meat%	Fat%	Bone%	[1]HVC%	[2]K+C%
Cross *et al.* (1973)	Steers	Conformation score (USDA standards)	-0.25*	0.42*	-0.72**	-0.36**	
Herring *et al.* (1994a)	Steers	USDA yield grade	-0.61**	0.64**			
Herring *et al.* (1994a)	Steers	USDA quality grade	-0.51**	0.56**			
Shalkelford *et al.* (1995)	Steers	USDA yield grade	-0.80	0.81	-0.51		
Johnson *and Rogers* (1997)	Cows	Conformation score	0.01	0.43	-0.74		
May *et al.* (2000)	Steers and heifers	USDA yield grade (USDA standards)	-0.82***	0.85***			
Cannel *et al.* (2002)	Steer and heifers	USDA yield grade	-0.63	0.70	-0.32		
Cannel *et al.* (2002)	Steer and heifers	Computer vision system (grade fat)					NS

Yield grade 1=best conformation, 5= poorest conformation. Thus, showing a negative effect with meat yield and a positive effect with fat.

[1] High-value cuts in the carcass;

[2] Perinephric and retroperitoneal fat weight

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Chapter 3

Experiment 1 - The relationship of live animal muscular and skeletal scores, ultrasound measurements and carcass classification scores with carcass composition and value in steers

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Experiment 1 - The relationship of live animal muscular and skeletal scores, ultrasound measurements and carcass classification scores with carcass composition and value in steers

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3.1 Abstract

This study examined the relationship of muscular and skeletal scores and ultrasound measurements in the live animal, and carcass conformation and fat scores with carcass composition and value using 336 steers, slaughtered at 2 years of age. Live animal scores and measurements were recorded at 8 to 12 months of age and pre-slaughter. Following slaughter, each carcass was classified for conformation and fatness and the right side dissected into meat, fat and bone. Carcass conformation scores and fat scores were both measured on a continuous 15 point scale and ranged from 2.0 to 12.0 and from 2.8 to 13.3, respectively. Pre-slaughter muscular scores showed positive correlations ($P<0.001$) ranging from 0.31 to 0.86 with carcass meat proportion, proportion of high-value cuts in the carcass, conformation score and carcass value, significant negative correlations with carcass fat ($r = -0.13$) and bone ($r = -0.81$) proportions, and generally low non-significant relationships with the proportion of high-value cuts in meat and carcass fat score. Pre-slaughter ultrasound muscle depth and carcass conformation score showed similar correlations with carcass traits to those using the pre-slaughter muscular scoring procedure. Pre-slaughter ultrasound fat depth showed positive correlations ($P<0.001$) with carcass fat proportion ($r = 0.59$) and fat score ($r = 0.63$), and significant negative correlations (-0.23 to -0.50) with carcass meat and bone proportions, high-value cuts in the carcass and in meat, and carcass value. Pre-slaughter skeletal scores generally showed poor correlations ranging from -0.38 to 0.52 with the various carcass traits. Corresponding correlations (-0.26 to 0.44) involving records collected at 8 to 12 months of age were lower than those using pre-slaughter records. A one unit increase in carcass conformation score increased carcass meat proportion and value by 11.2 g/kg and 5.6 c/kg, respectively. Corresponding values for fat score were -8.2 g/kg and -5.1 c/kg. In conclusion, both pre-slaughter live animal scores/measurements and carcass classification scores, explained an appreciable amount of the total variation in carcass meat, fat and bone proportions and carcass value, and a moderate amount of the variation in proportion of high-value meat cuts in the carcass.

Keywords: Beef carcass composition, carcass classification, muscular scores, ultrasonic scanning

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3.2 Introduction

Fisher (2007) has pointed out that beef carcass classification plays an important role in Europe, as a marketing aid within and between countries and as a means of increasing the precision of price reporting for administrative purposes. The purpose of carcass classification is to categorise carcasses according to their conformation and fatness. In the EU, beef carcasses are classified according to the official beef carcass classification scheme (Commissions of the European Communities, 1982). For conformation, the classes EUROP are used with E denoting carcasses with the best conformation with an option of an S class for carcasses with extremely good muscular development, whereas fat cover is assessed on a 5 point scale (1-5), with 1 being the leanest (Allen, 2007). By attaching a pricing schedule to the various classes, producers are incentivised to supply the type of carcass required by the market (Allen, 2007). However, the usefulness of carcass classification information for conformation and fatness is dependent on their relationship to economically important traits such as meat yield, meat distribution in the carcass and ultimately carcass value (Drennan, 2006). Delfa *et al.* (2007) using 69 bull carcasses, found that hot carcass weight and EU carcass classification for conformation and fatness explained 97, 60 and 85% of muscle, fat and bone weight, respectively. Perry *et al.* (1993a) reported that carcass weight and carcass muscle score accounted for 38% of the total variation in meat yield with carcass muscle score accounting for nearly all of the variation. In contrast, other studies have shown poor relationships between carcass shape score or conformation score and meat yield (Kempster and Harrington, 1980; Taylor *et al.,* 1990). Few studies have, however, examined the relationship between carcass conformation and fat scores as measured under the EU beef carcass classification scheme with carcass traits and value.

Information from carcass classification, which is based on visual examination of carcasses and has been replaced by mechanical classification in Ireland, could play an important role in breed improvement programmes. Additionally, live animal scores/measurements could be used to further assist the breeding and production of animals that meet market requirements through identification or screening earlier in life provided that there is a good relationship between these live animal records and the carcass traits of interest. Previous studies (Perry *et al.*, 1993a; MacAodhain, 2004; Drennan *et al.*, 2008) have shown that live animal muscular scores were useful in predicting meat yield. Furthermore, Greiner *et al.* (2003) found that live animal ultrasound measurements of the *longissimus dorsi* were useful predictors of retail product. Live animal ultrasound measurements were shown to have a good relationship with carcass meat proportion (Faulkner *et al.*, 1990; Tait *et al.*, 2005).

The objectives of this study were to determine the relationship of (1) live animal muscular and skeletal scores, and ultrasonically scanned muscle and fat depth measurements of the *longissimus dorsi* and, (2) carcass conformation and fat scores with carcass composition and value.

3.3 Materials and Methods

3.3.1 Animals and management

A total of 336 steers slaughtered over a two year period in eight different batches were used. The animals consisted of Holstein-Friesian, Aberdeen Angus × Holstein-Friesian and 0.5 to 1.0 late-maturing continental breed crosses. The finishing diet varied from grass silage only, grass or maize silage plus supplementary concentrates to concentrates offered *ad-libitum* plus 1 kg of roughage dry matter per head daily. All animals were slaughtered at the end of a winter housing period when approximately two years old.

3.3.2 Muscular and skeletal scores/measurements

At 8 to 12 months of age and pre-slaughter, animals were linear scored by 2 assessors (A and B) from the Irish Cattle Breeding Federation (ICBF). This involved assigning muscular scores on a scale of 1 (poor) to 15 (excellent), at six locations (width at withers, width behind withers, loin development, development of hind-quarter, width of hind-quarter and development of the inner thigh) and skeletal scores (scale of 1-10) at three locations (length of back, pelvic length and height at withers) (ICBF, 2002). The six muscular scores were then averaged to give one score per animal for each assessor. Skeletal scores were also averaged in a similar manner. Allowances were made for subcutaneous fat by the assessors when assigning muscular scores. Simultaneously, scores were also assigned using the Signet scoring system (Allen, 1990) by two staff members (assessors C and D) from the research centre. The Signet muscular score was also based on a scale of 1 to 15 extending to 18 for double-muscled animals. The three scoring locations were roundness of hind-quarter, width of hind-quarter and depth and width of loin, which were also averaged to give a mean score per animal for each assessor. All scoring was carried out by visual assessment except for height at withers, which was recorded using a measuring pole. Of the 336 animals that were boned out under commercial abattoir conditions, the assessors A, B, C and D recorded pre-slaughter live animal scores on 336, 246, 336 and 280 steers, respectively. Corresponding numbers scored at 8 to 12 months of age were 85, 67, 67, and 67.

3.3.3 Ultrasound measurements

Scanned ultrasound measurements were recorded on the right side of a proportion of the animals at 8 to 12 months of age (n = 85) and pre-slaughter (n = 146) were obtained by two technicians. A Dynamic Imaging Real Time Scanner (model – *Concept MLV,* with 3.5 MHz head) was used and eye muscle depth was measured at the 3rd lumbar vertebra, and fat depth at both the 3rd lumbar vertebra and 13th thoracic rib. Hair was clipped from each area pre-scanning and vegetable oil was applied to obtain adequate acoustic contact. Cattle were restrained at the head and physical palpation was used to accurately ascertain the scanning sites. The probe was placed perpendicular to the rib eye length (*longissimus dorsi* muscle) at the 3rd lumbar vertebra and 13th thoracic rib until bones appeared on the monitor, and when a satisfactory image was achieved it was frozen on the monitor. Eye muscle depth and fat depth were then measured using an internal calliper built into the software to give instant results. Fat depth was measured at three points at the 3rd lumbar vertebra across the width (0.4, 0.6 and 0.8) of the muscle and at four points (0.2, 0.4, 0.6 and 0.8) at the 13th thoracic vertebra. Fat depth was calculated by taking the mean of the average values for the 3rd lumbar and 13th thoracic rib. Muscle depth was obtained at the deepest point (0.25) of the muscle (from the bottom of the backfat to the top of the bone) at the 3rd lumbar vertebra.

3.3.4 Carcass Measurements

Carcass conformation and fat scores were obtained using the mechanical grading system (Allen, 2007) on a 15 point scale rather than a 5 point scale (Commission of the European Communities, 1982). Hot carcass weight was recorded and cold carcass weight was taken as 0.98 of hot carcass weight. Weight of perinephric and retroperitoneal fat was also recorded at slaughter. Following a period of 24 hours at 4°C, the right side of each carcass was quartered at the 5th rib into an 8-rib pistola and the remaining fore-quarter. After recording the weight, the pistola was dissected into thirteen cuts (leg, heel, silverside, topside, knuckle, rump, tail of rump, cap of rump, fillet, strip loin, cube roll, cap of rib and eye of round) from which all visible fat and bone (where applicable) was removed. The weight of each individual meat cut and total fat from the pistola was recorded as was bone weight following removal of all adhering tissues. Lean trim was weighed separately and added to the meat cuts to give total pistola meat yield. A similar procedure was carried out with the fore-quarter, which was dissected into eleven cuts (front shin, neck, brisket, chuck, flat ribs (1-5), plate, leg of mutton cut, bladesteak, braising muscle, chuck tender and clod). Pistola and fore-quarter meat, fat and bone weights were combined to give the weight of each component in the half carcass. High-value cuts in the carcass were defined as the meat in the cube roll, striploin and fillet. Carcass value was estimated as the sum of the commercial value on each meat cut with a small deduction for bone expressed as a proportion of half carcass weight.

3.3.5 Statistical analysis

Data were analysed using Proc REG and CORR of SAS (2007). Simple correlation coefficients of live animal scores/measurements and carcass conformation and fat scores with the various carcass traits were carried out using Pearson's correlations. The relationships between muscular scores, ultrasound muscle and fat depths, and conformation and fat scores and the dependant variables (meat, fat and bone proportions, proportion of high-value cuts in the carcass and meat, and carcass value) were determined using multiple regression. The contribution made to the estimation of each dependent variable by each independent variable was determined by comparison of the coefficient of determination (R^2) and the residual standard deviation (r.s.d.).

3.4 Results

The mean, range and standard deviations for live and carcass traits are summarised in Table 1. At slaughter, animals had a mean age of 745 days, live weight of 640 kg and cold carcass weight of 342 kg. Carcass conformation and fat scores ranged from 2.0 to 12.0 and from 2.8 to 13.3, respectively. Carcass meat, fat and bone proportions were 686, 119 and 195 g/kg, respectively. High-value cuts in the carcass and in meat were 70 and 103 g/kg, respectively.

3.4.1 Assessors

Correlations obtained between the four assessors (two using the ICBF system and two using the Signet system) for muscular scores at 8 to 12 months of age ranged from 0.74 to 0.87 and pre-slaughter ranged from 0.71 to 0.86 ($P<0.001$). Repeatability values using simple correlations obtained from scanning 84 animals on two consecutive days pre-slaughter were 0.92 for muscle depth and 0.84 for fat depth.

3.4.2 Correlations using live animal muscular scores

Correlations using live animal scores with the various carcass traits are shown in Tables 2 and 3. Based on the figures obtained by the ICBF Assessor A, positive correlations were obtained (Table 3) using the average muscular score pre-slaughter with carcass meat proportion ($r = 0.60$), value ($r = 0.55$), carcass conformation score ($r = 0.86$) and the proportion of high–value cuts in the carcass ($r = 0.31$). The corresponding correlations were negative with carcass bone ($r = -0.81$) and fat proportion ($r = -0.13$), whereas those with the proportion of high-value cuts in the meat, perinephric and retroperitoneal fat and carcass fat score were low, and generally non-significant ranging from -0.04 to 0.14. Corresponding correlations between live animal muscular scores at 8 to 12 months of age (Table 2) with the various carcass traits generally showed lower values and similar trends when compared to those using pre-slaughter figures. Correlations using muscular scores by assessors B, C and D were similar to those obtained by Assessor A. Correlations between ICBF hind-quarter development alone and the various carcass traits resulted in similar correlations to the ICBF average of all 6 individual locations.

3.4.3 Correlations using skeletal scores

Correlation coefficients (Table 4) using skeletal scores (3 locations combined) recorded pre-slaughter by Assessor A showed positive correlations with carcass weight (r = 0.40), carcass fat proportion (r = 0.30), carcass bone proportion (r = 0.13), perinephric and retroperitoneal fat (r = 0.52) and carcass fat score (r = 0.31), whereas negative correlations (P<0.01), ranging between -0.18 and -0.38, were obtained with carcass meat proportion, proportion of high-value cuts in the carcass and in meat, carcass value and carcass conformation score. Correlations between individual skeletal scores pre-slaughter generally had similar values to the average of the combined ICBF skeletal scores. Skeletal scores by Assessor B had lower correlations with the various carcass traits than those obtained by Assessor A. Correlations between skeletal scores taken at 8 to 12 months of age with the various carcass traits for both assessors A and B were poor, and generally not significant.

3.4.4 Correlations using ultrasonically scanned measurements

Positive correlations (P<0.001) were obtained (Table 5) between scanned muscle depth pre-slaughter and carcass weight (r = 0.72), carcass meat proportion (r = 0.52), proportion of high-value cuts in the carcass (r = 0.31), carcass conformation score (r = 0.80) and carcass value (r = 0.47), whereas a high negative correlation (P<0.001) was obtained with carcass bone proportion (r = -0.75). Low correlations, ranging from -0.08 to 0.21, were obtained between scanned muscle depth taken pre-slaughter and carcass fat proportion, proportion of high-value cuts in the meat, perinephric and retroperitoneal fat and carcass fat score. Corresponding correlations for scanned muscle depth at 8 to 12 months of age showed similar trends but were generally lower. Significant positive correlations were obtained between scanned fat depth taken pre-slaughter and carcass weight (r = 0.58), carcass fat proportion (r = 0.59), perinephric and retroperitoneal fat (r = 0.45), carcass conformation (r = 0.33) and fat score (r = 0.63), whereas significant negative correlations were obtained with carcass meat (r = -0.23) and bone (r = -0.50) proportions, proportion of high-value cuts in the carcass (r = -0.34) and in meat (r = -0.27), and carcass value (r = -0.32). Correlation coefficients between scanned fat depths at 8 to 12 months of age were in the same direction to those obtained pre-slaughter with carcass meat and fat proportions, proportion of high-value cuts in carcass and in meat, and carcass value. Corresponding correlations with carcass weight, perinephric and retroperitoneal fat, carcass bone proportion and carcass conformation score were not significant.

3.4.5 Correlations using carcass conformation and fat scores

Positive correlations (P<0.001), ranging between 0.60 and 0.71, were obtained (Table 6) for carcass conformation score with carcass weight, carcass meat proportion and carcass value, and a lower value obtained for the proportion of high-value cuts in the carcass (r = 0.29), whereas significant negative correlations were obtained with carcass bone (r = -0.84) and fat (r = -0.19) proportions and the proportion of high-value cuts in the meat (r = -0.11). Correlations of conformation score with perinephric and retroperitoneal fat and fat score were not significant. Positive correlations ($P<0.001$) were obtained for carcass fat score with carcass weight (r = 0.42), carcass fat proportion (r = 0.69), proportion of high-value cuts in the meat (r = 0.24) and perinephric and retroperitoneal fat (r = 0.47), whereas negative correlations ($P<0.001$), ranging between -0.31 and -0.43, were obtained with carcass meat and bone proportions, proportion of high-value cuts in the carcass and carcass value.

3.4.6 Regressions using live animal scores and measurements

Regression equations using live animal muscular scores (based on the figures recorded by ICBF Assessor A) and ultrasound muscle and fat depth measurements alone to predict carcass meat, fat and bone proportions are shown in Table 7. Both muscular score (average of the six locations) and scanned muscle and fat depth alone taken pre-slaughter explained 0.36 and 0.51, respectively, of the total variation in carcass meat proportion. Muscular score alone was a poor predictor of carcass fat proportion (R^2 = 0.02), whereas scanned muscle and fat depth alone explained 0.48 of the total variation in fat proportion. Muscular score alone and scanned muscle and fat depth measurements explained 0.66 and 0.59, respectively, of total variation in carcass bone proportion. The corresponding R^2 values involving muscular score alone and scanned measurements at 8 to 12 months of age were lower but generally followed a similar trend to values obtained using those taken pre-slaughter.

Multiple regression equations using the combined live animal muscular scores and ultrasound muscle and fat depth measurements to predict the various carcass traits and carcass value are shown in Table 8. Using pre-slaughter measurements, the combined muscular and scanned measurements explained between 0.53 and 0.68 of the total variation in carcass meat and bone proportions and carcass value with a lower proportion of total variation explained for carcass fat proportion (R^2 = 0.48) the proportion of high-value cuts in the carcass (R^2 = 0.37) and in meat (R^2 = 0.10), and perinephric and retroperitoneal fat (R^2 = 0.20). Again, corresponding R^2 using muscular score and scanned measurements taken at 8 to 12 months of age were considerably lower than those obtained using pre-slaughter figures.

3.4.7 Regressions using carcass conformation and fat scores

Regression analysis (Table 9) showed that carcass conformation and fat scores explained between 0.60 and 0.76 of the total variation in carcass meat and bone proportions and carcass value, whereas the variation explained with carcass fat proportion (R^2 = 0.54), proportion of high-value cuts in the carcass (R^2 = 0.28) and perinephric and retroperitoneal fat (R^2 = 0.23) was lower. Little variation was explained (R^2 = 0.06) in using carcass conformation and fat scores to predict the proportion of high-value cuts in meat.

3.5 Discussion

3.5.1 Assessors

Perry *et al.* (1993a) using two assessors for live animal muscle scoring found correlations ranging from 0.90 to 0.92 between the assessors, which was greater than the values of 0.71 to 0.87 obtained in the present study. One reason for the lower correlations in the present study was the fact that eight separate batches of animals were used over a 2-year period, which is likely to result in lower correlations than when all records are taken at the same time. Perkins *et al.* (1992) reported repeatabilities of ultrasonic estimates of carcass fat thickness and *longissimus* muscle area of 0.91 and 0.81, respectively, when repeated over two days. The corresponding values in the present study were 0.84 and 0.92 indicating that measurement of muscle size was better in the present study, whereas the lower repeatability for fat thickness may have been due to low subcutaneous fat depths making accurate measurement more difficult.

3.5.2 Correlations using live animal muscular scores

The positive correlations (r = ~0.60) obtained between live animal muscular scores taken pre-slaughter with carcass meat proportion and carcass value are in general agreement with the results of Perry *et al.* (1993a) and Drennan *et al.* (2008). This shows the potential of live animal muscular scores in predicting the economic value of the carcass. The low negative relationship (r = ~ -0.15) of live animal muscular scores with carcass fat proportion, fat score and the general lack of a relationship with perinephric and retroperitoneal fat agrees with Perry *et al.* (1993b) who found that most of the effect was attributed to the amount of subcutaneous fat and not intramuscular fat. Negative correlations between live animal muscular scores taken pre-slaughter and carcass bone proportion were obtained by MacAodhain (2004) (-0.58 to -0.65) and Drennan *et al.* (2008) (r = ~ -0.60) both of which were poorer than those (r = ~ -0.80) found in the present study. Similarly, Colomer-Rocher *et al.* (1980) found that animals in convex hind-quarter (heavy muscled) classes had more muscle and a higher muscle-to-bone ratio than those in concave classes. The positive relationship between pre-slaughter muscular scores and the proportion of high-value cuts in the carcass (r = 0.31) was higher than that obtained by Herring *et al.* (1994) using eight cuts from the carcass compared with three cuts in the present study. The lack of a relationship between live animal muscular scores and the proportion of high-value cuts in meat indicates that, when bone and fat are excluded, there is no effect of muscular score on the distribution of meat in the carcass. The significant positive relationship (r = 0.79 to 0.88) between muscular scores recorded pre-slaughter and carcass conformation score can be expected as both are indicators of muscularity. This concurs with the findings of Perry *et al.* (1993a, 1993b). Drennan *et al.* (2008) using bulls and heifers with a smaller range in carcass conformation score found a mean correlation of 0.70 between muscular score and conformation again, demonstrating a good relationship between these traits. Correlations with live animal muscular scores taken at 8 to 12 months of age were generally lower than those with records taken pre-slaughter, which is similar to the findings of Drennan *et al.* (2008). Correlations using one location of the ICBF scoring system namely, roundness of hind-quarter, were similar to the average of the entire six locations in the present study. The Signet scoring system (using three scoring locations) also showed similar correlations to the average ICBF muscular score suggesting that a more simplified muscular scoring system with emphasis on hind-quarter development could be used.

3.5.3 Correlations using skeletal scores

There was generally a non-significant relationship between the live animal skeletal scores at 8 to 12 months of age and the various carcass traits, which agrees with Hassen *et al.* (1999). Skeletal scores taken pre-slaughter showed a positive relationship (r = 0.22 to 0.52) with the three indicators of fat (carcass fat proportion, carcass fat score and perinephric and retroperitoneal fat) and a negative relationship (r = -0.18 to -0.38) with carcass meat proportion, proportion of high-value cuts in the carcass, carcass conformation score and carcass value. Other studies (Bailey *et al.,* 1986; Herring *et al.,* 1994) have also shown low negative correlations between various skeletal measurements and percentage carcass lean or retail product.

