INVESTIGATIONS INTO MUSCULARITY AS A CHARACTERISTIC OF SHEEP CARCASSES AT VARIOUS STAGES OF GROWTH

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DEDICATION

This thesis is dedicated to my wife, RAJA, for her love and support and to my daughters and son, FADIAH, LEENA, AND YOUSEF.

ABSTRACT

Muscularity is a meat animal characteristic defined as the depth of muscle relative to skeletal dimensions. It is usually assessed subjectively, but a possible objective measure involves obtaining an average muscle depth by taking the square root of the weight per unit length of muscles around the femur, and expressing this relative to femur length. A series of experiments was conducted to assess this objective measure of muscularity (MUSC), and the value of muscularity as a meat production trait. These involved evaluation of first, the pattern of change in MUSC with growth of sheep from birth to near maturity, secondly, relationships between MUSC in different parts of the carcass, thirdly, relationships between MUSC and muscle fibre size and number, fourthly, breed differences in MUSC, fifthly, relationships between MUSC measured objectively and subjectively, and finally, indirect predictors of MUSC based on simple measurements.

Southdown rams from lines selected for high- or low-backfat depths (n=40 per line) were studied at birth, 10, 20, 40, 60, and 80 kg liveweight and at near maturity. Muscularity and M:B ratios from different groups of muscles and bones, together with other indexes of carcass shape, including the depth to width ratio of a transverse section of *M.longissimus* and a carcass weight to length ratio (CWT:L^3), increased at a decreasing rate with increasing carcass weight. For most ratios this increase was parallel for both lines with the high-backfat line having higher values, but for muscularity in the femur region the differences between the lines increased with growth. Muscularity based on the muscles around the femur showed line differences most clearly. Line differences in muscularity did not appear to be associated with consistent differences in bone shape.

Proportions of muscle fibre types in the *M.semitendinosus* were generally similar for the two selection lines.

Data from 211 carcasses from 4 trials were evaluated to study differences between breed and sex groups of sheep in the pattern of change in muscularity with increasing carcass weight. Leg muscularity increased for all groups with increasing carcass weight, and the rate of increase was similar at carcass weights above 10 kg. The Southdown breed had higher muscularity values and M:B ratios than Texel crosses, which in turn had higher values than all other groups. For some comparisons, there were important sex effects. At a similar carcass weight, Coopworth rams had slightly higher muscularity values (+1.7%; $P<0.10$), but lower M:B values (-8.8%; $P<0.001$) than Poll Dorset-cross cryptorchids.

Relationships between objective measures of muscling and subjective scores of muscularity or conformation were studied using data from 95 lambs and 90 bulls. Muscularity calculated from the leg cut rather than whole side or eye-muscle dimensions had the closest relationships with subjective scores of muscularity or conformation ($R^2\%$ = 69 to 80% for lambs and 56% for bulls), with leg M:B being only slightly inferior ($R^2\%$ = 62% for lambs and 52% for bulls). Muscularity and M:B ratio calculated from the side were the next best as predictors, but variables based on the eye muscle were poor.

Data from 5 trials were used to examine indirect objective methods to predict leg muscularity for sheep carcasses. Muscularities based on *M.semimembranosus* or *M.biceps femoris* were accurate predictors when compared with indexes based on other individual muscles. Muscularities based on the topside and outside commercial boneless cuts were also good predictors. Indexes of muscularity calculated from carcass linear and eye-muscle dimensions were poor as predictors. Leg width to length (W/L) ratios obtained from lateral leg photographs proved useful as predictors. Individual W/L values or groups of W/L values combined as bands were moderately effective as predictors for some trials. However, the regression prediction equations varied between trials.

It is concluded that the objective measure of carcass muscularity investigated here is a carcass characteristic that reflects important differences in carcass shape, and that differences in this characteristic between carcasses are not necessarily accompanied by corresponding changes in muscle to bone ratio.

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TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

LIST OF APPENDICES

Table **Page**

Appendix 1

Appendix 2

Appendix 3

Appendix 3

Appendix 3

Appendix 3

Appendix 3

CHAPTER ONE

INTRODUCTION

Carcass characteristics of meat animals show a broad variation and they are evaluated in a variety of ways. Muscularity is considered to be an important carcass characteristic of meat-producing animals and is used as a measure of conformation or shape. Fleshiness and meatiness are other terms used to describe the degree of muscle development and are therefore used in a similar way to muscularity (Yeates, 1952).

The term muscularity has been defined in a number of general ways over the years. Because of the lack of an accepted common definition, this carcass characteristic was mainly measured subjectively rather than objectively until 1974. In this year a working group on carcass evaluation from the European Association for Animal Production (De Boer *et al.* 1974) reported reference methods for the assessment of carcass characteristics including a definition of muscularity which facilitated objective measurement. Muscularity was defined as the thickness of muscle relative to dimensions of the skeleton.

Prior to this definition, muscularity was described in various ways. For example Hedrick (1968) defined it as the absence of fat because the yield of lean meat was considered the single most important factor determining carcass value. Also, according to Butler (1957), Butterfield (1963), and Berg & Butterfield (1968) good muscling indicated that there were more of the right (high-priced) muscles, or, in other words, better-muscled animals should have a better distribution of muscle. Coop & Clark (1957) defined muscularity in terms of leg width relative to leg length, and Martin *et al.* (1966) reported that more desirable muscling meant a higher ratio of muscle to bone. The variations in the shape of the live animal or carcass are described as being either bulging or flat, convex or