3.5.4 Correlations using scanned muscle and fat depth

Depth of the *Longissimus dorsi* muscle at the 3rd lumbar vertebra as measured in this study, was shown by Doorley (2001) and Bergen *et al.* (2003) to be as valuable at predicting carcass composition as muscle area measurements. The positive correlation (r = 0.52) between pre-slaughter scanned muscle depth and carcass meat proportion is within the range (0.30 to 0.84) found in some studies (Doorley, 2001; Tait *et al.*, 2005), but higher than other (r = 0.07 to 0.17) results (Hamlin *et al.*, 1995; May *et al.,* 2000; Greiner *et al.,* 2003). The generally non-significant relationship between scanned muscle depth and the three indicators of carcass fat was as expected, and the high negative relationship with carcass bone proportion (r = -0.75) was in agreement with Bailey *et al.* (1986). The positive relationship (r = 0.31) obtained between scanned muscle depth recorded pre-slaughter and the proportion of high-value cuts in the carcass was similar to the findings of Tait *et al.* (2005). The positive correlation (r = 0.80) between scanned muscle depth pre-slaughter and carcass conformation score followed the same trend but was somewhat greater than that (r = ~0.50) found in previous studies (Bailey *et al.,* 1986; Doorley, 2001; MacAodhain, 2004). Correlations of pre-slaughter scanned fat depth were negative with carcass meat (r = -0.23) and bone (r = -0.34) proportions and positive with fat proportion (r = 0.59) and fat score (r = 0.63), which is in general agreement with previous findings (Doorley, 2001; MacAodhain, 2004). Correlations between carcass traits and scanned muscle depth obtained pre-slaughter were greater than those obtained at 8 to 12 months of age. Similarly, Hamlin *et al.* (1995) found that with animals scanned at intervals between weaning and slaughter the accuracy with which carcass traits were predicted from muscle area and fat depth increased the closer the measurements were obtained to slaughter. Wolcott *et al.* (2001) also found that the power of live animal measurements to predict retail beef yield percentage decreased as the time between scanning and slaughter increased. Tait *et al.* (2005) reported that ultrasound measures in the live animal were potentially more accurate predictors of retail product than measures collected on the carcass, while Herring *et al.* (1994) found that live animal and carcass equations were equally effective in ranking animals for retail product yield.

3.5.5 Correlations using carcass conformation and fat scores

The strong relationship between carcass conformation score and carcass meat proportion (r = 0.66) is as expected because conformation score measures the thickness of muscle and fat in relation to the size of the skeleton (De Boer *et al.*, 1974). Bjelka *et al.* (2002) also reported a higher proportion of meat in class U than class R bull carcasses. Similar to the present study, Perry *et al.* (1993a) found a correlation of 0.60 between carcass muscle score and saleable meat proportion, whereas in contrast, the correlation found by Bohuslávek (2002) was much lower (r = 0.05). However, the latter author found significant correlations between conformation and the proportion of saleable meat when animals of similar fatness were analysed. In the present study, the relationship between carcass conformation score and carcass value followed a similar trend to that of carcass meat proportion. This is because carcass value was mainly based on the value of individual meat cuts and not overall carcass weight, which includes carcass fat and bone, and can influence price. The significant correlation (r =

0.29) between conformation score and the proportion of high-value cuts in the carcass is consistent with the findings of Colomer-Rocher *et al.* (1980). However, in contrast, Bjelka *et al.* (2002) found no relationship between these traits. The high negative relationship between carcass conformation score and carcass bone proportion is in agreement with Colomer-Rocher *et al.* (1980) who reported that in steers at the same carcass weight and fatness, the muscle content of the hind-quarter increased linearly by 0.56 kg and bone decreased linearly by 0.13 kg per unit increase in conformation class. The low, generally negative, relationship of carcass conformation score with carcass fat proportion and fat score are similar to the correlations obtained by Bohuslávek (2002). Similarly, Bjelka *et al.* (2002) reported that the lowest content of separable fat in bulls was in conformation class E and it gradually increased through to the poorer classes. The significant negative correlation of carcass fat score with carcass meat proportion is similar to previous findings (May *et al.*, 2000; Greiner *et al.*, 2003). In accordance with Drennan *et al.* (2008), significant positive correlations were obtained between carcass fat score with carcass fat proportion and perinephric and retroperitoneal fat.

3.5.6 Regression of live animal scores and measurements to predict carcass composition and value

Pre-slaughter scanned muscle and fat depth measurements explained more variation in carcass meat proportion than pre-slaughter muscle score alone (R^2 = 0.51 v. 0.36). Ultrasound measurements explained a similar amount of total variation in carcass meat proportion as obtained in previous studies (Johnson *et al.*, 1992; Wolcott *et al.*, 2001). The R^2 for pre-slaughter muscular score alone was similar to the value of 0.37 for muscle score found by Perry *et al.* (1993b). When combined, scanned muscle and fat depth measurement and live animal muscular score explained 0.53 of the total variation in carcass meat proportion, which was only marginally greater than that obtained by scanned measurements alone. This implies that both muscular score and muscle depth were equally good indicators of muscularity as evidenced by their high correlations (~ > 0.8) with carcass conformation score. Perry *et al.* (1993a) explained a higher proportion of variation ($R^2 = 0.62$) in carcass meat proportion than the present study, using live weight, scanned P8 fat and live muscle score combined. The 0.48 of the total variation in carcass fat proportion explained by scanned measurements was less than the 0.85 found by Faulkner *et al.* (1990) using live-weight and ultrasound fat measurements in cows. In the present study, the combined pre-slaughter ultrasound measurements and muscular score explained 0.68 of the total variation in carcass bone proportion, which was only marginally greater than that explained by the individual records. This value is lower than the value of 0.79 found by Faulkner *et al.* (1990) using live weight and ultrasound fat measurements. When recorded pre-slaughter, both muscular score and scanned muscle and fat depth measurements combined accounted for 0.58 of the total variation in carcass value, which is lower than the value of 0.85 obtained by Perry *et al.* (1993a) using live weight, P8 fat and live muscle score. Live animal scores and measurements combined explained a moderate amount of total variation in the proportion of high-value cuts in the carcass ($R^2 = 0.37$) and a low amount in the proportion of high-value cuts in meat indicating that higher bone proportion of animals of low muscularity is the main reason for the positive relationship between these traits in the carcass. When recorded at weaning, the muscular score and scanned measurements combined explained only 0.23 and 0.30 of total variation in meat proportion and in carcass value, respectively, again showing that the relationship is better the closer to slaughter that the estimates are recorded.

3.5.7 *Regression of carcass composition and value on carcass conformation and fat scores*

When combined in a regression model, carcass conformation and fat scores accounted for 0.63 of the total variation in carcass meat proportion, which is greater than the values of 0.45 found by Jones *et al.* (1989) using fat and muscle thickness score, and 0.52 reported by Perry *et al.* (1993a) and 0.47 by Perry *et al.* (1993b), using carcass muscle score, fat depth and carcass weight. Using a commercial dissection procedure, Drennan *et al.* (2008) found that a one unit (scale 1-15) increase in carcass conformation score increased carcass meat proportion by 8.9 and 8.1 g/kg in bulls and heifers, respectively, which is in close agreement with the figures of 11.2 g/kg obtained in the present study. Similarly, in agreement with the current value of 8.2 g/kg, Drennan *et al.* (2008) found that a one unit increase in carcass fat score decreased carcass meat proportion of bulls and heifers by 11.9 and 9.7 g/kg, respectively. In the present study, carcass classification scores explained 0.54 of the total variation in carcass fat proportion, which was lower than the 0.77 found by Taylor *et al.* (1990) using a fat thickness measurement. The R^2 of 0.76 obtained with carcass bone proportion is considerably greater than the values of 0.34 and 0.30 for bulls and heifers, respectively, in the study by Drennan *et al.* (2008), which did not have a wide range of breed types. In the current study, carcass conformation and fat scores explained low amounts of the total variation (R^2 ranged from 0.06 to 0.28) in high-value cuts in the carcass and in meat and perinephric and retroperitoneal fat.

3.6 Conclusion

It can be concluded that pre-slaughter live animal scores and measurements were good predictors of carcass meat proportion and carcass value (R^2 = 0.53 to 0.58), and are therefore potentially useful in breed improvement programmes, particularly with breeding animals, where carcass data would not be available. However, the poorer relationships using data obtained at 8 to 12 months of age rather than pre-slaughter indicates the need to have animals at an advanced stage of finish when assessment is carried out. Muscular scoring systems can be simplified to three locations with emphasis on the hind-quarter and loin area. The EU beef carcass classification for conformation and fatness carried out mechanically was shown to be a good predictor of carcass meat proportion and value and thus, in addition to placing commercial value on carcasses would be useful in progeny testing programmes.

3.7 Implications

In breed improvement programmes repeatable live animal scores and measurements can be used in the identification of animals with superior genetic merit for carcass composition and value. This study also showed the potential of EU carcass conformation and fat scores to predict carcass meat proportion and thus, facilitate the operation of a payment system based on meat yield, which would reward farmers more adequately.

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Table 3.1: Mean, standard deviation and range for live animal and carcass scores and measurements of steers

	Mean	Standard Deviation	Minimum	Maximum
At 8-12 months of age				
Muscular scores (scale 1 to 15)				
Width between withers (ICBF assessor A)	6.5	2.00	2.0	10.0
Width behind withers (ICBF assessor A)	5.8	1.95	1.0	9.0
Loin development (ICBF assessor A)	6.5	1.57	2.0	9.0
Hindquarter development (ICBF assessor A)	6.8	1.88	3.0	10.0
Hindquarter width (ICBF assessor A)	6.8	1.46	4.0	10.0
Inner-thigh development (ICBF assessor A)	6.4	1.75	2.0	10.0
ICBF average muscular score (assessor A)	6.5	1.69	2.5	9.5
ICBF muscular score at 5 locations (assessor A)	6.5	1.69	2.6	9.4
ICBF muscular score at 2 locations (assessor A)	6.8	1.62	3.5	10.0
ICBF average muscular score (assessor B)	5.8	1.52	2.5	9.3
Signet muscular score (assessor C)	6.2	1.54	3.0	9.3
Signet muscular score (assessor D)	6.1	2.23	1.0	9.7
Scanned eye muscle depth (mm)	55.0	7.34	39.0	75.2
Scanned fat depth (mm)	0.95	0.269	0.25	1.45
Pre-slaughter				
Muscular scores (scale 1 to 15)				
Width between withers (ICBF assessor A)	7.8	2.29	1.0	12.0
Width behind withers (ICBF assessor A)	7.1	2.25	1.0	11.0
Loin development (ICBF assessor A)	8.1	1.90	1.0	11.0
Hindquarter development (ICBF assessor A)	7.6	2.15	2.0	12.0
Hindquarter width (ICBF assessor A)	8.3	1.47	3.0	12.0
Inner-thigh development (ICBF assessor A)	7.4	1.90	1.0	10.0
ICBF average muscular score (assessor A)	7.7	1.87	1.83	10.8
ICBF muscular score at 5 locations (assessor A)	7.8	1.89	1.8	11.0
ICBF muscular score at 2 locations (assessor A)	7.9	1.76	2.5	11.5
ICBF average muscular score (ICBF assessor B)	7.0	2.03	2.3	13.2
Signet muscular score (assessor C)	6.2	2.33	1.0	11.0
Signet muscular score (assessor D)	5.6	2.30	1.0	11.0
Scanned eye muscle depth (mm)	71.5	9.08	52.6	91.2
Scanned fat depth (mm)	3.5	1.78	0.3	9.1
Pre-slaughter weight (kg)	640	82.6	435	884
Post-slaughter				
Cold carcass weight (kg)	342	53.6	234	501
Kill-out (g/kg)	533	29.2	470	621
Slaughter age (kg)	745	55	437	915
Perinephric plus retroperitioneal fat (kg)	9.2	3.22	2.9	20.6
[1]Conformation score (scale 1 to 15)	7.1	2.27	2.0	12.0
[2]Fat score (scale 1 to 15)	8.5	1.92	2.8	13.3
Meat (g/kg)	686	36.0	593	785
Fat (g/kg)	119	29.1	54	211
Bone (g/kg)	195	21.8	150	262
High-value cuts in carcass (g/kg)	70	6.4	52	87
High-value cuts in meat (g/kg)	103	7.3	77	112
Carcass value (c/kg)	293	19.8	244	347

[1]15 = best conformation; [2]15 = fattest.

Table 3.2: Correlations of live animal muscular scores at 8 to 12 months of age with carcass weight, carcass meat, fat and bone proportions, proportion of high-value cuts in the carcass and meat, perinephic and retroperitoneal fat, carcass conformation and fat scores and carcass value

		Proportion in carcass						Carcass		
	Carcass weight	Meat	Fat	Bone	[1]HVC	[1]HVC in Meat	Perinephic + Retroperitoneal fat	Conformation Score	Fat Score	Value
Width between withers (A)	0.53***	0.33**	-0.11	-0.60***	0.29**	0.20	0.29**	0.61***	0.10	0.36***
Width behind withers (A)	0.48***	0.30**	-0.10	-0.58***	0.25**	0.16	0.25*	0.59***	0.14	0.34**
Loin development (A)	0.56***	0.27*	-0.07	-0.55***	0.26*	0.19	0.25*	0.54***	0.10	0.32**
Hind-quarter development (A)	0.56***	0.32**	-0.12	-0.58***	0.29**	0.19	0.29**	0.59***	0.13	0.35**
Hind-quarter width (A)	0.60***	0.22**	-0.03	-0.53***	0.11	0.03	0.11	0.44***	0.19	0.22*
Inner-thigh development (A)	0.54***	0.27*	-0.07	-0.55***	0.21	0.13	0.21	0.55***	0.14	0.30**
ICBF average muscular score (A)	0.57***	0.30**	-0.09	-0.60***	0.25*	0.16	0.25*	0.59***	0.14	0.33**
ICBF muscular score -5 locations (A)	0.57***	0.31**	-0.09	-0.60***	0.26*	0.17	0.26*	0.59***	0.13	0.34**
ICBF muscular score - 2 locations (A)	0.59***	0.29**	-0.09	-0.58***	0.22*	0.13	0.22*	0.54***	0.16	0.30**
ICBF average muscular score (B)	0.43***	0.45***	-0.25*	-0.62***	0.39**	0.22	-0.19	0.62***	0.05	0.47***
Signet muscular score (C)	0.49***	0.46***	-0.23	-0.68***	0.40***	0.23	-0.09	0.61***	-0.003	0.50***
Signet muscular score (D)	0.66***	0.50***	-0.27*	-0.70***	0.47***	0.29*	-0.21	0.77***	0.009	0.54***

[1] High-value cuts. Assessors A and B: ICBF linear muscular scoring system. Assessors C and D: Signet muscular scoring system.

*P < 0.05, **P < 0.01, ***P < 0.001

Table 3.3: Correlations of live animal muscular scores pre-slaughter with carcass weight, killing-out rate, carcass meat, fat and bone proportions, proportion of high-value cuts in the carcass and meat, perinephic and retroperitoneal fat, carcass conformation and fat scores and carcass value

		Proportion in carcass						Carcass		
	Carcass weight	Meat	Fat	Bone	[1]HVC	[1]HVC in Meat	Perinephic + Retroperitoneal fat	Conformation Score	Fat Score	Value
Width between withers (A)	0.57***	0.57***	-0.14*	-0.76***	0.32***	-0.02	0.01	0.80***	0.14*	0.53***
Width behind withers (A)	0.58***	0.58***	-0.11*	-0.82***	0.30***	-0.05	0.01	0.84***	0.17**	0.53***
Loin development (A)	0.59***	0.49***	-0.03	-0.77***	0.20***	-0.11	0.08	0.79***	0.18***	0.43***
Hind-quarter development (A)	0.51***	0.64***	-0.23***	-0.75***	0.37***	-0.01	-0.11	0.82***	-0.03	0.60***
Hind-quarter width (A)	0.63***	0.52***	-0.07	-0.77***	0.22***	-0.11*	0.04	0.81***	0.14**	0.47***
Inner-thigh development (A)	0.48***	0.55***	-0.14**	-0.72***	0.32***	-0.01	-0.06	0.76***	0.11	0.52***
Average muscular score (A)	0.59***	0.60***	-0.13*	-0.81***	0.31***	-0.04	0.007	0.86***	0.14*	0.55***
ICBF muscular score - 5 locations (A)	0.61***	0.60***	-0.13*	-0.82***	0.30***	-0.05	0.003	0.86***	0.14*	0.55***
ICBF muscular score - 2 locations (A)	0.58***	0.61***	-0.17**	-0.82***	0.32***	-0.04	-0.05	0.85***	0.08	0.57***
ICBF average muscular score (B)	0.58***	0.56***	-0.15*	-0.78***	0.44***	0.14*	0.14*	0.79***	0.20**	0.56***
Signet muscular score (C)	0.58***	0.63***	-0.17**	-0.81***	0.30***	-0.08	-0.09	0.88***	0.08	0.59***
Signet muscular score (D)	0.46***	0.62***	-0.24***	-0.70***	0.37***	-0.02	0.12*	0.79***	0.02	0.60***

[1] High-value cuts. Assessors A and B: ICBF linear muscular scoring system. Assessors C and D: Signet muscular scoring system.

*P < 0.05, **P < 0.01, ***P < 0.001

Table 3.4: Correlation of live animal skeletal scores with carcass weight, carcass meat, fat and bone proportions, proportion of high-value cuts in the carcass and meat, perinephric and retropertitoneal fat, carcass conformation and fat scores and carcass value

		Proportion in carcass						Carcass		
At 8-12 months of age	Carcass weight	Meat	Fat	Bone	[1]HVC	[1]HVC in Meat	Perinephic + Retroperitoneal fat	Conformation Score	Fat Score	Value
Height at withers (A)	0.44***	-0.26*	0.28**	0.02	-0.36***	-0.32**	0.27*	-0.20	0.28**	-0.30**
Length of back (A)	0.40***	-0.13	0.16	-0.02	-0.18	-0.16	0.09	-0.12	0.24*	-0.15
Length of pelvis (A)	0.41***	-0.96	0.14	-0.07	-0.19	-0.19	0.13	-0.04	0.21	-0.12
ICBF average skeletal (A)	0.44***	-0.17	0.20	-0.02	-0.26*	-0.24*	0.17	-0.12	0.26*	-0.20
Height at withers (B)	0.51***	-0.15	0.18	-0.007	-0.16	-0.10	0.33**	0.04	0.22	-0.13
Length of back (B)	0.41***	-0.15	-0.04	-0.30*	0.16	0.14	-0.10	0.26*	0.20	0.16
Length of pelvis (B)	0.33**	-0.03	0.06	-0.06	-0.02	0.003	0.17	0.11	0.06	0.002
ICBF average skeletal (B)	0.50***	-0.02	0.09	-0.14	-0.01	0.14	0.17	0.16	0.20	0.01
Pre-slaughter										
Height at withers (A)	0.36***	-0.31***	0.28***	0.15**	-0.38***	-0.26***	0.51***	-0.22***	0.30***	-0.38***
Length of back (A)	0.43***	-0.24***	0.25***	0.07	-0.29***	-0.19***	0.46***	-0.08	0.26***	-0.29***
Length of pelvis (A)	0.35***	-0.32***	0.29***	0.14*	-0.37***	-0.24***	0.47***	-0.19***	0.30***	-0.37***
ICBF average skeletal (A)	0.40***	-0.32***	0.30***	0.13*	-0.38***	-0.25***	0.52***	-0.18**	0.31***	-0.38***
Height at withers (B)	0.27***	-0.34***	0.20**	0.30***	-0.32***	-0.17**	0.38***	-0.41***	0.24***	-0.34***
Length of back (B)	0.33***	-0.13*	-0.13*	0.05	0.11	-0.05	0.27***	-0.08	0.24***	-0.12
Length of pelvis (B)	0.30***	-0.22***	0.20**	0.09	-0.16*	-0.05	0.32***	-0.23***	0.34***	-0.22***
ICBF average skeletal (B)	0.37***	-0.29***	0.22***	0.19**	-0.25***	-0.11	0.40***	-0.31***	0.33***	-0.29***

[1] High-value cuts. A= ICBF assessor A B= ICBF assessor B.

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

Table 3.5: Correlation of ultrasonically scanned measurements with carcass weight, carcass meat, fat and bone proportions, proportion of high-value cuts in the carcass, and in meat, perinephric and retroperitoneal fat, carcass conformation and fat scores and carcass value

		Proportion in carcass						Carcass		
	Carcass weight	Meat	Fat	Bone	[1]HVC	[1]HVC in Meat	Perinephic + Retroperitoneal fat	Conformation Score	Fat Score	Value
At 8-12 months of age										
Muscle depth	0.64***	0.31**	-0.08	-0.62***	0.23*	0.12	-0.03	0.60***	0.13	0.31**
Fat depth	0.15	-0.32**	0.37***	-0.01	-0.46***	-0.41***	0.14	-0.21	0.35**	-0.39***
Pre-slaughter										
Muscle depth	0.72***	0.52***	-0.08	-0.75***	0.31***	0.07	0.11	0.80***	0.21*	0.47***
Fat depth	0.58***	-0.23**	0.59***	-0.50***	-0.34**	-0.27***	0.45***	0.33***	0.63***	-0.32***

[1]High-value cuts. *P < 0.05, **P < 0.01, ***P < 0.001

Table 3.6: Correlation of carcass conformation and fat scores with carcass weight, carcass meat, fat and bone proportions, proportion of high-value cuts in the carcass and meat, carcass conformation and fat scores, perinephric and retroperitoneal fat and carcass value

		Proportion in carcass						Carcass		
	Carcass weight	Meat	Fat	Bone	[1]HVC	[1]HVC in Meat	Perinephic + Retroperitoneal fat	Conformation Score	Fat Score	Value
Conformation Score	0.71***	0.66***	-0.19***	-0.84***	0.29***	-0.11*	-0.01	1	0.10	0.60***
Fat Score	0.42***	-0.37***	0.69***	-0.31***	-0.41***	0.24***	0.47***	0.10	1	-0.43***

[1]High-value cuts. *P < 0.05, **P < 0.01, ***P < 0.001

Table 3.7: Regression equations using live animal muscular and ultrasound scanned measurements at 8 to 12 months of age and pre-slaughter for predicting carcass meat, fat and bone proportions

	Intercept	Muscular score	Scanned muscle depth	Scanned fat depth	R^2	Residual standard deviation
At 8-12 months of age						
Meat proportion						
Muscular score	662	6.4(2.20)**			0.08	34.0
Scanned muscle and fat	655		1.7(0.48)***	-49.0(13.00)***	0.21	31.7
Fat proportion						
Muscular score	133	-1.7(2.03)			0.01	31.4
Scanned muscle and fat	111		-0.6(0.44)	45.4(12.10)***	0.13	29.3
Bone proportion						
Muscular score	205	-4.7(0.70)***			0.35	10.8
Scanned muscle and fat	234		-1.1(0.16)***	3.4(4.36)	0.37	10.6
Pre-slaughter						
Meat proportion						
Muscular score	596	11.6(0.84)***			0.36	28.9
Scanned muscle and fat	531		2.8(0.24)***	-10.3(1.21)***	0.51	23.3
Fat proportion						
Muscular score	135	-2.1(0.84)*			0.02	28.9
Scanned muscle and fat	173		-1.33(0.217)***	12.9(1.11)***	0.48	21.4
Bone proportion						
Muscular score	268	-9.4(0.37)***			0.66	12.7
Scanned muscle and fat	296		-1.43(0.129)***	-2.57(0.661)	0.59	12.8

*P < 0.05, **P < 0.01, ***P < 0.001

Table 3.8: Regression equations using live animal muscle scores and ultrasound muscle and fat measurements at 8 to 12 months of age and pre-slaughter for predicting the proportions of meat, fat, bone and high-value meat cuts in the carcass and carcass value

	Intercept	Muscular score	Muscle depth	Fat depth	R^2	Residual Standard Deviation
At 8-12 months of age						
Meat proportion (g/kg)	660	4.3(2.55)	1.1(0.59)	-49.1(12.87)***	0.23	31.3
Fat proportion (g/kg)	109	-1.5(2.41)	-0.4(0.55)	45.5(12.10)***	0.13	29.4
Bone proportion (g/kg)	231	-2.9(0.81)***	-0.8(0.19)***	3.6(4.08)	0.45	9.9
Proportion of high-value cuts (g/kg)	66	0.9(0.52)	0.18(0.120)	14.2(2.62)***	0.30	6.4
High-value cuts as proportion of meat (g/kg)	100	0.77(0.609)	0.09(0.141)	-13.3(3.07)***	0.18	7.5
Perinephric plus retroperitoneal fat (kg)	10.1	-0.2(0.27)	0.008(0.0617)	1.8(1.34)	0.03	3.3
Carcass value (c/kg)	276	3.3(1.45)*	0.59(0.335)	-34.9(7.30)***	0.30	17.8
Pre-slaughter						
Meat proportion (g/kg)	535	5.4(1.84)**	-2.1(0.33)***	-10.5(1.18)***	0.53	22.7
Fat proportion (g/kg)	173	0.34(1.74)	-1.4(0.31)***	12.9(1.11)***	0.48	21.5
Bone proportion (g/kg)	292	-5.8(0.92)***	-0.7(0.16)***	-2.4(0.59)	0.68	11.3
Proportion of high-value cuts (g/kg)	48	0.7(0.42)	0.31(0.073)***	-2.1(0.27)***	0.37	5.1
High-value cuts as proportion of meat (g/kg)	91	0.2(0.58)	0.16(0.102)	-1.6(0.37)***	0.10	7.1
Perinephric plus retroperitoneal fat (kg)	9.5	0.08(0.231)	-0.05(0.041)	0.9(0.15)***	0.20	2.9
Carcass value (c/kg)	211	3.2(0.97)**	1.1(0.17)***	-6.7(0.62)***	0.58	12.0

*P < 0.05, **P < 0.01, ***P < 0.001

Table 3.9: Regression on carcass conformation and fat scores of carcass meat, fat and bone proportions, proportion of high-value cuts in the carcass and in meat and carcass value

	Intercept	Conformation Score	Fat Score	R^2	Residual standard deviation
Meat proportion (g/kg)	675***	11.2(0.53)***	-8.2(0.629)***	0.63	22.2
Fat proportion (g/kg)	51***	-3.3(0.47)***	10.9(0.56)***	0.54	19.7
Bone proportion (g/kg)	273***	-7.9(0.26)***	-2.7(0.30)***	0.76	10.6
Proportion of high-value cuts (g/kg)	76***	0.96(0.131)***	-1.5(0.16)***	0.28	5.4
High-value cuts as proportion of meat (g/kg)	112***	-0.27(0.169)	-0.9(0.20)***	0.06	7.0
Perinephric plus retroperitoneal fat (kg)	2.9***	-0.08(0.068)	0.8(0.08)***	0.23	2.8
Carcass value (c/kg)	296***	5.6(0.30)***	-5.1(0.36)***	0.60	12.6

*P < 0.05, **P < 0.01, ***P < 0.001

Chapter 4

Experiment 2 - The relationship of various of muscular and skeletal scores and ultrasound measurements in the live animal, and carcass classification scores with carcass composition and value in bulls

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Experiment 2 - The relationship of various muscular and skeletal scores and ultrasound measurements in the live animal, and carcass classification scores with carcass composition and value of bulls

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4.1 Abstract

The relationship of live animal muscular and skeletal scores and ultrasound measurements and carcass conformation and fat scores with carcass composition and value were determined using 74 bulls. The animals consisted of 53 late-maturing breed crosses and 21 Holstein-Friesian slaughtered at 13 to 17 months of age. They were offered concentrates *ad-libitum* and 1 kg of grass silage dry matter per head daily for the final 139 day finishing period. Live animal muscular and skeletal scores and ultrasonic muscle and fat depth measurements of the *m. longissimus dorsi* were recorded at 8 to 12 months of age and pre-slaughter. Following slaughter, carcasses were classified for conformation and fatness and the right side of each carcass was dissected into meat, fat and bone. Carcass conformation and fat scores, (scale 1 to 15) ranged from 4.7 to 14.4 and 2.7 to 11.5, respectively. Pre-slaughter muscular scores showed significant positive correlations with kill-out proportion ($r = 0.82$), carcass meat proportion ($r = 0.72$), conformation score ($r = 0.94$), carcass value ($r = 0.72$), and the proportion of high-value meat cuts in the carcass ($r = 0.49$), and significant negative correlations with carcass bone (r = -0.89) and fat (r =-0.32) proportions. The association between pre-slaughter muscular scores and proportion of high-value cuts in meat, perinephric plus retroperitoneal fat and fat score were not significant. Corresponding correlations with muscular scores at 8 to 12 months of age were generally lower than those recorded pre-slaughter. Correlations of ultrasound muscle depth with carcass traits showed similar trends but lower values to those obtained using the muscular scoring procedure. Ultrasound fat depth pre-slaughter was positively correlated with carcass fat proportion (r = 0.56) and fat score (r = 0.54), and negatively correlated with carcass meat proportion, proportion of high-value cuts and carcass value. Correlations with other carcass traits were not significant. Correlations of live animal skeletal scores with carcass traits were generally non-significant. A one unit (scale 1-15) increase in carcass conformation score was associated with significant increases in kill-out proportion, meat yield and carcass value of 11.9 g/kg, 11.9 g/kg and 5.8 cent/kg, respectively. Corresponding effects for a one unit change in fat score were –2.9 g/kg, -11.1 g/kg and –4.9 c/kg. In conclusion, live animal muscular scores and ultrasound measurements and carcass conformation and fat scores were shown to be useful predictors of carcass composition and value.

Keywords: Beef cattle, Carcass classification, Muscular scores, Ultrasonic scanning

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4.2 Introduction

Beef carcass classification plays an important role as a marketing aid within and between European countries, and as a means of increasing the precision of price reporting for administrative purposes (Fisher, 2007). Beef carcasses are classified according to the official EU beef carcass classification scheme (Commissions of the European Communities, 1982) for conformation (E, U, R, O, P scale with E best and with an additional score S for superior double-muscled carcasses) and fatness (1-5 with 5 fattest). This classification scheme, which is based on visual assessment for conformation and fatness, was recently replaced in Ireland by mechanical scoring (Allen, 2007). Both meat yield and distribution, due to differences in the value of meat cuts are primary determinants of carcass value (Drennan, 2006). Very few studies have looked at the relationship between carcass scores (using the EU classification scheme) and carcass composition and value. Delfa *et al.* (2007) using 69 bull carcasses, found that hot carcass weight and EU carcass classification for conformation and fatness explained 97, 60 and 85% of muscle, fat and bone weight respectively. Recent studies (Drennan *et al.,* 2008; Conroy *et al.,* 2009) have shown that carcass classification for conformation and fatness explained from 0.55 to 0.70 of total variation in carcass meat proportion. These findings are supported by Perry *et al.* (1993b) who reported that carcass weight alone, carcass weight with carcass muscle score and carcass weight with carcass muscle and fat scores, accounted for 0.1, 37.9 and 46.7%, respectively, of the total variation in saleable meat yield. However, Kempster and Harrington (1980) reported that conformation classes rarely accounted for more than 0.30 of the total variation in meat yield.

In addition to carcass classification in breed improvement programmes, repeatable live animal scores and measurements can be used in the identification of animals with superior genetic merit for killing-out proportion, carcass composition and value. Studies (Perry *et al.,* 1993a; Conroy *et al.,* 2009) have shown correlations of 0.6 to 0.7 between muscular scores on the live animal and meat yield. Ultrasound measurements have also shown a good relationship with meat yield (Greiner *et al.,* 2003; Tait *et al.,* 2005). Robinson *et al*. (1992) stated that ultrasound scanning was accurate and effective in predicting carcass measurements and has potential use in breeding decisions. The objectives of the study were to determine the relationship of live animal muscular and skeletal scores, ultrasonically scanned muscle and fat depth measurements of the *m. longissimus dorsi,* and carcass conformation and fat scores with kill-out proportion, carcass composition and value.

4.3 Materials and Methods

4.3.1 Animals and management

Seventy-four bulls slaughtered at 13 to 17 months of age were used in the experiment. Fifty-three were late-maturing continental breed crosses from crossbred suckler dams, bred using artificial insemination to Belgian Blue (n=6), Charolais (n=23), Limousin (n=16) and Simmental (n=8) sires. These bulls were suckled and were purchased following weaning at 8 to 9 months of age from November 2005 to January 2006. The remaining 21 animals were Holstein-Friesian, purchased as calves and artificially reared at the Grange research farm. They received an *ad-libitum* concentrate diet from early life. Following purchase, the continental crossbred weanlings were offered grass silage (dry matter digestibility, 671 g/kg) *ad-libitum* and a concentrate supplement (barley, 865 g/kg; soya bean meal, 70 g/kg; molasses, 50 g/kg and minerals/vitamins, 15 g/kg).

The daily concentrate allowance was gradually increased and silage gradually reduced over a period until animals were offered concentrates to appetite and approximately 1 kg of grass silage dry matter per head daily. All bulls remained on this diet from 28th January until slaughter on 26th June. Following purchase, the suckled animals were treated for the control of parasitic infections of the gastro–intestinal tract and lungs and Fascioliasis. All animals were also vaccinated with Covexin 8, Bovipast RSP and Infectious Bovine Rhinotrachietis (IBR) marker for control of clostridial and respiratory diseases. Treatment for the control of lice was given to all animals as deemed necessary.

4.3.2 Muscular and skeletal scores/measurements

At 8 to 12 months of age and again pre-slaughter, muscular and skeletal scores were carried out by the same two trained assessors from the Irish Cattle Breeding Federation (ICBF). Muscular scores were also obtained at those times using the Signet scoring system (Collins, 1998) by two experienced staff members from Grange research centre. All scoring was carried out by visual assessment except for height at withers, which was recorded by the members of ICBF using a measuring pole. Linear scoring (ICBF, 2002) by the ICBF assessors involved assigning muscular scores on a scale of 1 (poor) to 15 (excellent), at six locations (width at withers, width behind withers, loin development, development of hind-quarters, width of hind-quarters and development of the inner thigh) and skeletal scores (scale of 1-10) at three locations (length of back, pelvic length and height at withers). The six muscular scores were then averaged to give one score per animal for each assessor on each occasion. Skeletal scores were also averaged in a similar manner. Allowances were made for subcutaneous fat by the assessors when assigning muscular scores. The Signet muscular score was also based on a 1 to 15 point scale extending, where appropriate, to 18 for double-muscled animals. The three scoring locations used were roundness of hind-quarters, width of hind-quarters, and depth and width of loin. Each animal was given a score for each of the three locations, which were again averaged to give a mean score per animal for each assessor.

4.3.3 Ultrasound measurements

At 8 to 12 months of age and again pre-slaughter eye muscle depth was measured at the 3rd lumbar vertebra and fat depth at both the 3rd lumbar vertebra and 13th thoracic rib using a Dynamic Imaging real time ultrasound scanner (model – *Concept MLV*, with 3.5 MHz transducer). All measurements were obtained on the right side of each animal by the same operator. Hair was clipped from areas to be scanned and vegetable oil was applied to obtain adequate acoustic contact. Cattle were restrained by the head in a chute and physical palpation was used to accurately ascertain the scanning sites. The animals were only scanned when they were in a relaxed posture thus permitting more accurate measurement. The transducer had a built-in stand-off with a silicone rubber strip attached which facilitated contact with curvature of the animal's body. The probe was placed perpendicular to the horizontal trajectory of the rib eye muscle (*M. longissimus dorsi*) at the 3rd lumbar vertebra and 13th thoracic rib until bones appeared on the monitor. When a satisfactory image was achieved, it was frozen on the monitor and the depth of the eye muscle and fat were then measured using an internal electronic callipers and measurement software. Fat depth was measured at 3 points at the 3rd lumbar vertebra across the width (0.4, 0.6 and 0.8) of the muscle and at four points (0.2, 0.4, 0.6 and 0.8) at the 13th vertebra. Fat depth was calculated by taking the mean of the average values at the 3rd lumbar and 13th thoracic rib. Muscle depth was obtained at the deepest point (0.25) of the muscle (from the bottom of the backfat to the top of the bone) at the 3rd lumbar vertebra.

4.3.4 Carcass measurements

Carcass conformation and fat scores were recorded using a mechanical grading system (Allen, 2007) on a 15 point continuous scale rather than the 5 point EU Beef Carcass Classification Scheme scale (Commission of the European Communities, 1982). Hot carcass weight was recorded and cold carcass weight was estimated as 0.98 of hot carcass weight. Weight of perinephric and retroperitoneal fat were also recorded at slaughter. Following a period of 24 hours at 4° C, the right side of each carcass was quartered at the 5th rib into an 8-rib pistola and the remaining fore-quarter. After recording the weight, the pistola was dissected into 13 cuts (leg, heel, silverside, topside, knuckle, rump, tail of rump, cap of rump, fillet, striploin, cube roll, cap of rib and salmon) from which, all visible fat and bone (where applicable) was removed. The weight of each individual meat cut and total fat from the pistola was recorded as was bone weight following removal of all adhering tissues. Lean trim was weighed separately and added to the meat cuts to give total pistola meat yield. A similar procedure was carried out with the fore-quarter, which was dissected into 11 cuts (front shin, neck, brisket, chuck, flat ribs (1-5), plate, leg of mutton cut, bladesteak, braising muscle, chuck tender and clod). Pistola and fore-quarter meat, fat and bone weights were combined to give the weight of each component in the half carcass. High-value cuts in the carcass were taken as meat in the cube roll, striploin and fillet. Carcass value was estimated as the sum of the commercial values on each meat cut with a small deduction for bone expressed as a proportion of half carcass weight.

4.3.5 Statistical analysis

Data were analysed using the REG and CORR procedures of SAS (2007). Pearson's correlation coefficients of live animal scores/measurements and carcass conformation and fat scores with the various carcass traits were derived. The relationships between muscular and skeletal scores, ultrasound muscle and fat depths, and conformation and fat scores and the dependant variables (carcass weight, kill-out proportion, meat, fat and bone proportions, proportion of high-value cuts in carcass and meat, and carcass value) were determined using multiple regressions. The contribution made to the estimation of each dependent variable by each independent variable was determined by comparison of the coefficient of determination (R^2) and the residual standard deviation (r.s.d.).

4.4 Results

The mean, range and standard deviations for live and carcass traits and yield components for the bulls are summarised in Table 1. At slaughter animals had a mean age of 458 days, a live weight of 575 kg and a cold carcass weight of 322 kg. Carcass conformation and fat scores (scale 1 to 15) ranged from 4.7 to 14.4 and 2.7 to 11.5, respectively. Mean carcass meat, fat and bone proportions were 712, 96 and 192 g/kg, respectively. The mean proportion of high-value cuts in the carcass and in meat were 72 and 102 g/kg, respectively.

4.4.1 Assessors

High correlations for muscular scores were obtained between the four Assessors (two ICBF and two Signet) at both 8 to 12 months of age (r = 0.88 to 0.93) and pre-slaughter (r = 0.86 to 0.94).

4.4.2 Correlations between live animal scoring methodologies and carcass characteristics

The association between live animal scores taken at 8 to 12 months of age and pre-slaughter and carcass characteristics are shown in Tables 2 and 3, respectively. Correlations of average muscular score on the live animal obtained pre-slaughter by ICBF Assessor A with kill-out proportion, carcass meat proportion, carcass conformation, the proportion of high-value cuts in the carcass and carcass value were 0.82, 0.72, 0.94, 0.49 and 0.72, respectively, all of which were highly significant (Table 3). Correlations of average muscular score pre-slaughter showed significant negative relationships with carcass bone ($r = -0.89$) and fat ($r = -0.32$) proportions. There was no association ($P > 0.05$) between live animal muscular scores pre-slaughter and the proportion of high-value cuts in meat, perinephric and retroperitoneal fat weight or carcass fat score. Correlations of live animal muscular scores at 8 to 12 months of age with the various carcass traits generally showed similar trends but lower absolute values than at pre-slaughter. The corresponding correlations obtained by Assessors B, C and D were comparable to those obtained by Assessor A. Correlation between hind-quarter development and the various carcass traits were similar to the correlations obtained using the average of all six individual muscular scoring locations with these carcass traits.

4.4.3 Correlation between skeletal scores and carcass characteristics

Correlation coefficients between the ICBF skeletal scores (individual or combined) recorded by both Assessors A and B and the various carcass traits were found to be poor and generally non-significant (Table 4).

4.4.4 Correlation between ultrasound measurements and carcass characteristics

Significant positive correlations were obtained for scanned muscle depth pre-slaughter and kill-out proportion (r = 0.71), carcass meat proportion (r = 0.68), proportion of high-value cuts in the carcass (r = 0.52), carcass conformation score (r = 0.83) and carcass value (r = 0.69) (Table 5). Significant negative correlations were obtained between scanned muscle depth pre-slaughter and both carcass fat (r = -0.34) and bone (r = -0.81) proportions. Although showing similar trends, corresponding correlations with scanned muscle depth at 8 to 12 months of age were generally lower. Correlations of scanned muscle depth at both 8 to 12 months of age and pre-slaughter with the proportion of high-value cuts in meat, carcass fat score and perinephric and retroperitoneal fat were not significant. Correlations of scanned fat depth at 8 to 12 months and pre-slaughter with the various carcass traits were inconsistent (Table 5). Significant positive correlations (r = 0.53 to 0.72) were obtained for scanned fat depth at 8 to 12 months and kill-out proportion, carcass meat proportion, carcass conformation score and carcass value, whereas a negative relationship (r = -0.67) was found with carcass bone proportion. Correlations of scanned fat depth at 8 to 12 months with carcass fat proportion, high-value cuts in meat, perinephic and retroperitoneal fat and carcass fat score were not significant. Positive correlation coefficients were obtained for scanned fat depth pre-slaughter with carcass fat proportion (r = 0.56) and fat score (r = 0.54). The only other statistically significant correlations obtained with scanned fat depth pre-slaughter were negative values (r = ~ -0.30) recorded with carcass meat proportion, proportion of high-value cuts in the carcass and carcass value.

4.4.5 Correlation between carcass conformation and fat scores and carcass characteristics

Significant positive correlations were obtained (Table 6) for carcass conformation score with kill-out proportion (r = 0.84), carcass meat proportion (r = 0.78), proportion of high-value cuts in the carcass (r = 0.50) and carcass value (r = 0.76), whereas negative correlations were obtained with carcass fat (r = -0.41) and bone (r = -0.90) proportions. Correlations of conformation score with high-value cuts in meat, fat score and perinephric and retroperitoneal fat were not significant. Correlations between carcass fat score and the various carcass traits were generally low and non-significant except for significant positive correlations with carcass fat proportion (r = 0.63) and perinephric and retroperitoneal fat (r = 0.29), and significant negative correlations with carcass meat proportion (r = -0.38) and value (r = -0.33).

4.4.6 Regressions using live animal scores/measurements

Multiple regression equations using live animal muscular scores obtained by Assessor A and ultrasound muscle and fat depth measurements to predict carcass meat, fat and bone proportions are shown in Table 7. Both muscular score alone and scanned muscle and fat depth alone at 8 to 12 months of age and pre-slaughter, were significant in predicting carcass meat proportion. Muscular score alone explained slightly more variation at 8 to 12 months than the scanning measurements (R^2 = 0.43 v 0.39), whereas scanned muscle and fat depth explained a greater proportion of total variation pre-slaughter than the muscular score (R^2= 0.51 v 0.62). Although muscular scores were significant in predicting carcass fat proportion, a very small proportion of total variation was explained at 8 to 12 months of age (R^2 = 0.09) and pre-slaughter (R^2 = 0.10). Likewise, scanned muscle and fat depth at 8 to 12 months were poor predictors of carcass fat proportion (R^2 = 0.10), whereas pre-slaughter they accounted for 48% of the total variation. Both muscular score and scanned muscle and fat depth measurements at 8 to 12 months of age and pre-slaughter were significant in predicting carcass bone proportion with muscular score explaining more variation than scanned measurements at 8 to 12 months (R^2 = 0.65 v. 0.58) and pre-slaughter (R^2 = 0.80 v. 0.65). The residual standard deviation (r.s.d) was generally higher at 8 to 12 months than at slaughter. Multiple regression equations using the combined effects of live animal muscular scores and scanned muscle and fat depth measurements to predict kill-out proportion, the various carcass traits and carcass value are shown in Table 8. At slaughter, the combined muscular score and scanned measurements explained a high proportion of total variation (R^2= 0.69 to 0.81) in killing-out rate, carcass meat proportion, bone proportion and carcass value. The corresponding R^2 values at 8 to 12 months were always lower than those obtained pre-slaughter. When predicting carcass fat proportion, 49% of the total variation was explained pre-slaughter using the combined muscular score, and scanned measurements, whereas there was no significant relationship at 8 to 12 months of age. The amount of total variation explained when predicting the proportion of high-value cuts in the carcass was low to moderate at 8 to 12 months (R^2 = 0.19) and pre-slaughter (R^2 = 0.42). The R^2 values for the proportion of total variation in predicting high-value cuts expressed as proportion of meat and perinephric and retroperitoneal fat were minimal on both occasions. In all of the above cases the r.s.d was lower at slaughter than for the corresponding regressions at 8 to 12 months of age.

4.4.7 Regressions using carcass conformation and fat scores

Regression analysis showed that carcass conformation and fat scores explained from 68% to 80% of the total variation in predicting kill-out proportion, carcass meat and bone proportions and carcass value, 55% of the total variation in predicting carcass fat proportion and 28% of the variation in predicting the proportion of high-value cuts in the carcass. Little or no variation was explained in using carcass conformation and fat scores to predict the proportion of high-value cuts in the meat.

4.5 Discussion

4.5.1 Assessors

In the present study, correlations for muscular scores taken at the same time (8 to 12 months or pre-slaughter) between the four assessors ranged from 86% to 94% which agrees with the values (0.90 to 0.92) of Perry *et al.* (1993a) and is somewhat higher than the values ranging from 0.74 to 0.87 by Drennan *et al.* (2008) and from 0.71 to 0.87 by Conroy *et al.* (2009). The latter study involved assessing eight separate batches of animals over a 2-year period which likely resulted in lower correlations than when all records are taken at the same time. The lower correlations in the study by Drennan *et al.* (2008) is probably due to having animals in a relatively narrow range of conformation scores compared to the other studies. As muscular scoring involves a subjective visual assessment, it must be emphasised that proper training and frequent assessment is needed to obtain reliable results.

4.5.2 Muscular scores

The positive correlation (r = ~ 0.85) between muscular scores pre-slaughter and carcass weight is not surprising as the suckled animals had better muscular scores and heavier carcasses than the Holstein-Friesian. The positive correlation between muscular scores taken pre-slaughter and kill-out proportion of about 0.80 in the present study was greater than the values, of about 0.60 obtained by MacAodhain (2004) and Drennan *et* *al.* (2008). The correlation between muscular scores and carcass meat proportions of about 0.72 is similar to that of Perry *et al.* (1993a) but higher than those (r = ~ 0.60) of Drennan *et al.* (2008) and Conroy (2009), while May *et al.* (2000) obtained a correlation of 0.35 between these traits. These data clearly show that animals with better muscular scores have higher kill-out proportions and carcass meat proportion. In agreement with the present study, Drennan *et al.* (2008) and Conroy *et al.* (2009) found that the use of two muscular scoring locations (width and roundness of hind-quarter) were equally as good an indicator of carcass meat proportion (and the other carcass traits) as the average of all the muscular scoring locations. The negative correlation obtained between muscular scores recorded pre-slaughter and carcass bone proportion (r = ~ -0.89) is similar to that (r = -0.82) of Conroy *et al.* (2009) and higher than the value of -0.64 found by MacAodhain (2004). Similarly, Colomer-Rocher *et al.* (1980) found that carcasses in convex classes had more muscle, less bone and a higher muscle to bone ratio than those in the concave classes. Tatum *et al.* (1986) reported that within an animal frame size, the percentage of separable muscle increased and percentage bone decreased, with increased muscle thickness when adjusted to a constant fat percentage. The negative relationship between muscular scores obtained pre-slaughter with carcass fat proportion (r = -0.32) is in agreement with results (r ranging from -0.21 to -0.46) obtained by Perry *et al.* (1993a) and MacAodhain (2004). The absence of any relationship between muscular score and carcass fat score is in accord with the results obtained by MacAodhain (2004). The negative relationship between muscular scores and the carcass fat traits clearly shows that subcutaneous fat cover was not interfering with the muscular scoring procedure.

The positive correlations (r = 0.49) obtained between muscular scores taken pre-slaughter and the proportion of high-value cuts in the carcass followed a similar trend but with higher values than those (r = ~ 0.30) obtained by Conroy *et al.* (2009). The absence of a relationship between muscular scores and the proportion of high-value cuts in the meat indicates that a higher proportion of bone in the carcass of animals of poor muscularity is the main reason for the positive relationship between muscular scores and proportion of high-value cuts in the carcass. The high positive correlation (r = 0.94) obtained between muscular scores pre-slaughter and carcass conformation score, was greater than the values (r = 0.6 to 0.86) obtained by Doorley (2001), MacAodhain (2004) and Conroy *et al.* (2009) showing that both are indicators of the muscularity of the animal. In the present study, correlations of live animal muscular scores taken at 8 to 12 months with various carcass traits were found to be lower than those obtained pre-slaughter which is in agreement with previous findings (Drennan *et al.*, 2008; Conroy *et al.*, 2009).

4.5.3 Skeletal scores

The general lack of a relationship between the live animal skeletal scores and the various carcass traits, does not agree with the findings of Conroy et al. (2009) who found that, when using scores recorded at slaughter, low negative but significant correlations with carcass meat proportion, proportion of high-value cuts in the carcass and conformation score but significant positive correlations with carcass fat and bone proportion and fat score. In the present study, the main significant correlation was a positive relationship between skeletal scores and carcass weight, which agrees with the results of Conroy *et al.* (2009) and demonstrates as expected, that larger animals have heavier carcass weights.

4.5.4 Ultrasound muscle and fat depth

The high correlation (0.71) obtained between scanned muscle depth at slaughter and kill-out percentage is similar to the results (r = 0.64) of Doorley (2001) and higher than those (r = ~0.43) obtained by MacAodhain (2004) showing that animals with greater muscularity had superior kill-out percentages. The positive relationship (r = 0.68) between scanned muscle depth pre-slaughter and carcass meat proportion is in good agreement with previous findings by Doorley (2001) but greater than values (r = ~ 0.3 to 0.5) obtained in other studies using *m. longissimus* muscle area (Cross *et al.,* 1973; MacAodhain, 2004; Tait *et al*., 2005). In contrast, poor relationships (r = <0.2) were found between scanned muscle area and percentage meat yield in other studies (Herring *et al.,* 1994; Hamlin *et al.,* 1995; May *et al.,* 2000). The positive correlation between scanned muscle depth at slaughter and the proportion of high-value cuts in the carcass was 0.52, whereas Cross *et al*. (1973) also recorded a positive but lower correlation of 0.19 between *longissimus* muscle area and the proportion of high value cuts. A high positive correlation of 0.83 was obtained in the current study between scanned muscle depth at slaughter and carcass conformation score, which was similar to the value of 0.80 obtained by Conroy *et al*. (2009) but higher than the values of about 0.5 obtained by Doorley (2001) and MacAodhain (2004). This may be explained by the wider range in carcass conformation scores of the animals used in the present study and that of Conroy *et al.* (2009) than those used in the other two studies. In general, scanned muscle depth measurements recorded at slaughter showed better correlations with the various carcass traits than those recorded at 8-12 months of age. This is in agreement with Bailey *et al*. (1986) who obtained correlations of -0.16, 0.57 and 0.48 between scanned muscle area and carcass conformation score in light, medium and heavy weight categories, respectively, of Holstein bulls. Similarly, Wolcott *et al*. (2001) found that the power of live animal measurements to predict retail meat yield percentage decreased as the time between scanning and slaughter increased.

Unlike scanned muscle depth, relationships between scanned fat depth measurements taken at 8 to 12 months and pre-slaughter with most carcass traits were inconsistent. In accordance with the findings of MacAodhain (2004), scanned fat depth recorded pre-slaughter had a significant negative relationship (r = -0.30) with carcass meat proportion, which was poorer than the values of up to -0.66 obtained by Simm *et al.* (1983) and -0.74 obtained by Greiner *et al.* (2003). Scanned fat depth pre-slaughter showed a similar positive relationship with carcass fat proportion (r = 0.56) and fat score (r = 0.54). Other studies have recorded correlations of scanned fat measurements with carcass fat proportion ranging from 0.39 (Tait *et al.*, 2005) to about 0.8 (May *et al.*, 2000; Doorley, 2001). In agreement with other findings (Hamlin *et al.*, 1995; MacAodhain, 2004) the correlation of perinephric and retroperitoneal fat weight with scanned fat depth was not significant. The absence of a relationship of scanned fat depth at 8 to 12 months of age with all other indicators of fatness show that scanned fat measurements are a reasonable indicator of carcass fat proportion and fat scores when taken pre-slaughter but are not useful indicators earlier in the animal’s life.

When recorded pre-slaughter, scanned muscle and fat measurements explained 62% of the total variation in carcass meat proportion, which shows agreement with the value of 51% found by Conroy *et al.* (2009). Bergen *et al.* (2005) also found that lean meat yield can be accurately predicted using scanned fat and muscle depth measurements. Hamlin *et al.* (1995) found that ultrasonically measured fat thickness recorded pre-slaughter explained 59% of retail product percentage and inclusion of *longissimus* muscle area and final liveweight in the model only increased the R^2 values to 62%. The small change indicates the large influence that fat thickness had on the percentage of retail yield in that study. In contrast, Johnson *et al.* (1993) found that fat thickness and carcass weight explained 42% of the variation in percentage muscle in beef carcasses and inclusion of eye muscle area increased this to 53%. In the present study, inclusion of muscular score with the scanned measurements increased the proportion of total variation in meat yield explained to 72% but its inclusion had no major effect in the study by Conroy *et al.* (2009). In accordance with the findings of the latter authors the proportion of total variation in carcass meat proportion explained was considerably lower ($R^2 = 0.44$) when the scores/measurements were recorded at 8 to 12 months than pre-slaughter.

4.5.5 Carcass conformation and fat scores

The strong relationship between conformation score and carcass weight in the current study was not unexpected because the late-maturing breed crosses of good conformation (11.2) had considerably greater carcass weights (351 kg) than the Holstein-Friesian (249 kg) of lower conformation (8.2). The significant correlation between carcass conformation score and meat yield of 0.78 is greater than the values of 0.60 to 0.66 obtained by Perry *et al.* (1993a and b) and Conroy *et al.* (2009). In contrast, Kempster and Harrington (1980) found correlations of about 0.4, whereas, Taylor *et al.* (1990) obtained no relationship between carcass conformation and carcass composition. The negative relationship (r = -0.90) between carcass conformation and carcass bone content agrees with the values of -0.84 obtained by Conroy *et al.* (2009). Conformation score showed a negative correlation of -0.41 with carcass fat proportion, which is in general agreement with the results obtained by Perry *et al.* (1993a). The absence of a relationship between carcass conformation score and carcass fat score or perinepheric and retroperitoneal fat weight is in agreement with the findings of Conroy *et al.* (2009).

In the present study, carcass conformation score had a moderate positive relationship (r = 0.50) with the proportion of high-value cuts in the carcass, which is consistent with the findings of Drennan *et al.* (2008) with heifers but greater than the value they obtained (r = ~ 0.20) for bulls. The negative correlation (r = -0.38) between carcass fat score and meat yield was similar to the results of Cannel *et al.* (2002). The positive correlation (r = 0.63) between fat score and carcass fat proportion shows that fat score is a reasonable indicator of carcass fat proportion and agrees with the findings of Cannel *et al.* (2002). Using regression analysis, conformation and fat scores combined accounted for 74% of the total variation in carcass meat proportion, which is greater than the values of 63% obtained by Conroy *et al.* (2009) and 45% by Jones *et al.* (1989).

On a scale of 1 to 15, a one unit increase in carcass conformation score was associated with an increase in carcass meat proportion of 11.9 g/kg, high value-cuts in the carcass of 1.1 g/kg and carcass value of 5.8 c/kg. These values show good agreement with corresponding figures obtained by Drennan *et al.* (2008) for bulls of 8.9 g/kg, 0.04 g/kg and 3.5 c/kg and for heifers of 8.1 g/kg, 2.0 g/kg and 4.4 c/kg, and Conroy *et al.* (2008) for steers of 11.2 g/kg, 1.0 g/kg and 5.6 c/kg. In the current study, the increased proportion of carcass meat as a result of a one unit increase in carcass conformation score was offset by a 4.0 and 7.9 g/kg decrease in the proportions of carcass fat and bone, respectively. A one unit increase in carcass fat score (scale 1 to 15) in the current study led to decreases of -11.1 g/kg in carcass meat proportion and -4.9 c/kg in carcass value. Similarly, corresponding values obtained by Drennan *et al.* (2008) for bulls were -11.9 g/kg and -5.4 c/kg and for heifers were -9.7 g/kg and -3.8 c/kg, and by Conroy *et al.* (2009) for steers were -8.2 g/kg and -5.1 c/kg.

4.6 Conclusion

The results show that pre-slaughter live animal scores and measurements are good predictors of kill-out proportion, carcass meat and bone proportions and carcass value, modest predictors of carcass fat proportion and proportion of high-value cuts in the carcass and poor predictors of high-value cuts as proportion of meat. Records taken at 8 to 12 months of age were not as good in predicting carcass traits as those taken pre-slaughter. A simplified muscular scoring system using three locations, which were roundness of hind-quarter, width of hind-quarter and depth and width of the loin is as effective as the six locations used by ICBF in predicting carcass composition and value. Live animal skeletal scores showed a poor relationship with the various carcass traits. Carcass classification for conformation and fatness were shown to be good predictors of carcass traits accounting for about 0.7 of total variation in carcass meat proportion and carcass value. The relationship developed between carcass conformation and fat scores with carcass composition provide a basis on which to develop a carcass pricing structure that better reflects carcass value in terms of meat yield and distribution.

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Table 4.1: Mean, standard deviation and range for live and carcass measurements and yield components for 74 young beef bulls

	Mean	Standard Deviation	Minimum	Maximum
At 8 to 12 months				
Muscular scores				
Width between withers (ICBF assessor A)	6.0	2.29	1.0	10
Width behind withers (ICBF assessor A)	5.3	2.22	1.0	9.0
Loin development (ICBF assessor A)	6.0	1.91	1.0	10.0
Hind-quarter development (ICBF assessor A)	6.3	2.22	2.0	12.0
Hind-quarter width (ICBF assessor A)	6.3	1.76	2.0	10.0
Inner thigh development (ICBF assessor A)	6.0	2.14	2	10
Average muscular score (ICBF assessor A)	6.0	2.04	1.5	10.2
ICBF muscular score at 5 locations (assessor A)	6.0	2.03	1.4	10.2
ICBF muscular score at 2 locations (assessor A)	6.3	1.95	2	11
ICBF average muscular score (assessor B)	5.8	1.98	2.3	10.5
Signet muscular score (assessor C)	5.9	2.17	1.7	12.3
Signet muscular score (assessor D)	6.3	2.94	1.0	13.0
Scanned eye muscle depth (mm)	57.6	9.64	38.9	87.5
Scanned fat depth (mm)	1.0	0.37	0.4	2.5
Pre-slaughter				
Pre-slaughter weight (kg)	575	84.6	408	857
Muscular scores				
Width between withers (ICBF assessor A)	8.8	3.06	1.0	13.0
Width behind withers (ICBF assessor A)	8.0	2.99	1.0	12.0
Loin development (ICBF assessor A)	8.6	2.35	3.0	13.0
Hind-quarter development (ICBF assessor A)	8.4	2.62	2.0	14.0
Hind-quarter width (ICBF assessor A)	8.7	2.09	4.0	13.0
Inner thigh development (ICBF assessor A)	8.3	2.51	2.0	13.0
Average muscular score (ICBF assessor A)	8.5	2.53	3	13
ICBF muscular score at 5 locations (assessor A)	8.5	2.55	3.2	13
ICBF muscular score at 2 locations (assessor A)	8.5	2.32	3	13.5
ICBF average muscular score (assessor B)	8.1	2.22	3.3	12.16
Signet muscular score (assessor C)	7.8	2.75	2.3	15
Signet muscular score (assessor D)	7.2	2.79	2.3	14.7
Scanned eye muscle depth (mm)	67.7	9.71	46.2	87.5
Scanned fat depth (mm)	1.8	1.07	0.3	6
Post-slaughter				
Cold carcass weight (kg)	322	57.6	207	475
Kill-out (g/kg)	569	36.9	494	680
Slaughter age (days)	458	41.0	386	569
Perinephric plus retoperitioneal fat (kg)	6.2	2.38	2.2	12.5
[1]Conformation score (scale 1 to 15)	9.6	2.60	4.7	14.4
[2]Fat score (scale 1 to 15)	7.9	1.33	2.7	11.5
Meat (g/kg)	712	39.6	627	840
Fat (g/kg)	96	25.2	31	163
Bone (g/kg)	192	22.8	129	251
High-value cuts (g/kg)	72	5.6	57	85
High-value cuts in meat (g/kg)	102	6.1	87	12
Carcass value (c/kg)	305	19.8	260	358

[1] 15 = best conformation; [2] 15 = fattest.

Table 4.2: Correlation coefficients for the association of live animal muscular scores recorded at 8 to 12 months of age with carcass weight, kill-out proportion, carcass meat, fat and bone proportions, proportion of high-value cuts in the carcass and meat, perinephric and retroperitoneal fat, carcass conformation and fat scores and carcass value

			Proportion in carcass						Carcass		
	Carcass weight	[1]KO	Meat	Fat	Bone	[2]HVC	[2]HVC in Meat	Perinephric + Retroperitoneal fat	Conformation Score	Fat Score	Value
Width between withers (A)	0.73***	0.76***	0.64***	-0.29*	-0.79***	0.49***	0.06	-0.08	0.86***	0.00	0.64***
Width behind withers (A)	0.71***	0.75***	0.65***	-0.33**	-0.76***	0.46***	0.01	-0.12	0.84***	-0.07	0.64***
Loin development (A)	0.73***	0.75***	0.63***	-0.30*	-0.77***	0.45***	0.02	-0.07	0.84***	-0.02	0.62***
Hind-quarter development (A)	0.72***	0.80***	0.67***	-0.33**	-0.81***	0.48***	0.02	-0.11	0.84***	-0.01	0.67***
Hind-quarter width (A)	0.77***	0.74***	0.63***	-0.28*	-0.79***	0.44***	0.01	-0.04	0.81***	-0.00	0.62***
Inner thigh development (A)	0.77***	0.79***	0.67***	-0.31**	-0.82***	0.42***	-0.06	-0.09	0.85***	-0.03	0.65***
ICBF average muscular score (A)	0.76***	0.78***	0.66***	-0.32**	-0.81***	0.47***	0.01	-0.09	0.86***	-0.02	0.66***
ICBF muscular score - 5 locations (A)	0.75***	0.78***	0.66***	-0.31**	-0.80***	0.48***	0.02	-0.09	0.86***	-0.02	0.65***
ICBF muscular score - 2 locations (A)	0.75***	0.78***	0.66***	-0.31**	-0.81***	0.47***	0.02	-0.08	0.84***	-0.01	0.66***
ICBF average muscular score (B)	0.81***	0.71***	0.60***	-0.26*	-0.76***	0.46***	0.04	0.03	0.81***	0.02	0.60***
Signet muscular score (C)	0.75***	0.78***	0.70***	-0.35**	-0.82***	0.45***	-0.04	0.007	0.85***	-0.01	0.66***
Signet muscular score (D)	0.81***	0.78***	0.70***	-0.33**	-0.85***	0.48***	-0.01	0.006	0.89***	0.00	0.67***

[1]Kill-out proportion; [2]High-value cuts. Assessors A and B: ICBF linear muscular scoring system. Assessors C and D: Signet muscular scoring system.

*P < 0.05, **P < 0.01, ***P < 0.001

Table 4.3: Correlation coefficients for the association of live animal muscular scores pre-slaughter with carcass weight, kill-out proportion, carcass meat, fat and bone proportions, proportion of high-value cuts in the carcass and meat, perinephric and retroperitoneal fat, carcass conformation and fat scores and carcass value

			Proportion in carcass						Carcass		
	Carcass weight	[1]KO	Meat	Fat	Bone	[2]HVC	[2]HVC in Meat	Perinephric + Retroperitoneal fat	Conformation Score	Fat Score	Value
Width between withers (A)	0.81***	0.78***	0.68***	-0.30*	-0.85***	0.52***	0.05	0.04	0.90***	0.05	0.70***
Width behind withers (A)	0.82***	0.78***	0.67***	-0.27*	-0.86***	0.52***	0.06	0.06	0.92***	0.07	0.68***
Loin development (A)	0.82***	0.76***	0.66***	-0.26*	-0.85***	0.45***	-0.02	0.10	0.87***	0.10	0.66***
Hind-quarter development (A)	0.82***	0.85***	0.77***	-0.41***	-0.88***	0.47***	-0.09	-0.08	0.94***	-0.03	0.74***
Hind-quarter width (A)	0.87***	0.80***	0.72***	-0.33**	-0.89***	0.47***	-0.05	0.05	0.92***	0.04	0.70***
Inner thigh development (A)	0.83***	0.83***	0.71***	-0.32**	-0.88***	0.42***	-0.10	-0.05	0.90***	0.07	0.68***
ICBF average muscular score (A)	0.85***	0.82***	0.72***	-0.32**	-0.89***	0.49***	-0.02	0.02	0.94***	0.05	0.72***
ICBF muscular score - 5 locations (A)	0.85***	0.82***	0.72***	-0.32**	-0.89***	0.50***	-0.00	0.03	0.94***	0.05	0.72***
ICBF muscular score - 2 locations (A)	0.85***	0.84***	0.76***	-0.38***	-0.90***	0.48***	-0.07	-0.02	0.94***	0.00	0.74***
ICBF average muscular score (B)	0.84***	0.77***	0.73***	-0.40***	-0.83***	0.46***	-0.06	0.03	0.93***	0.06	0.73***
Signet muscular score (C)	0.70***	0.83***	0.77***	-0.42***	-0.87***	0.56***	0.03	-0.07	0.89***	-0.04	0.78***
Signet muscular score (D)	0.77***	0.77***	0.73***	-0.40***	-0.83***	0.46***	-0.06	0.03	0.87***	-0.09	0.71***

Assessors A and B: ICBF linear muscular scoring system. Assessors C and D: Signet muscular scoring system.

[1] Kill-out proportion; [2] High value cuts. Assessors A and B: ICBF linear muscular scoring system. Assessors C and D: Signet muscular scoring system.

*P < 0.05, **P < 0.01, ***P < 0.001

Table 4.4: Correlation coefficients for the association of live animal skeletal scores with carcass weight, kill-out proportion, carcass meat, fat and bone proportions, proportion of high-value cuts in the carcass and meat, perinephric and retroperitoneal fat, carcass conformation and fat scores and carcass value

			Proportion in carcass						Carcass		
At 8 to 12 months	Carcass weight	^{1}KO	Meat	Fat	Bone	^{2}HVC	^{2}HVC in Meat	Perinephric + Retroperitoneal fat	Conformation Score	Fat Score	Value
Height at withers (A)	0.55***	0.11	0.01	0.14	-0.17	0.02	0.01	0.29*	0.13	0.14	0.03
Length of back (A)	0.60***	0.18	0.06	0.14	-0.26*	0.09	0.05	0.24*	0.27*	0.17	0.09
Length of pelvis (A)	0.34***	0.11	0.00	0.18	-0.21	0.02	0.03	0.34**	0.18	0.17	0.04
ICBF average skeletal (A)	0.51***	0.15	0.02	0.17	-0.23	0.05	0.03	0.31**	0.21	0.17	0.06
Height at withers (B)	0.26*	-0.04	-0.16	0.22	0.04	-0.20	-0.12	0.11	-0.03	0.15	-0.17
Length of back (B)	0.09	-0.01	-0.16	0.12	0.16	-0.23*	-0.17	-0.05	-0.16	0.05	-0.18
Length of pelvis (B)	0.09	-0.02	-0.02	0.09	-0.06	-0.08	-0.10	0.11	-0.04	0.07	-0.04
ICBF average skeletal (B)	0.19	-0.07	-0.15	0.18	0.06	-0.22	0.16	0.06	-0.09	0.11	-0.16
Slaughter											
Height at withers (A)	0.60***	0.11	0.05	0.01	-0.09	-0.08	-0.15	0.21	0.20	0.09	0.03
Length of back(A)	0.52***	0.00	-0.07	0.16	-0.05	-0.12	-0.09	0.22	0.10	0.13	-0.07
Length of pelvis (A)	0.52***	0.08	0.05	0.01	-0.10	-0.11	-0.19	0.20	0.12	0.03	0.025
ICBF average skeletal(A)	0.59***	0.07	0.01	0.06	-0.09	-0.10	-0.16	0.23	0.16	0.09	-0.00
Height at wither (B)	0.38***	0.00	-0.13	0.19	0.02	-0.30**	-0.28*	0.13	0.02	0.13	-0.16
Length of back (B)	0.47***	0.26*	0.18	-0.12	-0.19	0.01	-0.16	-0.03	0.20	0.07	0.17
Length of pelvis (B)	0.13	-0.09	-0.18	0.17	0.13	-0.37**	-0.30**	0.19	-0.14	0.16	-0.26*
ICBF average skeletal (B)	0.41***	0.08	-0.05	0.10	-0.02	-0.26*	-0.31**	0.12	0.05	0.15	-0.12

A = ICBF Assessor A B = ICBF assessor B.

^{1}Kill-out proportion; ^{2}High-value cuts. A= ICBF assessor A B= ICBF assessor B.

*P < 0.05, **P < 0.01, ***P < 0.001

Table 4.5: Correlation coefficients for the association of ultrasonically scanned measurements with carcass weight, kill-out proportion, carcass meat, fat and bone proportions, proportion of high-value cuts in the carcass and meat, perinephric and retroperitoneal fat, carcass conformation and fat scores and carcass value

			Proportion in carcass						Carcass		
	Carcass weight	[1]KO	Meat	Fat	Bone	[2]HVC	[2]HVC in Meat	Perinephric + Retroperitoneal fat	Conformation Score	Fat Score	Value
At 8 to 12 months											
Muscle depth	0.81***	0.70***	0.61***	-0.32**	-0.71***	0.40***	-0.03	0.00	0.73***	-0.04	0.60***
Fat depth	0.64***	0.64***	0.53***	-0.22	-0.67***	0.37	-0.00	-0.06	0.72***	0.05	0.56***
Slaughter											
Muscle depth	0.80***	0.71***	0.68***	-0.34**	-0.81***	0.52**	0.05	0.04	0.83***	-0.03	0.69***
Fat depth	0.20	-0.01	-0.30**	0.56***	-0.09	-0.31**	-0.13	0.20	0.08	0.54***	-0.31**

[1] Kill-out proportion; [2] High-value cuts.

*P < 0.05, **P < 0.01, ***P < 0.001

Table 4.6: Correlation of carcass conformation and fat scores with carcass weight, kill-out proportion, carcass meat, fat and bone proportions, proportion of high-value cuts in the carcass and meat, carcass conformation and fat scores, perinephric and retroperitoneal fat and carcass value

			Proportion in carcass						Carcass		
	Carcass weight	[1]KO	Meat	Fat	Bone	HVC	[2]HVC in Meat	Perinephric + Retroperitoneal fat	Conformation Score	Fat Score	Value
Conformation Score	0.80***	0.84***	0.78***	-0.41***	-0.90***	0.50***	-0.06	-0.08	1.00	0.03	0.76***
Fat Score	0.06	-0.11	-0.38***	0.63***	-0.04	-0.20	0.08	0.29*	0.03	1.00	-0.33**

[1] Kill-out proportion; [2] High-value cuts.

*P < 0.05, **P < 0.01, ***P < 0.001

Table 4.7: Multiple regression equations using live animal muscular scores obtained by Assessor A and ultrasound scanned measurements taken at 8 to 12 months and pre-slaughter for predicting carcass meat, fat and bone proportions

	Intercept	Muscular score (scale 1 to 15)	Scanned muscle depth (mm)	Scanned fat depth (mm)	R^2	Residual Standard Deviation
8 to 12 months						
Meat proportion						
Muscular score (g/kg)	635	12.9(1.71)***			0.43	29.8
Scanned muscle and fat (g/kg)	578		1.9(0.476)***	25.9(12.39)*	0.39	30.9
Fat proportion						
Muscular score (g/kg)	119	-3.9(1.38)**			0.09	24.1
Scanned muscle and fat (g/kg)	143		-0.76(0.372)*	-3.1(9.70)	0.10	24.2
Bone proportion						
Muscular score (g/kg)	246	-9.0(0.776)***			0.65	13.5
Scanned muscle and fat (g/kg)	279		-1.1(0.23)***	-22.8(5.94)***	0.58	14.8
Slaughter						
Meat proportion						
Muscular score (g/kg)	616	11.3(1.28)***			0.51	27.7
Scanned muscle and fat (g/kg)	534		3.0(0.30)***	-15.0(2.69)***	0.62	24.4
Fat proportion						
Muscular score (g/kg)	123	-3.23(1.111)**			0.10	24.0
Scanned muscle and fat (g/kg)	146		-1.12(0.222)***	14.5(2.01)***	0.48	18.3
Bone proportion						
Muscular score (g/kg)	260	-8.1(0.47)***			0.80	10.2
Scanned muscle and fat (g/kg)	320		-1.92(0.164)***	0.53(1.483)	0.65	13.5

*P < 0.05, **P < 0.01, ***P < 0.001

Table 4.8: Regression equations using live animal muscle scores obtained by Assessor A and ultrasound muscle and fat measurements at 8 to 12 months and pre-slaughter for predicting the proportions of meat, fat, bone and high-value meat cuts in the carcass and carcass value

	Intercept	Muscular Score (scale 1 to 15)	Muscle depth (mm)	Fat depth (mm)	R^2	Residual Standard Deviation
8 to 12 months						
Carcass weight (kg)	73	5.7(3.40)	3.3(0.654)***	24.4(14.16)	0.69	31.9
Kill-out proportion (g/kg)	459	9.8(2.41)***	0.6(0.46)	15.9(10.0)	0.62	22.6
Meat proportion (g/kg)	604	8.4(3.16)**	0.8(0.61)	10.7(13.17)	0.44	29.7
Fat proportion (g/kg)	137	-2.1(2.59)	-0.5(0.50)	0.7(10.77)	0.07	24.3
Bone proportion (g/kg)	260	-6.3(1.40)***	-0.33(0.270)	-11.5(5.84)	0.67	13.1
Proportion of high priced cuts (g/kg)	63	1.0(0.53)	0.03(0.103)	1.3(2.23)	0.19	5.0
High-value cuts as proportion of meat (g/kg)	104	0.27(0.672)	-0.06(0.129)	-0.07(2.80)	0.00	6.3
Carcass value (c/kg)	252	3.8(1.58)*	0.38(0.304)	8.9(6.58)	0.44	14.8
Slaughter						
Carcass weight (kg)	84	13.3(2.56)***	1.8(0.66)**	2.5(3.28)	0.74	30.0
Kill-out proportion (g/kg)	466	11.8(1.766)***	0.2(0.46)	-5.6(0.23)*	0.69	20.5
Meat proportion (g/kg)	593	9.2(1.82)***	1.0(0.47)*	-16.4(2.34)***	0.72	21.0
Fat proportion (g/kg)	129	-2.5(1.56)	-0.57(0.403)	14.9(2.003)***	0.49	18.1
Bone proportion (g/kg)	277	-6.7(0.86)***	-0.47(0.222)*	1.5(1.10)	0.81	9.9
Proportion of high priced cuts (g/kg)	57	0.56(0.366)	0.21(0.094)*	-2.1(0.47)***	0.42	4.2
High-value cuts as proportion of meat (g/kg)	97	-0.5(0.54)	0.15(0.138)	-0.74(0.690)	0.03	6.2
Carcass value (c/kg)	241	4.1(0.90)***	0.6(0.233)**	-8.1(1.16)***	0.72	10.4

*P < 0.05, **P < 0.01, ***P < 0.001

Table 4.9: Regression on carcass conformation and fat scores of carcass weight, kill-out proportion, carcass meat, fat and bone proportions, proportion of high-value cuts in the carcass and in meat and carcass value

	Intercept	Conformation Score (Scale 1 to 15)	Fat Score (Scale 1 to 15)	R^2	Residual Standard Deviation
Carcass weight (kg)	128	17.8 (1.56)***	2.8 (3.0)	0.64	34.5
Kill-out proportion (g/kg)	477	11.9 (0.89)***	-2.9 (1.73)	0.71	2.0
Meat proportion (g/kg)	685	11.9(0.91)***	-11.1 (1.77)***	0.74	20.2
Fat proportion (g/kg)	41.7	-4.0 (0.76)***	11.8 (1.48)***	0.55	16.9
Bone proportion (g/kg)	273	-7.9 (0.46)***	-0.7 (0.89)	0.80	10.2
Proportion of high priced cuts in carcass (g/kg)	68.6	1.1 (0.21)***	-0.9 (0.42)*	0.28	4.8
High-value cuts as proportion of meat (g/kg)	100	-0.1 (0.28)	0.4 (0.55)	0.01	6.3
Carcass value (c/kg)	287	5.8 (0.50)***	-4.9 (0.99)***	0.68	11.3

*P < 0.05, ***P < 0.001

Chapter 5

Experiment 3 - Predicting beef carcass meat, fat and bone proportions from carcass conformation and fat scores or hind-quarter dissection

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Experiment 3 - Predicting beef carcass meat, fat and bone proportions from carcass conformation and fat scores or hind-quarter dissection

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Running heading: Predicting carcass composition from carcass traits

5.1 Abstract

Equations for predicting the meat, fat and bone proportions in beef carcasses using the EU carcass classification scores for conformation and fatness, and hind-quarter composition were developed and their accuracy was tested using data from 662 cattle. The animals comprised of bulls, steers and heifers, and consisted of Holstein, British Friesian, early- and late-maturing breeds × Friesian, early-maturing × early-maturing, late-maturing × early-maturing and genotypes with 0.75 or greater late-maturing ancestry. Bulls, heifers and steers were slaughtered at 15, 20 and 24 months of age, respectively. The diet offered prior to slaughter comprised of grass silage only, grass or maize silage plus supplementary concentrates, or concentrates offered ad-*libitum* plus 1 kg of roughage dry matter per head daily. Following slaughter, carcasses were classified mechanically for conformation and fatness (scale 1 to 15), and the right side of each carcass was dissected into meat, fat, and bone. Carcass conformation score ranged from 4.7 to 14.4, 5.4 to 10.9 and 2.0 to 12.0 for bulls, heifers and steers, respectively; the corresponding ranges for fat score were 2.7 to 11.5, 3.2 to 11.3 and 2.8 to 13.3. Prediction equations for carcass meat, fat and bone proportions were developed using multiple regression, with carcass conformation and fat score both included as continuous independent variables. In a separate series of analyses, the independent variable in the model was the proportion of the trait under investigation (meat, fat or bone) in the hind-quarter. In both analyses, interactions between the independent variables and gender were tested. The predictive ability of the developed equations was assed using cross-validation on all 662 animals. Carcass classification scores accounted for 0.73, 0.67 and 0.71 of the total variation in carcass meat, fat, and bone proportions, respectively, across all 662 animals. The corresponding values using hind-quarter meat, fat and bone in the model were 0.93, 0.87 and 0.89. The bias of the prediction equations when applied across all animals was not different from zero, but bias did exist among some of the genotypes of animals present. In conclusion, carcass classification scores and hind-quarter composition are accurate and efficient predictors of carcass meat, fat and bone proportions.

Keywords: Beef cattle, carcass classification, prediction equations, carcass dissection

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5.2 Implications

This study shows the potential of European Union carcass conformation and fat scores to predict carcass meat proportion and thus, facilitate the operation of a payment system based on meat yield, which would reward farmers more equitably. Also, prediction equations developed from hind-quarter composition would reduce the huge cost associated with whole carcass dissection and make it more beneficial and appealing to those carrying out carcass studies.

5.3 Introduction

In the European Union (EU), beef carcasses are classified according to their conformation and fatness (ECIR0811981) (Allen, 2007). In 2004, Ireland replaced visual assessment with mechanical classification using a video image analysis (VIA) system. Automated classification simply mimics the human assessor by analysing an image of the carcass (Fisher, 2007). Machine classification is deemed preferable to visual assessment because of greater consistency and producers can have more confidence in the objectivity of the results (Allen *et al.*, 2007). Several studies quantified the associations of ultrasound (Faulkner *et al.,* 1990; Herring *et al.,* 1994; Hamlin *et al.*, 1995) and live animal scores (Perry *et al.*, 1993a and 1993b) with carcass traits. However, few studies have examined the relationship between EU carcass classification scores and carcass composition (Drennan *et al.*, 2008; Conroy *et al.,* 2009; Conroy *et al.,* 2010). Muldowney *et al.* (1997) reported that although conformation (EUROP coded 1 to 5) and fat scores (1 to 5) are routinely measured on beef carcasses their value as indicators of carcass characteristics and commercial value is not well established. Carcass conformation and fat scores have explained moderate to high proportions of the variation (R^2 ranged from 0.47 to 0.70) in carcass meat yield (Perry *et al.*, 1993b; Drennan *et al.,* 2008; Conroy *et al.,* 2009,2010). According to Gardner *et al.* (1997), the evaluation technique used to predict meat yield must be able to function on-line in a commercial setting without disrupting the normal product flow. Johnson and Chant (1998) noted that research has used very expensive technologies to improve the accuracy of carcass composition prediction, while Shackelford *et al*. (1995) reported that, to their knowledge, equations to predict boneless and totally trimmed retail cut yields have not been published.

Considering that payment for carcasses in the EU is based on carcass conformation and fat scores, and that these data are routinely available on carcasses, it seems logical to develop equations that predict carcass meat, fat and bone proportions using these scores. Accurate equations to predict carcass characteristics from routinely collected data would facilitate payment systems based on carcass meat proportion which, in addition to the specific market, is the main determinant of carcass value. Due to the differences in the value of different meat cuts, both meat yield and distribution are the primary determinants of carcass value (Drennan, 2006). Purchas *et al.* (1999) concluded that improvements in accuracy of predicting saleable meat yield proportion would provide an opportunity to increase the premiums paid on carcasses that excel in this characteristic. Payment based on meat yield would also send a stronger market signal to the producer since in a value-based marketing system the viability of the beef industry is dependent on the production of high quality, consistent carcasses (Hassan *et al.*, 1998).

In an industry that is seeking increasingly detailed data on carcass composition, an accurate and rapid technique to estimate carcass composition would be invaluable. A long-term objective of carcass dissection studies should be the development of accurate part to whole carcass composition relationships that would reduce the resource requirement that is now an integral part of detailed carcass dissection (Johnson and Charles, 1981). Zgur *et al.* (2006) reported that various individual cuts from the carcass explained moderate to high amounts of variation (0.58 to 0.80) in the percentage of carcass meat, fat and bone.

Therefore, the objectives were (1) to develop and test the accuracy of prediction equations for carcass meat, fat and bone proportions, derived from carcass conformation and fat scores, and (2) to develop prediction equations for total carcass composition from hind-quarter composition.

5.4 Materials and Methods

5.4.1 Animals and Management

A total of 662 animals comprising of 115 bulls, 40 heifers and 507 steers were available for inclusion in the analysis. The animals were partitioned into the following genotype groups (i) Holstein-Friesian; (ii) Early-maturing × Holstein Friesian and early-maturing × early-maturing; (iii) Late-maturing × Holstein Friesian and late-maturing × early-maturing and (iv) genotypes with 0.75 or greater late-maturing ancestry.

Bulls were slaughtered at 13 to 17 months of age on 3 different dates. The heifers were slaughtered at approximately 20 months of age on one day, whereas the steers were slaughtered at approximately 24 months of age on 12 different dates. Prior to slaughter, the bulls were offered *ad-libitum* access to a barley-based concentrate plus 1 kg of grass silage dry matter per head daily or, grass silage plus approximately 4 kg of a barley-based concentrate per head daily. The heifers were offered grass silage *ad-libitum* and approximately 4 kg of a barley-based concentrate per head daily. The diets offered to the steers prior to slaughter comprised either, grass silage only, grass or maize silage plus supplementary concentrates, or concentrates offered ad-*libitum* plus 1 kg of roughage dry matter per head daily.

Treatment for endo- and ecto-parasites and vaccination against clostridial and respiratory diseases was carried out as deemed necessary.

5.4.2 Carcass evaluations and measurements

Carcass conformation and fat scores were obtained using the mechanical grading system on a 15 point scale (Hickey *et al.*, 2007) rather than a 5 point scale (Commission of the European Communities, 1982). Hot weight of both sides of each carcass was recorded and cold carcass weight was taken as 0.98 of hot carcass weight. Following a period of 24 hours at 4°C, the right side of each carcass was quartered at the 5th rib into an 8-rib hind-quarter (pistola) and the remaining fore-quarter. After recording the weight, the hind-quarter was dissected into thirteen cuts (leg, heel, silverside, topside, knuckle, rump, tail of rump, cap of rump, fillet, strip loin, cube roll, cap of rib and eye of the round) from which all visible fat and bone (where applicable) were removed (Conroy *et al.*, 2009). The weight of each individual meat cut and total fat from the hind-quarter was recorded, as was bone weight following removal of all adhering lean tissues. Lean trim was weighed separately and included with the meat cuts to give total hind-quarter meat yield. A similar procedure was carried out with the fore-quarter, which was dissected into eleven cuts (front shin, neck, brisket, chuck, flat ribs (1-5), plate, *M. triceps brachii*, bladesteak, braising muscle, chuck tender and clod) (Conroy *et al.*, 2009). Hind-quarter and fore-quarter meat, fat and bone weights were combined to give the weight of each component in the half carcass. Recovered weights were calculated and expressed as a proportion of side weight to check for errors in weighing (Perry *et al.*, 1993a).

5.4.3 Statistical Analysis

Two series of analyses were undertaken (SAS, 2008), where in all cases, the dependent variable was carcass meat, fat or bone proportion. In the first series of analyses carcass conformation and fat score were included as continuous independent variables, while in the second series of analyses the continuous independent variable was the hind-quarter proportion of the dependent variable under investigation (i.e., when the dependent variable was carcass meat proportion the independent variable was hind-quarter meat proportion). In both series of analyses the same procedures were used.

Preliminary analyses were undertaken on all data to develop the most parsimonious multiple regression prediction model using backward elimination. Gender, linear and non-linear associations with the regressors, as well as two way interactions between gender and the continuous independent variables, were initially included in the model; gender was included as a class effect with 3 levels (bulls, steers and heifers). Terms that didn't make a significant contribution ($P>0.05$) to the regression equation were removed. The proportion of variation in the dependent variable explained by the model was quantified.

The ability of the developed equation at predicting meat, fat and bone yield was undertaken using cross-validation. This involved omitting each of the 662 animals individually from the development of the prediction equation and then applying the equation to the omitted animal to predict its meat, fat and bone yield. Residuals were calculated as the difference between true total carcass composition and predicted carcass composition. Parameters used to quantify the predictive ability of the equations were: 1) the normality of the residuals, 2) the average bias, computed as the mean of the residuals, 3) the root mean square error (RMSE), computed as the standard deviation of the residuals, 4) accuracy of the fit defined as the variance of the dependent variable divided by the sum of the variance of the dependent variable and the variance of the residuals, 5) the 25% and 75% quartiles of the residuals, and 6) the correlation between the predicted proportions and the residuals.

Additional analyses were undertaken using a fixed effects linear model to determine if there was any systematic bias in the estimation of total carcass composition across genotype. Genotypes were (1) Holstein-Friesian (2) Early-maturing × Holstein-Friesian and early-maturing × early-maturing (3) Late-maturing × Holstein-Friesian and late-maturing × early-maturing and (4) genotypes with 0.75 or greater late-maturing ancestry. Following the completion of the analysis, prediction equations using carcass conformation and fat scores or hind-quarter composition were developed on the entire dataset and these are presented in this study.

5.5 Results

The mean, range and standard deviation for live animal, carcass traits and carcass yield components for bulls, heifers and steers are summarised in Table 1. At slaughter, the bulls, heifers and steers had a mean age of 454, 606 and 751 days, a live weight of 583, 535 and 625 kg, and a cold carcass weight of 332, 293 and 333 kg, respectively. Carcass conformation scores ranged from 4.7 to 14.4 for bulls, 5.4 to 10.9 for heifers and 2.0 to 12.0 for steers. Corresponding fat scores ranged from 2.7 to 11.5, 3.2 to 11.3, and 2.8 to 13.3.

5.5.1 Prediction equations using carcass conformation and fat scores

Prediction equations developed from the entire dataset for carcass meat, fat and bone proportions using carcass conformation and fat scores are summarised in Table 2. Gender was associated ($P<0.001$) with carcass composition although the relationship between either carcass conformation or fat score and carcass composition did not differ by gender. Furthermore, no non-linear associations ($P > 0.05$) between carcass conformation or fat score and carcass composition were evident. The correlation between carcass conformation and fat score (r = -0.07) was not different from zero.

Across genders, and at a constant carcass fat score, a one unit increase in carcass conformation score on a 15 point scale was associated with an increase in carcass meat proportion of 11.8 g/kg, whereas a one unit increase in carcass fat score was associated with a 9.6 g/kg decrease in carcass meat proportion. For carcass fat proportion a one unit increase in conformation score was associated with a reduction in fat proportion of 4.4 g/kg, whereas a one unit increase in carcass fat score was associated with an increase of 12.0 g/kg in carcass fat proportion. Both regression coefficients in the model showed a negative association with carcass bone proportion, with decreases of 7.4 g/kg and 2.4 g/kg per unit increase in carcass conformation and fat score, respectively.

The prediction of carcass composition from carcass conformation and fat scores across genders accounted for 73%, 67% and 71% of total variation in carcass meat, fat and bone proportions, respectively.

There was no significant bias in estimating carcass composition across all animals nor was there any trend in the bias across different values for each carcass composition trait as evidenced by the lack of a correlation between the residuals and the predicted dependent variable. The root mean square error of prediction varied from 11.2 g/kg (carcass bone proportion) to 22.3 g/kg (carcass meat proportion); the accuracy of predicting carcass composition across genders ranged from 0.75 (carcass fat proportion) to 0.79 (carcass meat proportion). In the prediction of carcass meat proportion, 50% of the predicted values were within -14.07 to 15.00 g/kg of the true value. The interquartile range was lower, for the prediction of carcass fat proportion and lower still for the prediction of carcass bone proportion than for carcass meat proportion.

Using the equations developed with carcass conformation and fat scores there was no bias in prediction for carcass meat proportion across the different genotypes (Table 3), except for genotype 2 (Early-maturing × Holstein-Friesian and early-maturing × early-maturing) which was significantly overestimated (7.54 g/kg). Carcass fat proportion was found to be significantly under-estimated (-14.18 g/kg) and over-estimated (3.29 g/kg) in genotypes 2 (Early-maturing × Holstein-Friesian and early-maturing × early-maturing) and 3 (Late-maturing × Holstein-Friesian and late-maturing × early-maturing), respectively. Furthermore, carcass bone proportion in genotype 1 (Holstein-Friesian) and 2 was significantly under- and over-estimated by -2.92 g/kg and 6.60, respectively.

5.5.2 Prediction equations using hind-quarter composition

The prediction equations for estimating carcass meat, fat and bone proportions from dissected hind-quarter meat, fat and bone proportions are summarised in Table 4.

Although animal gender was associated ($P<0.001$) with carcass meat, fat and bone proportions, the association between total carcass composition and hind-quarter composition did not differ by gender nor was the association with hind-quarter composition non-linear.

Regression coefficients for hind-quarter meat, fat and bone proportions relative to the corresponding proportion in the carcass were 1.03, 1.17 and 0.89, respectively; the respective R^2 were 0.93, 0.87 and 0.89. The corresponding root mean squared error values were 11.43, 12.56 and 6.69; accuracy of predicting carcass meat, fat and bone proportions from carcass hind-quarter meat, fat and bone was 0.94, 0.91 and 0.77, respectively.

The lack of a significant bias across the entire data set signifies that carcass meat, fat and bone proportions were not under- or over-estimated from hind-quarter composition. Predictions of carcass meat, fat and bone proportions were under-estimated by at least 6.89 g/kg, 8.56 g/kg and 3.62 g/kg, respectively, in 25% of the dataset (i.e., 1st quartile) and over-estimated by at least 7.49 g/kg, 8.00 g/kg and 4.09 g/kg, respectively, in 75% of the dataset (i.e., 3rd quartile). Correlations between the residuals and predicted meat, fat and bone proportions were not different from zero.

Using the equation developed from hind-quarter composition across genotypes for the entire dataset (Table 5), carcass meat proportion was significantly over-estimated for genotype 2 (6.65 g/kg). Carcass fat proportion was significantly under-estimated in genotypes 1 (-2.88 g/kg) and 2 (-8.18 g/kg) and over-estimated (2.79 g/kg) in genotype 4. Hind-quarter bone over- and under-estimated carcass bone proportion for genotypes 2 (3.90 g/kg) and 3 (-2.13 g/kg), respectively.

5.6 Discussion

5.6.1 Carcass conformation and fat score prediction equations

Carcass conformation and fat scores on a 15 point scale were used in the prediction of carcass composition. Previous studies using 336 steers (Conroy *et al.,* 2009) and 74 bulls (Conroy *et al.,* 2010) showed carcass conformation and fat scores to be potential predictors of carcass meat, fat and bone proportions. The current study includes animals used by Conroy *et al.* (2009, 2010) in addition to bulls, heifers and steers of other genotypes, thus representing a greater proportion of the EU carcass classification grid.

The proportion of variation explained by the prediction equations in the present study using carcass conformation and fat scores for carcass meat proportion (0.73) was similar to the R^2 value of 0.70 reported by Drennan *et al.* (2008) for bulls but higher than the value they reported in heifers ($R^2 = 0.55$). Delfa *et al.* (2007) explained higher amounts of variation ($R^2 = 0.97$) in carcass muscle weight using hot carcass weight and EU carcass conformation score (on 15 point scale). However, the latter authors also reported that a lower proportion of variation in carcass meat, fat and bone are explained, when they are expressed as a percentage of carcass. In contrast, Taylor *et al.* (1990) found that using P8 fat thickness and shape score (i.e. carcass conformation) explained little variation ($R^2 = 0.17$) in carcass meat proportion. Similarly, Perry *et al.* (1993a, b) in predicting carcass meat proportion using hot carcass weight, P8 fat depth and carcass muscle score (15 point scale), obtained R^2 values of 0.47 and 0.52, which are lower than values obtained in the current study. However, according to Amer *et al.* (1998) carcass conformation score has emerged as a more important determinant of value of finished cattle than was implied previously.

The proportion of variation in total carcass fat proportion explained by carcass conformation and fat scores in the present study (0.67) is within the range of 0.57 to 0.77 reported for bulls, steers and heifers (Taylor *et al.*, 1990; Drennan *et al.*, 2008). Equations developed by Jones *et al.* (1989) using visual carcass muscle and fat thickness scores on the cold carcass explained 56% of total variation in carcass fat proportion. Using stepwise regression, Delfa *et al.* (2007) reported that EU carcass fat score (on a 15 point scale) explained 32% of total variation in carcass fat weight, increasing to 39% when hot carcass weight was added and to 60% with the addition of EU carcass conformation score.

Carcass conformation and fat scores accounted for 0.71 of total variation in carcass bone proportion, which is considerably greater than the values of 0.34 and 0.30 obtained by Drennan *et al.* (2008) for bulls and heifers, respectively. The low R^2 values obtained by those authors may be attributed to the fact that the animals used were 7/8 continental ancestry and had a high meat yield and low bone yield compared to the wide range of genotypes in the present study.

In addition to R^2 values, both a value for accuracy and RMSE were also used to measure the precision with which carcass conformation and fat scores predicted carcass composition. The high accuracy (0.75 to 0.79) and low RMSE (ranging from 1.1 to 2.2% for meat yield) values obtained using equations developed from carcass conformation and fat scores, indicate that carcass classification scores could be used as an acceptable predictor of carcass composition. Perry *et al.* (1993a) also reported low RMSE of 1.77 and 1.76% for carcass meat and fat percent, respectively. Using hot carcass weight, fat class and conformation score, Kempster and Harrington (1980) obtained a RMSE of 1.68% for saleable meat percentage in the carcass. Allen and Finnerty (2001) found that carcass conformation was the single best predictor of saleable meat yield (RMSE = 1.23%), with fat score and carcass weight adding little to precision, which is probably due to the fact that not all fat was trimmed from the carcass in that study. Purchas *et al.* (1999) in their review of six studies found that the typical RMSE encountered when predicting beef carcass saleable meat percentage generally fell within the range of 1.4 and 2.7%. Given the fact that carcass classification scores are already recorded for carcasses throughout the EU and that it is a non-invasive method of estimating carcass composition this makes it practical for abattoirs to implement at little additional cost. Also, the fact that predicted values were unbiased relative to actual values in the present study, agrees with Purchas *et al.* (1999) who suggested that unbiased prediction equations are needed if equations based on meat yield are to be used by the industry. In the current study the interquartile range was lower for the prediction of carcass fat proportion and lower still for the prediction of carcass bone proportion than for carcass meat proportion. This is not unexpected as the quartiles Q1 and Q3 are not dimensionless and carcass meat proportion values are appreciably higher than fat and bone; thus it may be noted that on a proportionate basis the interquartile range is lowest for meat.

5.6.2 Hind-quarter prediction equations

Hind-quarter composition was used in prediction equations as it is more easily and accurately dissected than the fore-quarter and is the most valuable part of the carcass. Hind-quarter dissection apart from requiring less time to dissect is associated with less experimental error (Johnson and Charles, 1981; Fan *et al.*, 1992). The accurate prediction of carcass composition from hind-quarter also probably results from the fact that it represents a high proportion of the side (Johnson and Charles, 1981).

In the current study, the regression coefficients (0.89 to 1.17) obtained from the prediction equations when hind-quarter meat, fat and bone were used to predict the corresponding tissues in the carcass were similar (0.94 to 1.10) to those obtained by Johnson and Charles (1981) using Angus, Friesian and Hereford steer carcasses. The proportion of total variation in carcass composition explained by hind-quarter composition in the present study (0.87 to 0.93) was greater than that obtained by Zgur *et al.* (2006) who reported R^2 values of 0.78, 0.80 and 0.59 when predicting carcass meat, fat and bone proportions, respectively, from a leg cut (similar to hind-quarter in the current study). Fan *et al.* (1992) also reported that the proportion of lean in individual cuts (i.e. hip, loin, flank, rib, chuck, brisket, and plate) were found to be a strong predictor (R^2, 0.47 to 0.78) of the proportion of lean in the carcass. The RMSE from predicting carcass composition from hind-quarter composition ranged from 6.7 to 12.6 g/kg, which is similar to values (RMSE = 2.1 to 11.3 g/kg) obtained by Zgur *et al.* (2006). The lack, in general, of any bias in estimating carcass composition agrees with the findings of Kempster and Jones (1977) who predicted carcass lean percent from percentage lean in the various cuts. However, Zgur *et al.* (2006) concluded that carcass muscle percentage was under-estimated in very lean carcasses and over-estimated in fat carcasses, and vice versa for fat percentage, whereas the accuracy of bone prediction was not affected by fat percentage in the carcass. The lack of a correlation between the residuals and predicted values indicate that this was not the case in the present study.

5.6.3 Genotype effects on prediction bias

In the present study bias of prediction of carcass composition was evident in some genotypes. These findings agree with Kempster and Cuthbertson (1977) who reported that breed group differences existed in both carcass conformation and composition at constant subcutaneous fat levels. However, Johnson and Charles (1981) reported no breed differences in the prediction of carcass components from hindquarter meat, fat and bone. Kempster and Chadwick (1986) using both visual assessment and measurements of fat, examined the robustness of prediction equations by applying them to independent sets of data (a total of 334 carcasses) from 4 trials involving steers, heifers, cows and young bulls and found that equations were stable for cattle of the same breed, gender and similar level of fatness but important biases were obtained between more extreme types of cattle. In contrast, Crouse *et al.* (1975) examining various prediction equations from different studies using USDA grading concluded that use of a single prediction equation for all genotype groups would rank animals well within a breed group but on average would under- or over-estimate animals of a breed group by up to 1% relative to its actual carcass cutability.

In the current study, some biases may have been obtained possibly due to the smaller number of animals dissected in the respective category. It may also be considered that genotype 2, which was biased with carcass meat fat and bone may be a result of early-maturing genotypes having a higher percentage of separable fat than other genotypes (Barton *et al.*, 2006).

5.7 Conclusion

These results show that equations developed using carcass conformation and fat scores were accurate predictors (i.e. high R^2 and low RMSE) of carcass meat, fat and bone proportions and are applicable across gender and genotype. These equations could have a useful role in rewarding farmers for producing animals with better carcass traits by implementing a payment system based on predicted meat yield. As carcass classification in Ireland is carried out using video imaging analysis machines, the implementation of a payment system based on carcass composition would be quick and practical with little or no additional expense to the abattoir.

Equations developed using hind-quarter composition were also shown to accurately predict carcass meat, fat and bone proportions. These equations would reduce the huge cost associated with whole carcass dissection and make it more beneficial and appealing to those carrying out carcass studies.

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Table 5.1. Mean, standard deviation (SD) and range for live and carcass measurements and yield components of bulls, heifers and steers.

Trait	Mean	SD	Minimum	Maximum
Bulls (n =115)				
Pre-slaughter weight (kg)	583	81.89	408	857
Cold carcass weight (kg)	332	56.0	207	475
Kill-out (g/kg)	567	34.0	484	669
Slaughter age (days)	454	38	386	569
Conformation score[1]	9.8	2.23	4.7	14.4
Fat score[1]	7.8	1.35	2.7	11.5
Carcass meat proportion (g/kg)	727	41.4	627	840
Carcass fat proportion (g/kg)	85	27.4	31	163
Carcass bone proportion (g/kg)	188	21.2	129	251
Heifers (n = 40)				
Pre-slaughter weight (kg)	535	55.1	441	642
Cold carcass weight (kg)	293	30.1	242	359
Kill-out (g/kg)	548	22.8	497	585
Slaughter age (days)	606	27	554	647
Conformation score[1]	8.4	1.48	5.4	10.9
Fat score[1]	7.6	2.22	3.2	11.3
Carcass meat proportion (g/kg)	722	39.3	637	798
Carcass fat proportion (g/kg)	93	34.1	37	171
Carcass bone proportion (g/kg)	185	13.6	158	210
Steers (n = 507)				
Pre-slaughter weight (kg)	625	77.8	435	884
Cold carcass weight (kg)	333	49.8	234	501
Kill-out (g/kg)	532	27.3	469	621
Slaughter age (days)	751	52	437	915
Conformation score[1]	6.8	2.20	2.0	12.0
Fat score[1]	8.5	1.89	2.8	13.3
Carcass meat proportion (g/kg)	679	13.3	564	785
Carcass fat proportion (g/kg)	123	31.8	47	260
Carcass bone proportion (g/kg)	197	20.2	150	262

[1] Scale 1 to 15

Table 5.2. Prediction equations for meat, fat and bone proportion estimated using a linear model on the entire dataset (662 animals) using carcass conformation and fat score. The table contains the intercept and regression coefficient of the regression model estimated from the entire dataset including the r-square of the model fit using the entire dataset. Also included are the bias, root mean square error (RMSE), and accuracy of prediction as well as the 25% (Q1) and 75% (Q3) quartiles of the residuals and the correlation between the predicted compositions and residuals (r_e).

	Entire dataset				Validation dataset					
Trait	Intercept (se)[1]	Conformation score (se)	Fat score (se)	R-square	Bias (se)	RMSE	Accuracy	Q1	Q3	r_e
Meat proportion (g/kg)	704 (2.20) [2] 713 (3.52) 698 (1.12)	11.82 (0.40)	-9.56 (0.47)	0.73	-0.004 (0.867)[3]	22.3	0.79	-14.07	15.00	0.004[4]
Fat proportion (g/kg)	96 (2.00) 100 (3.20) 113 (1.014)	-4.40 (0.36)	11.95 (0.43)	0.67	-0.003 (0.778) [3]	20.27	0.75	-12.60	13.50	0.005[4]
Bone proportion (g/kg)	200(1.10) 187 (1.76) 190 (0.56)	-7.41 (0.20)	-2.39 (0.24)	0.71	-0.002 (0.434) [3]	11.16	0.77	-6.89	7.49	0.004[4]

RMSE = root mean squared error

[1] Intercept chosen to represent conformation score of 8 and fat score of 8; intercepts presented from top to bottom represent bulls, heifers and steers, respectively

[2] Example: Meat yield (g/kg) of bulls = 704 + 11.82* (conformation score - 8) - 9.56* (fat score - 8)

[3] Bias not different from zero

[4] Correlation not different from zero

Table 5.3. Average bias in prediction across genotypes (662 animals) from prediction equation including carcass conformation and fat scores as well as 25% (Q1) and 75% (Q3) quartiles of the residuals

Trait	Genotype[1]	Bias (se)	Q1	Q3
Meat proportion (g/kg)	1	3.20 (1.79)	-10.94	17.43
	2	7.54 (2.58)**	-4.36	21.05
	3	-2.30 (1.67)	-15.24	8.59
	4	-2.41 (1.36)	-17.25	15.42
Fat proportion (g/kg)	1	-0.258 (1.59)	-13.24	13.52
	2	-14.17 (2.30)***	-27.73	0.859
	3	3.29 (1.49)*	-6.66	13.95
	4	1.90 (1.21)	-12.13	15.87
Bone proportion (g/kg)	1	-2.92 (0.881)**	-9.13	4.38
	2	6.60 (1.27)***	1.72	13.81
	3	-0.96 (0.823)	-7.58	6.50
	4	0.49 (0.670)	-6.51	7.12

*Value different ($P<0.05$) from zero

[1] Genotypes = 1) Holstein-Friesian (n = 152); 2) Early-maturing × Holstein-Friesian and early-maturing × early-maturing (n = 73); 3) Late-maturing × Holstein-Friesian and late-maturing × early-maturing (n = 174) and 4) genotypes with 0.75 or greater late-maturing ancestry (n = 263).

Table 5.4. Prediction equations for meat, fat and bone proportion estimated using a linear model on the entire dataset (662 animals) using hindquarter weights. The table contains the intercept and regression coefficient of the regression model estimated from the entire dataset including the r-square of the model fit using the entire dataset. Also included are the bias, root mean square error (RMSE), and accuracy of prediction as well as the 25% (Q1) and 75% (Q3) quartiles of the residuals and the correlation between the predicted compositions and residuals (r_e).

	Entire dataset			Validation dataset					
Trait	Intercept (se)[1]	Hindquarter (se)	R-squared	Bias (se)	RMSE	Accuracy	Q1	Q3	r_e
Meat proportion (g/kg)	686.6 (1.17) 674.8 (1.89) 676.6 (0.51)	1.03 (0.013)	0.93	-0.001 (0.444)[2]	11.43	0.94	-6.89	7.49	0.0013[3]
Fat proportion (g/kg)	118.8 (1.30) 126.9 (2.06) 130.4 (0.57)	1.17 (0.020)	0.87	-0.001 (0.488)[2]	12.56	0.91	-8.56	8.00	0.002[3]
Bone proportion (g/kg)	197.2 (0.64) 199.9 (1.08) 194.3 (0.30)	0.89 (0.012)	0.89	-0.0004 (0.26)[2]	6.69	0.77	-3.62	4.09	0.002[3]

RMSE = root mean squared error

[1] Intercept chosen to represent conformation score of 8 and fat score of 8; intercepts presented from top to bottom represent bulls, heifers and steers, respectively

[2] Bias not different from zero

[3] Correlation not different from zero

Table 5.5. Average bias in prediction across genotypes (662 animals) from prediction equation including carcass hindquarter meat fat and bone proportions as well as 25% (Q1) and 75% (Q3) quartiles of the residuals

Trait	Genotype[1]	Bias (se)	Q1	Q3
Meat proportion (g/kg)	1	0.44 (0.91)	-7.46	8.61
	2	6.65 (1.31)***	-0.41	13.70
	3	-0.32 (0.85)	-7.49	6.94
	4	-1.89 (0.69)	-9.12	4.49
Fat proportion (g/kg)	1	-2.88 (0.98)**	-11.36	4.87
	2	-8.18 (1.41)***	-15.50	0.91
	3	1.18 (0.91)	-6.48	8.92
	4	2.79 (0.74)***	-4.89	10.06
Bone proportion (g/kg)	1	0.47 (0.53)	-3.60	5.12
	2	3.90 (0.76)***	0.19	7.47
	3	-2.13 (0.49)***	-5.83	1.82
	4	0.05 (0.40)	-3.17	3.86

*Value different ($P<0.05$) from zero

[1] Genotypes = 1) Holstein-Friesian (n = 152); 2) Early-maturing × Holstein-Friesian and early-maturing × early-maturing (n = 73); 3) Late-maturing × Holstein-Friesian and late-maturing × early-maturing (n = 174) and 4) genotypes with 0.75 or greater late-maturing ancestry (n = 263).

Chapter 6

Experiment 4 - Live animal muscular scores as predictors of carcass traits in suckler-bred and artificially reared dairy-bred male cattle.

Experiment 4 - Live animal muscular scores as predictors of carcass traits in suckler-bred and artificially reared dairy-bred male cattle

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6.1 Abstract

The effectiveness of various live animal visual muscular scores as predictors of carcass traits was determined using data from a total of 622 suckler-bred and artificially reared, dairy-bred male cattle. The animals included 115 bulls and 507 steers slaughtered at 15 and 24 months of age, respectively, and comprised of Holstein–Friesian, early- and late-maturing breeds × Holstein–Friesian, early-maturing × early-maturing, late-maturing × early-maturing and genotypes with 0.75 or greater late-maturing ancestry. The diet offered prior to slaughter comprised of grass silage only, grass or maize silage plus supplementary concentrates, or concentrates offered ad-*libitum* plus 1 kg of roughage dry matter per head daily. Live animal muscular scores were recorded at 6 locations,

width at withers, width behind withers, loin development, development of hind-quarters, width of hind-quarters and development of the inner thigh, at 8 to 12 months of age and pre-slaughter at 13 to 26 months of age. Following slaughter, each carcass was classified mechanically for conformation and fatness (scale 1 to 15) and the right side was dissected into meat, fat and bone. Prediction equations were developed using multiple regression analysis. When recorded at 8 to 12 months of age hind-quarter development score alone accounted for 0.48 to 0.61 and 0.28 to 0.53 of the variation in carcass traits for bulls and steers, respectively. Corresponding ranges in values pre-slaughter were 0.57 to 0.84 and 0.40 to 0.62. Relatively little additional variation was explained by other traits of which, hindquarter width was the most prominent. In all cases live animal scores obtained pre-slaughter explained more variation in the various carcass traits measured than those obtained at 8 to 12 months of age. For suckler-bred steers, correlations of individual live animal muscular scores at 8 to 12 months of age with proportion of meat in the carcass and pistola were not statistically significant. Corresponding correlations for dairy-bred steers, although low (0.15 to 0.40), were significantly different from zero. In both dairy-bred and suckler-bred steers, correlations of live animal muscular scores at 8 to 12 months of age with carcass and pistola meat to bone ratio and, carcass conformation score were significantly different from zero (r ranging from 0.21 to 0.43). Pre-slaughter, correlations of live animal muscular scores with proportions of carcass and pistola meat content ranged from 0.20 to 0.49 for suckler-bred and, 0.30 to 0.59 for dairy-bred steers, respectively. Corresponding ranges in correlations with both carcass and pistola meat to bone ratios and, carcass conformation score were 0.59 to 0.72 and 0.53 to 0.70. In conclusion, visual muscular scoring systems are useful predictors of carcass traits in male cattle and can be simplified, to focus on development of hind-quarter, without decreasing accuracy.

Muscular scores obtained pre-slaughter explained more variation in carcass traits than those obtained at 8 to 12 months of age. The relationship between muscular scores obtained pre-slaughter and carcass traits was relatively similar for both suckler-bred and artificially reared dairy-bred steers.

Keywords: Beef cattle, carcass classification, carcass dissection, muscular scores

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6.2 Introduction

Live animal muscular and skeletal scores are becoming more widely used as early predictors of carcass traits in genetic improvement programmes for beef cattle. These indicators are particularly important in pedigree breeding programmes because carcass data is not available on those animals. The Irish Cattle Breeding Federation (ICBF) uses a linear scoring system, across all breeds, to assess muscular and skeletal characteristics of individual animals (ICBF, 2002). Recent studies have shown that live animal muscular scores were useful indicators of carcass conformation score and carcass meat proportion but that live animal skeletal scores were generally poorly related to carcass traits (Drennan *et al.,* 2008; Conroy *et al.,* 2009 and 2010).

Muscular scoring is a subjective assessment, which needs continual up-skilling and comparison to an experienced assessor (McKiernan, 2001). The ICBF scoring system assigns muscular scores on a scale of 1 (poor) to 15 (excellent), at a number of anatomical locations including width at withers, width behind withers, loin development, development of hind-quarters, width of hind-quarters and development of the inner thigh (ICBF, 2002). A more simplified muscular scoring system, using fewer locations, without any deterioration in accuracy of evaluations, would result in a greater throughput at a lower cost per animal. This would facilitate improved accuracy of genetic evaluations that assist farmers in making the best breeding decisions for their herd.

Currently, little information is available on the usefulness of live animal muscular scores as predictors of carcass traits in suckler-bred and dairy-bred beef cattle. In commercial practice, animals from both suckled and bucket-reared production systems are linear scored and these data are used in genetic evaluations. Consequently, it is important to quantify the relationship between carcass traits across suckler-bred and dairy-bred beef cattle.

The objectives of this study were (1) to determine the relationship of live animal muscular scores at two distinct phases during their productive life, *viz.* 8 to 12 months of age and pre-slaughter, in predicting carcass traits in both bulls and steers and (2) to examine this relationship across suckler-bred and artificially reared dairy-bred steers.

6.3 Materials and methods

6.3.1 Animals and Management

A total of 622 animals comprising of 115 bulls and 507 steers were available for inclusion in the analysis. The animal genotypes included Holstein-Friesian, early-maturing × Holstein–Friesian, early-maturing × early-maturing, late-maturing × Holstein–Friesian and late-maturing × early-maturing and genotypes with 0.75 or greater late-maturing ancestry. The dairy-bred male calves were purchased at between 2 and 6 weeks of age and reared indoors on milk replacer, concentrates and hay as described by Fallon and Harte (1987) before being turned out to pasture. The suckled-bred animals were reared on their dams at pasture up until weaning at about nine months of age. At the end of the first grazing season animals were housed indoors. Bulls were offered barley-based concentrates ad-libitum plus 1 kg of grass silage dry matter per head daily, as roughage. Steers were offered grass silage and 1 to 3 kg of supplementary concentrates during the indoor winter period following which, they were grazed for a second grazing season and finished indoors. The diets offered to the steers before slaughter included one of the following; (i) grass silage only; (ii) grass or maize silage plus supplementary concentrates, or (iii) concentrates offered ad libitum plus 1 kg of roughage dry matter per head daily.

Bulls were slaughtered at 13 to 17 months of age on 3 different dates, whereas the steers were slaughtered at approximately 24 months of age on 12 different dates. Treatment for endo- and ecto-parasites and vaccination against respiratory diseases was carried out as deemed necessary.

6.3.2 Muscular and skeletal scores/measurements

At 8 to 12 months of age and again pre-slaughter, all animals were linear scored by a trained assessor from the Irish Cattle Breeding Federation (ICBF). This involved assigning visual muscular scores on a scale of 1 (poor) to 15 (excellent), at six locations (width at withers, width behind withers, loin development, development of hind-quarters, width of hind-quarters and development of the inner thigh) (ICBF, 2002). Allowances were made for subcutaneous fat by the assessor when assigning muscular scores.

Of the 622 animals that had carcasses dissected, live animal muscular scores were available on 115 bulls and 252 steers at 8 to 12 months of age, and 115 bulls and 507 steers pre-slaughter.

6.3.3 Carcass measurements

Carcass conformation and fat scores were obtained using the mechanical grading system on a 15-point scale (Allen, 2007) rather than a five-point scale (Commission of the European Communities, 1982). Hot carcass weight was recorded at slaughter and cold carcass weight was taken as 0.98 of hot carcass weight. Following a period of 24 h at 4°C, the right side of each carcass was quartered at the fifth rib into an eight-rib hind-quarter or pistola, and the remaining fore-quarter. After recording the weight, the pistola was dissected into 13 cuts (leg, heel, silverside, topside, knuckle, rump, tail of rump, cap of rump, fillet, strip loin, cube roll, cap of rib and eye of the round) from which all visible fat and bone (where applicable) were removed. The weight of each meat cut and total fat from the pistola was recorded, as was bone weight following removal of all adhering tissues. Lean trim was weighed separately and included with the meat cuts to give total pistola meat yield. A similar procedure was carried out with the fore-quarter, which was dissected into 11 cuts (front shin, neck, brisket, chuck, flat ribs (1 to 5), plate, *M. triceps brachii*, bladesteak, braising muscle, chuck tender and clod). Pistola and fore-quarter meat, fat and bone weights were combined to give the weight of each component in the half carcass. Recovered weights were calculated and expressed as a proportion of side weight to check for errors in weighing (Perry *et al.,* 1993a).

6.3.4 Statistical Analysis

Two series of analyses were undertaken (Statistical Analysis Systems Institute, 2009), where in all cases, the dependent variables were carcass and pistola meat proportion, carcass and pistola meat to bone ratio or carcass conformation score. The independent variables were taken as the live animal muscular scores (6 locations). The first series of analyses was undertaken on bulls (n =115) and steers (n =507) separately, both at 8 to

12 months of age and pre-slaughter to develop the most parsimonious multiple regression prediction model using backward elimination. All 6 muscular scores were initially included in the model and scores that were not associated ($P>0.05$) with the dependent variable were removed by backward elimination. The proportion of variation in the dependent variable explained by the model was quantified.

The second series of analyses used only steer data based on two production systems categorised as suckler-bred or dairy bred. Muscular scores on 179 dairy-bred and 73 suckler-bred steers at 8 to 12 months of age and, on 185 suckler-bred and 249 dairy-bred steers pre-slaughter were available for analysis. As live animal muscular score data for a significant number of dairy-bred steers was limited to four locations (width behind withers, loin development, development of hind-quarter and width of hind-quarter) rather than six locations, Pearson correlation coefficients using four locations instead of six with the various carcass traits were estimated for dairy-bred and suckler-bred animals, separately. Preliminary analysis on dairy-bred steers with all six scores available indicated that the two missing scores had little or nothing to offer above the four score in predicting the various carcass traits. The contribution made to the estimation of each dependent variable by each independent variable for both dairy-bred and suckler-bred animals was then determined by comparison of the coefficient of determination (R^2) and the residual standard deviation (r.s.d.) at both 8 to 12 months of age and pre-slaughter using multiple regression.

6.4 Results

The mean, range and standard deviation for various live animal muscular scores and carcass traits for bulls and steers are summarised in Tables 1 and 2, respectively. At slaughter, the bulls and steers had a mean age of 454 and 751 days, live weight of 583 and 625 kg and cold carcass weight of 332 and 333 kg, respectively. Mean carcass conformation and fat scores on a 15-point scale were 9.8 and 6.8 for bulls and, 7.8 and 8.5 for steers, respectively. Carcass meat, fat and bone proportions were 727, 85 and 188 g/kg respectively, for bulls and, 679, 123 and 197 g/kg respectively, for steers. Corresponding values for carcass meat to bone ratios were 3.94 and 3.49.

6.4.1 Prediction equations using live animal muscular scores in bulls

Prediction equations using six live animal muscular scores for estimating various carcass traits at both 8 to 12 months of age and pre-slaughter in bulls are summarised in Table 3. Development of hind-quarter score, both at 8 to12 months of age and pre-slaughter, explained between 0.48 to 0.61 and 0.57 to 0.84, respectively, of total variation in the various carcass traits. The only other muscular score that added significantly to the prediction of any carcass trait was width of hind-quarter in predicting carcass conformation score. Including this score improved the R^2 of the base model by 3.7 and 2.2 percentage units when scored at 8 to 12 months of age and pre-slaughter, respectively. In all cases, live animal scores obtained pre-slaughter explained more variation in the respective carcass traits than those obtained at 8 to 12 months of age.

6.4.2 Prediction equations using live animal muscular scores in steers

Multiple regression equations using six live animal muscular scores to predict various carcass traits at both 8 to 12 months of age and pre-slaughter in steers are shown in Table 4. At 8 to 12 months of age, development of hind-quarter score explained 0.28 to 0.53 of total variation in the various carcass traits. No other live animal muscular score added significantly to the prediction model. Pre-slaughter, 0.62 of the variation in carcass conformation score was explained when the model included just development of hind-quarter score and together with width of hind-quarter and width between withers scores this increased to 0.68. Similarly, development of hind-quarter score alone explained 0.56 of total variation in pistola meat to bone ratio, with both width behind withers and width of hind-quarter explaining an additional 0.05 of variation in the model. Development of hind-quarter score assessed pre-slaughter explained 0.40 and 0.39 of the variation in carcass and pistola meat proportions, respectively, with both loin development and width between withers, significantly improving the prediction models for both traits by one percentage unit. Hind-quarter development alone explained 0.56 of total variation in carcass meat to bone ratio with width behind withers score significantly increasing the amount of variation explained to 0.62. In all cases, muscular scores taken pre-slaughter explained a greater amount of variation in the various carcass traits than those obtained at 8 to 12 months of age.

6.4.3 Prediction equations using suckler-bred and artificially reared dairy-bred steers

Correlations and R^2 values using live animal muscular scores (four locations) taken at 8 to 12 months of age and pre-slaughter, in suckler-bred and dairy-bred steers are presented in Table 5. For suckler-bred steers, correlations of individual live animal muscular scores at 8 to 12 months of age with carcass and pistola meat proportions were not statistically significant. Corresponding correlations for dairy-bred steers, although low (0.15 to 0.40), were significantly different from zero. In both dairy-bred and suckler-bred steers, correlations of live animal muscular scores at 8 to 12 months of age with carcass and pistola meat to bone ratio and carcass conformation were significantly different to zero (r ranging from 0.21 to 0.43). Correlations of live animal muscular scores pre-slaughter with carcass and pistola meat proportion ranged from 0.20 to 0.49 for suckler-bred and 0.30 to 0.59 for dairy-bred steers. Corresponding ranges in correlations with both carcass and pistola meat to bone ratio and, carcass conformation score were 0.59 to 0.72 and 0.53 to 0.70.

At 8 to 12 months of age, when all four live animal muscular scores were combined in a regression model, the amount of variation explained in the various carcass traits was generally low for both suckler-bred (R^2 ranged from 0.02 to 0.16) and dairy-bred (R^2 ranged from 0.16 to 0.19) steers. Using pre-slaughter scores, the combined individual live animal muscular scores explained between 0.25 and 0.29 of the variation in carcass and pistola meat proportions, respectively, in suckled-bred steers. For carcass and pistola meat to bone ratios and carcass conformation score the proportion of variation explained was between 0.53 and 0.58. Corresponding R^2 values for dairy-bred steers were similar.

6.5 Discussion

For beef cattle genetic improvement programmes, estimates of meat yield, meat distribution and ultimately carcass value are desirable (Drennan *et al.*, 2008). In the absence of an objective assessment for muscularity, a standardised visual score for shape is required (Perry *et al.*, 1993b). Tatum *et al.*, (1986a, b) found that a subjective score for muscle thickness and an objective measurement for hindquarter width on the live animal were significantly related to higher meat yield and muscularity.

Previous studies using 336 steers (Conroy *et al.,* 2009) and 74 bulls (Conroy *et al.,* 2010) showed live animal muscular scores obtained at 8 months of age and pre-slaughter to be potential predictors of carcass traits and value. This study includes steers and bulls used by Conroy et al. (2009 and 2010) in addition to bulls and steers of other genotypes thus, representing more of the commercial animal population and representing a greater proportion of the EU carcass classification grid.

6.5.1 Prediction of carcass traits using live animal muscular scores

In accordance with the present results, Drennan et al. (2008) also found development of hind-quarter and width of hind-quarter to be the two most important live animal muscularity scores for predicting carcass traits, both at 8 to 12 months of age and pre-slaughter. Furthermore, both development and width of hind-quarter are highly correlated (r = 0.85 in the current study across gender). In a study of 149 steers Perry et al. (1993b) obtained a correlation of 0.70 between live animal muscle score taken on 15 point scale pre-slaughter and saleable meat percentage. This result is similar to the R^2 values of 0.57 and 0.42 for bulls and steers, respectively, obtained from the regression predicting carcass meat proportion from hindquarter development and width in the current study. However, May et al. (2000) obtained a lower correlation of 0.35 between muscle score and percentage yield of boneless sub-primals.

Perry et al. (1993a) in a study of 156 steers of mixed breeds reported that live animal muscle score and live-weight accounted for 33% of the variation in lean meat percentage, and Perry et al. (1993b) reported that live animal muscle score and carcass-weight accounted for 50% of the variation in saleable meat yield percentage.

Similar to the findings in the current study, Drennan et al. (2008) showed that the relationship of live animal muscular scores taken pre-slaughter with carcass meat proportion and carcass conformation score increased only slightly when the number of live animal muscular scores was reduced from nine (r = 0.39 to 0.70) to 2 (r = 0.50 to 0.74). Likewise, MacAodhain et al. (2004) concluded in a study of 46 bulls that visually scoring for hindquarter width and rump width explained similar amounts of variation (R^2 ranged from 0.32 to 0.64) in predicting meat yield and carcass conformation, to scoring nine locations on the live animal (R^2 ranged from 0.28 to 0.58). This may be attributed to the fact that live animal scoring is subjective and scorers may have achieved a higher degree of accuracy when scoring a particular location on the animal that can be more readily classified and which may relate more closely to the carcass traits studied. In a repeatability study of 25 live animal measurements Fisher (1975) found that the error of a number of the measurements ranged from 3 to 5%. While, Perry et al. (1993a) obtained correlations ranging from 0.91 to 0.95 between the scores of 3 different assessors for live animal muscularity taken pre-slaughter. Taken together, these results indicate that a more simplified visual muscular scoring system, based on development of hind-quarter, could be used for predicting carcass traits without decreasing accuracy.

Similar to this study, Drennan et al. (2008) also found that correlations of muscular scores taken at 8 to 12 months of age with various carcass traits were much lower than corresponding muscular scores obtained pre-slaughter. Other studies have also found live animal muscular scores obtained post-weaning to be a much poorer predictor of carcass traits than those obtained at pre-slaughter (Doorley, 2001; MacAodhain, 2004). This discrepancy may be attributed to variation in animal body condition at weaning resulting from differences in pre-weaning nutritional level, compared with a better and more uniform level of fat cover pre-slaughter. Drennan et al. (2008) concluded that live animal scores carried out at 8 months of age (weaning) may not be useful where pre-weaning growth rates are low, resulting in poor body condition and thus, preventing animals from expressing in muscular development.

6.5.2 Live animal muscular scores as predictors of carcass traits in suckler-bred and dairy-bred steers.

Few have attempted to quantify the ability of live animal muscular scores to predict carcass traits from suckler-bred and artificially reared dairy-bred cattle, which are the two main rearing systems in Ireland. The similarity in variation explained using live animal scores obtained pre-slaughter to predict the various carcass traits for suckler-bred (25 to 58%) and dairy-bred (31 to 58%) animals suggests that when animals are scored prior to slaughter there is no effect of production system.

6.6 Conclusion

This study indicates that potential exists to reduce the number of anatomical sites assessed in the live animal muscular scoring procedure where the end goal is prediction of carcass meat proportion. Hind-quarter development was the single best predictor of the various carcass traits examined. Simplification of live animal scoring with fewer records taken on each animal would be likely to facilitate more accurate recording. Live animal scores obtained pre-slaughter explained higher amounts of variation when compared to scores obtained at 8 to 12 months of age. The amount of variation explained using live animal scores taken pre-slaughter to predict carcass traits only varied slightly across the suckler-bred and artificially reared dairy-bred steers, indicating there was no effect of production system in predicting carcass traits.

6.7 Implications

For breed improvement live animal scores and measurements are a valuable tool in the identification of animals with good carcass characteristics. Live animal measurements allow the breeder to identify animals with superior genetic merit that should be retained in the herd for breeding, thus increasing genetic merit going forward. This is very relevant to pedigree herds where slaughter data is not available. This study also shows the potential for a more simplified live animal scoring system which would allow breeders to carry out on-farm recording with a higher degree of accuracy that would be used in genetic evaluations and the greater effectiveness of the scoring system when animals are recorded at a more advanced stage of finish.

6.8 Acknowledgements

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Table 6.1. Mean, standard deviation and range for live animal and carcass measurements of 115 bulls

	Mean	Standard Deviation	Minimum	Maximum
At 8-12 months of age				
[1]Width between withers	6.7	2.22	1.0	10.0
[1]Width behind withers	5.93	2.08	1.0	9.0
[1]Loin development	6.8	1.98	1.0	10.0
[1]Hindquarter development	7.0	2.15	2.0	12.0
[1]Hindquarter width	6.6	1.68	2.0	12.0
[1]Inner-thigh development	6.39	2.15	2.0	11.0
[1] ICBF average muscular score	6.6	1.98	1.5	10.2
Pre-slaughter				
Live-weight (kg)	583	81.89	408	857
[1]Width between withers	9.37	2.66	1.0	13.0
[1]Width behind withers	8.6	2.60	1.0	12.0
[1]Loin development	9.09	2.13	3.0	13.0
[1]Hindquarter development	8.8	2.28	2.0	14.0
[1]Hindquarter width	8.9	1.82	4.0	13.0
[1]Inner-thigh development	8.75	2.21	2.0	13.0
[1]ICBF average muscular score	8.9	2.20	3.0	13.0
Post-slaughter				
Cold carcass weight (kg)	332	56.0	207	475
Kill-out (g/kg)	567	34.0	484	669
Slaughter age (days)	454	37.8	386	569
[1]Conformation score	9.8	2.23	4.7	14.4
[1]Fat score	7.8	1.35	2.7	11.5
Meat (g/kg)	727	41.4	627	840
Fat (g/kg)	85	27.4	31	163
Bone (g/kg)	188	21.2	129	251
Pistola meat (g/kg)	739	38.89	630.5	842.6
Carcass meat to bone ratio	3.94	0.62	2.62	6.54
Pistola meat to bone ratio	3.98	0.658	2.56	6.46

[1]Scale 1 to 15;

Table 6.2. Mean, standard deviation and range for live and carcass measurements of steers

	Mean	Standard Deviation	Minimum	Maximum
At 8-12 months of age (n = 252)				
[1]Width between withers (n=85)	6.5	1.99	2.0	10.0
[1]Width behind withers	4.60	1.74	1.0	9.0
[1]Loin development	4.8	1.91	1.0	9.0
[1]Hindquarter development	4.6	2.16	1.0	10.0
[1]Hindquarter width	5.34	1.77	1.0	10.0
[1]Inner-thigh development (n=85)	6.0	1.72	2.0	10.0
[1] ICBF average muscular score	4.83	1.79	1.0	9.5
Pre-slaughter (n = 507)				
Live-weight (kg)	625	77.8	435	884
[1]Width between withers (n = 336)	7.8	2.29	1.0	12.0
[1]Width behind withers	6.6	2.24	1.0	11.0
[1]Loin development	7.4	2.08	1.0	11.0
[1]Hindquarter development	6.9	2.26	2.0	12.0
[1]Hindquarter width	7.9	1.43	3.0	12.0
[1]Inner-thigh development (n=336)	7.42	1.9	1.0	10.0
[1]ICBF average muscular score	7.2	1.89	1.83	10.8
Post-slaughter (n = 507)				
Cold carcass wt (kg)	333	49.83	233.8	500.8
Kill-out (g/kg)	532	27.3	469	621
Slaughter age (days)	751	52	437	915
[1]Conformation score	6.8	2.20	2.0	12.0
[1]Fat score	8.5	1.89	2.8	13.3
Meat (g/kg)	679	13.3	564	785
Fat (g/kg)	123	31.8	47	260
Bone (g/kg)	197	20.2	150	262
Pistola meat (g/kg)	703	34.32	619	797
Carcass meat to bone ratio	3.49	0.485	2.37	5.18
Pistola meat to bone ratio	3.5	0.50	2.43	5.37

[1]Scale 1 to 15;

Table 6.3. Regression equations obtained by backward elimination using live animal muscular scores to predict carcass traits at both 8 to 12 months of age and pre-slaughter in 115 bulls

		Trait 1[3]		**Trait 2[4]**			
Weaning	**Intercept (se)**	**b (se)**	**R^2**	**b (se)**	**R^2**	**Final R^2**	**RMSE[5]**
Carcass conformation	10.04 (0.144)	+0.39 (0.129) (dev hq[1])**	0.61	+0.60 (0.166) (hq width[2])***	0.04	0.65	1.34
Carcass meat proportion	726 (2.7)	+13.9 (1.26) (dev hq[1])***	0.52			0.52	28.8
Pistola meat proportion	738 (2.6)	+12.6 (1.23) (dev hq[1])***	0.48			0.48	28.1
Carcass meat to bone ratio	3.93 (0.038)	+0.22 (0.018) (dev hq[1])***	0.58			0.58	0.40
Pistola meat to bone ratio	3.97 (0.041)	+0.23 (0.019) (dev hq[1])***	0.55			0.55	0.44
Slaughter							
Carcass conformation	7.9 (0.12)	+0.58 (0.085) (dev hq[1])***	0.84	+0.44 (0.106) (hq width[2])***	0.02	0.86	0.83
Carcass meat proportion	702 (3.3)	+13.72 (1.121) (dev hq[1])***	0.57			0.57	27.3
Pistola meat proportion	715 (3.1)	+12.85 (1.057) (dev hq[1])***	0.57			0.57	25.7
Carcass meat to bone ratio	3.53 (0.043)	+0.23 (0.015) (dev hq[1])***	0.67			0.67	0.36
Pistola meat to bone ratio	3.55 (0.046)	+0.23 (0.016) (dev hq[1])***	0.66			0.66	0.34

[1] Development of hind-quarter

[2] Width of hind-quarter

[3] The live animal score has the highest R^2 with the relevant carcass trait

[4] Live animal score that significantly adds to the model

[5] Root Mean Squared Error

Table 6.4. Regression equations obtained by backward elimination using live animal muscular scores to predict carcass traits at both 8 to 12 months of age (n = 252) and pre-slaughter (n = 507) in steers

		Trait 1[5]		**Trait 2[6]**		**Trait 3[6]**			
Weaning	**Intercept (se)**	**b (se)**	**R^2**	**b (se)**	**R^2**	**b (se)**	**R^2**	**Final R^2**	**RMSE[7]**
Carcass conformation	9.07 (0.156)	+0.77 (0.049) (dev hq[1])***	0.50					0.50	1.7
Carcass meat proportion	703 (3.2)	+9.9 (0.994) (dev hq[1])***	0.28					0.28	34.0
Pistola meat proportion	729 (2.9)	+9.2 (0.89) (dev hq[1])***	0.30					0.30	30.5
Carcass meat to bone ratio	3.99 (0.033)	+0.17 (0.103) (dev hq[1])***	0.53					0.53	0.35
Pistola meat to bone ratio	4.01 (0.348)	0.175 (0.01) (dev hq[1])***	0.51					0.51	0.37
Slaughter									
Carcass conformation	6.79 (0.097)	+0.34 (0.051) (dev hq[1])***	0.62	+0.24 (0.072) (hq width[2])***	0.028	+0.36 (0.051) (wdbehwt[3])***	0.030	0.68	1.24
Carcass meat proportion	684 (1.7)	+11.77 (1.176) (dev hq[1])***	0.40	-4.9 (1.395) (loin dev[4])***	0.009	+2.96 (1.292) (wdbehwt[3])*	0.006	0.41	28.7
Pistola meat proportion	707 (1.5)	+10.0 (1.09) (dev hq[1])***	0.39	-4.3 (1.29) (loin dev[4]) ***	0.006	+3.4 (1.20) (wdbehwt[3]) **	0.009	0.40	26.6
Carcass meat to bone ratio	3.54 (0.139)	+0.08 (0.011) (dev hq[1])***	0.56	+0.099 (0.011) (wdbehwt[3]) ***	0.059			0.62	0.3
Pistola meat to bone ratio	3.5 (0.05)	+0.08 (0.0128) (dev hq[1])***	0.56	+0.08 (0.0128) (wdbehwt[3]) ***	0.048	+0.04 (0.018) (hqwidth[2]) *	0.005	0.61	0.3

*** P<0.05; * * P<0.01; * * * P<0.001**

[1] Development of hind-quarter; [2] Width of hind-quarter; [3] Width behind withers; [4] Loin development;

[5] The live animal score has the highest R^2 with the relevant carcass trait; [6] Live animal score that significantly adds to the model; [7] Root Mean Squared Error

Table 6.5. Correlations and overall R^2 values between various live animal muscular scores and carcass traits for suckler and bucket reared animals at both weaning (n = 73 suckler-bred, 179 bucket-bred) and slaughter (n = 185 suckler-bred, 249 bucket-bred) in steers.

Trait	Group	Width behind withers	Loin development	Development of hind-quarter	Width of hind-quarter	Total R^2
Weaning						
Carcass meat proportion	Suckler-bred	0.06	0.07	0.11	0.10	0.02
	Dairy-bred	0.26***	0.24**	0.37***	0.15*	0.16
Pistola meat proportion	Suckler-bred	0.12	0.14	0.21	0.20	0.06
	Dairy-bred	0.29***	0.26***	0.40***	0.16*	0.19
Carcass meat to bone ratio	Suckler-bred	0.31**	0.33**	0.35**	0.37**	0.14
	Dairy-bred	0.23**	0.28***	0.42***	0.23**	0.19
Pistola meat to bone ratio	Suckler-bred	0.35**	0.32**	0.37**	0.39***	0.16
	Dairy-bred	0.27***	0.30***	0.43***	0.22**	0.19
Carcass conformation score	Suckler-bred	0.29*	0.34**	0.35**	0.27*	0.14
	Dairy-bred	0.21**	0.28***	0.39***	0.23**	0.16
Slaughter						
Carcass meat proportion	Suckler-bred	0.32***	0.20**	0.42***	0.27***	0.25
	Dairy-bred	0.37***	0.33***	0.55***	0.30***	0.31
Pistola meat proportion	Suckler-bred	0.41***	0.30***	0.49***	0.37***	0.29
	Dairy-bred	0.45***	0.38***	0.59***	0.38***	0.36
Carcass meat to bone ratio	Suckler-bred	0.72***	0.61***	0.67***	0.62***	0.55
	Dairy-bred	0.66***	0.54***	0.66***	0.53***	0.53
Pistola meat to bone ratio	Suckler-bred	0.70***	0.59***	0.67***	0.61***	0.53
	Dairy-bred	0.65***	0.54***	0.67***	0.53***	0.53
Carcass conformation score	Suckler-bred	0.72***	0.67***	0.71***	0.66***	0.58
	Dairy-bred	0.68***	0.59***	0.70***	0.58***	0.58

* P<0.05 ; * * P<0.01 ; * * * P<0.001

Chapter 7

Overall Summary,

Conclusions and Implications

7.1 Thesis Summary

The first two chapters of this thesis, the introduction (**Chapter 1**) and literature review (**Chapter 2**), provide background information and review the published literature on the research area of interest, respectively.

The objectives of the research reported in this thesis were to:

(i) determine the relationship in beef cattle of live animal muscular and skeletal score measurements, ultrasonically scanned muscle and fat depth measurements of the *M. longissimus dorsi*, and carcass conformation and fat scores with kill-out proportion, carcass composition and carcass value in steers (Experiment 1 - **Chapter 3**) and bulls (Experiment 2 - **Chapter 4**)

(ii) determine the relationship of live animal muscular scores in bulls and steers at two distinct phases during their productive life, 8 to 12 months of age and pre-slaughter, in predicting carcass traits and to,

(iii) examine this relationship across suckler-bred and artificially reared dairy-bred steers (Experiment 4 - **Chapter 6**)

(iv) develop and test the accuracy of prediction equations for carcass meat, fat and proportions derived from carcass conformation and fat scores and to

(v) develop prediction equations for total carcass composition from hind quarter composition (Experiment 3 - **Chapter 5**)

Experiment 1 - Chapter 3: The relationship of live animal muscular and skeletal scores, ultrasound measurements and carcass classification scores with carcass composition and value in steers

Objective: To determine the relationship between live animal muscular and skeletal scores and ultrasonically scanned muscle and fat depth measurements of the *longissimus dorsi* muscle, with carcass conformation and fat scores with carcass composition and value in steers.

- A total of 336 carcasses consisting of Holstein-Friesian, Aberdeen Angus × Holstein-Friesian and 0.5 to 1.0 late-maturing continental breed crosses steers were used in the analysis.
- Multiple regression and correlation analyses were performed to quantify associations among traits.

The main results from this study were:

- Pre-slaughter muscular scores (6 locations) were positively correlated (0.31 to 0.86) with carcass meat proportion, proportion of high-value cuts in the carcass, conformation score and carcass value, and were negatively correlated with carcass fat (r = -0.13) and bone (r = -0.81) proportions. Pre-slaughter muscular scores were not correlated with the proportion of high-value cuts in meat and carcass fat score.
- Pre-slaughter ultrasound muscle depth and carcass conformation score showed similar correlations with carcass traits to those using the pre-slaughter muscular scores.
- Pre-slaughter ultrasound fat depth was positively correlated with carcass fat proportion (r = 0.59) and fat score (r = 0.63), and negatively correlated (-0.23 to

-0.50) with carcass meat and bone proportions, high-value cuts in the carcass and in meat, and carcass value.

- Pre-slaughter skeletal scores were generally more poorly correlated (-0.38 to 0.52) with the various carcass traits measured.
- Skeletal scores at 8 to 12 months of age had poorer correlation coefficients (-0.26 to 0.44) with the various carcass traits than those using pre-slaughter records.
- Conformation and fat score explained between 54% and 79% of variation for carcass meat, fat and bone proportion and carcass value.
- Overall, results showed that muscular scores and ultrasound measurements in the live animal and carcass conformation and fat scores explained a high amount of the observed variation in carcass meat, fat and bone proportions and carcass value, and a moderate amount of variation for the proportion of high-value meat cuts in the carcass. However, data collected at 8-12 months of age was more poorly related with the various carcass traits than those collected pre-slaughter.

Experiment 2 - Chapter 4: The relationship of various muscular and skeletal scores and ultrasound measurements in the live animal, and carcass classification scores with carcass composition and value of bulls.

Objective: To determine the relationship between live animal muscular and skeletal scores, ultrasonically scanned muscle and fat depth measurements of the longissimus *dorsi,* and carcass conformation and fat scores with killing-out rate, carcass composition and carcass value in bulls.

- Seventy-four bulls slaughtered at 13 to 17 months of age used. Fifty-three were late-maturing continental breed crosses from crossbred suckler dams, bred using Belgian Blue (n=6), Charolais (n=23), Limousin (n=16) and Simmental (n=8) sires.
- Multiple regression and correlation analyses used to quantify the association.

The main results from this study were:

- Pre-slaughter muscular scores were positively correlated with killing-out rate (r = 0.82), carcass meat proportion (r = 0.72), conformation score (r = 0.94), carcass value (r = 0.72) and the proportion of high-value cuts in the carcass (r = 0.49), and negatively correlated with carcass bone (r = -0.89) and fat (r =-0.32) proportions.
- Corresponding correlations with muscular scores at 8 to 12 months of age were generally lower than those recorded pre-slaughter.
- Correlations between ultrasound muscle depth with carcass traits showed similar trends but weaker values compared to pre-slaughter muscular scores with carcass traits. Ultrasound fat depth pre-slaughter was positively correlated with

carcass fat proportion (r = 0.56) and fat score (r = 0.54), and negatively correlated with carcass meat proportion, the proportion of high-value cuts in the carcass and carcass value. Correlations with other carcass traits were not different from zero.

- Correlations of live animal skeletal scores with carcass traits were generally not different from zero.
- Carcass conformation and fat scores explained a large amount of variation (R^2 ranged from 0.55 to 0.80) carcass composition, carcass weight, killing-out rate and carcass value but a low amount of variation (R^2 ranged from 0.08 to 0.28) in proportion of high-value cuts in carcass, high priced cuts as proportion of meat and perinephric plus retroperitoneal fat.
- Overall, results showed that muscular scores and ultrasound measurements in the live animal and carcass conformation and fat scores were useful predictors of carcass composition and carcass value in bulls.

Experiment 3 - Chapter 5: Predicting carcass meat, fat and bone proportions from carcass conformation and fat scores or hind-quarter dissection of beef carcasses.

Objective: (1) to develop and test the accuracy of prediction equations for carcass meat, fat and bone proportions, derived from both carcass conformation and fat scores, or (2) from carcass hind-quarter composition.

- A total of 662 animals comprising of bulls (n = 115), heifers (n = 40) and steers (n = 507) used in the analysis.
- Prediction equations were developed using a once-out cross validation that involved omitting each of the 662 animals individually in turn from the development of the prediction equation and then applying the equation to the omitted animal to predict its meat, fat and bone yield.

The main results from this study were:

- Carcass classification scores accounted for 0.73, 0.67 and 0.71 of total variation in carcass meat, fat, and bone proportions, respectively. The corresponding values using hind-quarter meat, fat and bone in the model were 0.93, 0.87 and 0.89.
- The bias of the prediction equations when applied to the validation dataset (n=166) were not different from zero, and there was no systematic bias in estimation of carcass composition for gender but bias did exist among some of the genotypes of animals present.
- Overall, carcass classification scores and hind-quarter composition are accurate predictors of carcass meat, fat and bone proportions. Furthermore, equations developed using hind-quarter composition was also shown to accurately predict carcass meat, fat and bone proportions across gender.

Experiment 4 - Chapter 6: Live animal muscular scores as predictors of carcass traits in suckler-bred and artificially reared dairy-bred male cattle

Objective: To (1) determine the relationship between live animal muscular scores at two distinct phases during their productive life, 8 to 12 months of age and pre-slaughter, with carcass traits in bulls and steers and (2) to examine this relationship across suckler-bred and artificially reared dairy-bred steers.

- A total of 622 animals comprising of bulls (n = 115) and steers (n = 507) were available used.
- Analysis was undertaken in bulls and steers separately, both at weaning and pre-slaughter. Multiple regression models were used. All 6 muscular scores were initially included in the model and scores that were not associated (P>0.05) with the dependent variable were removed by backward elimination.
- A second analysis used only steer data categorised into suckler-bred and dairy bred at weaning (n = 252) and pre-slaughter (n = 434). Pearson correlation coefficients estimated for dairy-bred and suckler-bred animals, separately.

The main results from this study were:

- Hind-quarter development score accounted for 0.48 to 0.65 and 0.28 to 0.53 of the variation in carcass traits at weaning for bulls and steers, respectively. Corresponding ranges in values pre-slaughter were 0.57 to 0.86 and 0.40 to 0.68.
- Correlations of live animal muscular scores pre-slaughter with carcass and pistola meat proportion ranged from 0.20 to 0.49 for suckler-bred and 0.30 to 0.59 for dairy-bred steers. Corresponding ranges in correlations with both carcass and pistola meat to bone ratio and, carcass conformation score were 0.59

to 0.72 and 0.53 to 0.70. Corresponding values at weaning were found to be lower in all cases.

- Using pre-slaughter scores, the combined individual live animal muscular scores explained between 25% and 29% of the variation in carcass and pistola meat proportions, respectively, in suckled-bred steers. For carcass and pistola meat to bone ratios and carcass conformation score the proportion of variation explained was between 0.53 and 0.58. Corresponding R^2 values for dairy-bred steers were similar.
- Overall, potential exists to reduce the number of live animal measurements scored on an animal where the end goal is prediction of carcass quality, with hind-quarter development the single best predictor of the various carcass traits. Furthermore, at weaning and pre-slaughter the amount of variation explained using live animal scores to predict carcass traits only varied slightly across the two production systems, indicating there was no effect of production system in predicting carcass traits.

7.2 Overall conclusions and implications

In Experiment 1 (**Chapter 3)**, it was concluded that both pre-slaughter live animal scores/measurements and carcass classification scores explained an appreciable amount of the total variation in carcass meat, fat and bone proportions and carcass value, and a moderate amount of the variation in proportion of high-value meat cuts in the carcass. Therefore, live animal scores and measurements could be useful in breeding programmes, particularly with breeding animals, where carcass data would not be available. However, the poorer relationship between muscular scores and measurements obtained at 8 to 12 months of age with carcass traits than those obtained using pre-slaughter muscular scores and measurements indicates the need to have animals at an advanced stage of finish when assessment is carried out. Muscular scoring systems can be simplified to three locations with emphasis on the hind-quarter and loin area. Furthermore, the fact that the EU beef carcass classification for conformation and fatness carried out mechanically was shown to be a good predictor of carcass meat proportion and value would allow it to be a useful tool in placing commercial value on carcasses and also in breeding programmes.

Similarly, in Experiment 2 (**Chapter 4)** with a trial using bulls it was concluded that pre-slaughter live animal scores and measurements are good predictors of carcass weight, killing-out rate, carcass meat and bone proportion, carcass conformation and carcass value, modest predictors of carcass fat proportion and proportion of high-value cuts in the carcass and poor predictors of high priced cuts as a proportion of meat and perinephric plus retropertitoneal fat. Records taken at 8 to 12 months of age followed a similar trend in predicting carcass traits to those taken pre-slaughter but were generally lower. This study confirms that a more simplified muscular scoring system involving three locations using roundness of hind-quarter, width of hind-quarter and depth and width of the loin area is as effective as the six locations used by ICBF in predicting carcass composition and value. Live animal skeletal scores showed a poor relationship with the various carcass traits, consistent with the findings of **Chapter 3**, further indicating that scoring for skeletal traits is not useful in predicting carcass traits. Carcass classification scores for conformation and fatness were shown to be a good predictor of carcass traits, accounting for about 0.7 of total variation in carcass meat proportion and carcass value, indicating that pricing guidelines for a beef carcass payment system, based on carcass conformation as a predictor of carcass value, should be pursued.

Results from Experiment 3 (**Chapter 5)** showed that equations developed using carcass conformation and fat scores were accurate predictors (i.e. high R^2 and low root mean squared error (RMSE)) of carcass meat, fat and bone proportions and are applicable across gender and genotype with no systematic bias in estimation of carcass composition for gender, but bias of prediction of carcass composition was evident in some genotypes, although this is possibly due to the smaller number of animals dissected in the respective category.

These equations could have a useful role in rewarding farmers for producing animals with better carcass traits by implementing a beef carcass payment system based on predicted meat yield. As carcass classification in Ireland is by video imaging analysis machines, the implementation of a payment system based on carcass composition would be quick and practical, with little or no additional expense to the abattoir. As carcass conformation and fat score was measured on 15 point scale it can be concluded that a payment system based on a similar scale should be introduced with the payment increasing as conformation score of the animal increases and decreasing once the animal exceeds threshold fat scores.

This study also concluded that equations developed using hind-quarter composition was also shown to accurately predict carcass meat, fat and bone proportions across gender and genotype. These equations would reduce the huge cost associated with whole carcass dissection and make it more beneficial and appealing to those carrying out carcass studies.

In Experiment 4 (**Chapter 6)**, it was concluded that hind-quarter development score was the single best predictor of the various carcass traits at weaning and pre-slaughter for bulls and steers. These results indicate the potential to further reduce the number of live animal measurements scored on an animal, where the end goal is prediction of carcass quality. The simplification of live animal scoring would facilitate the potential for more accurate recording. This would allow breeders to record live animal measurement information on their farms that would be used in genetic evaluations and thus, would allow more data to be recorded for genetic evaluations. It can also be concluded from this study, that at weaning and pre-slaughter, the amount of variation explained using live animal scores to predict carcass traits only varied slightly across the two production systems, indicating there was no effect of production system in predicting carcass traits. As there was no difference in predicting carcass traits from linear scoring across production systems, dairy bred animals should not be omitted from genetic evaluations.

A beef carcass quality payment scheme was introduced in Ireland in December 2009 which now rewards farmers for producing cattle with better conformation and appropriate fat cover with carcass grades based on a 15 point scale instead of the old 5 point scale. The research conducted for this thesis provided the scientific base underpinning this new scheme.

7.3 Areas for further research

Ultrasound has being shown to be an accurate predictor of carcass meat and fat yield in Chapters 3 and 4 and from previous studies (Doorley, 2001; MacAodhain, 2004; Lambe *et al.*, 2010). Therefore, the ability of ultrasound to predict marbling in meat to allow breeder to select animals for different markets should be quantified. It would be important to quantify if ultrasound has the ability to predict variations in meat eating quality, with a view to finding the genetic differences between animals for meat eating quality.

Computer tomography (CT) scanning is a method of non-invasive imaging of subjects developed for use in humane medicine (Young *et al.*, 2001). Computer tomography can be used to provide very accurate assessment of body composition in live animals (Young *et al.*, 2001). CT scanning could be used as an alternative to whole carcass dissection to predict carcass composition, thereby increasing the number of animals and thus, the robustness of the equations presented in this thesis. Alternatively, more carcass dissection work, which incorporates cows and older bulls, should be carried out to validate further the work embodied in this thesis and to test the robustness of equations developed.

Considering that there are substantially different market values for each cut on the carcass, it would be important to examine further whether or not each individual cut could be estimated from mechanical grading in order to facilitate a more accurate and fairer payment system to farmers. Research reported by Pabiou *et al.* (2011) has attempted to assess the potential of video image analysis (VIA) in predicting various wholesale cuts in cattle and concluded that wholesale cuts in steers and heifers could be accurately predicted using multiple regression models that incorporated carcass weight and VIA variables, therefore providing a powerful aid in beef breeding programs to select animals that produce more valuable carcasses. The same principles in terms of establishing a payment system based on carcass dissection work could be applied to other livestock species such as sheep.

7.4 References

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Chapter 8

Publication List

8.1 Published papers

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8.2 Conference proceedings

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Conroy S, Drennan MJ, and Kenny DA. 2007. The relationship between live animal scores and ultrasonically scanned measurements with carcass traits. *Proceedings of the Agricultural Research Forum, Tullamore, Ireland, page 81.*

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Drennan MJ, Conroy S, McGee M, and Keane MG 2008. Irish beef carcass prices do not reflect carcass quality. *Proceedings of the Agricultural Research Forum, Tullamore, Ireland, page 91.*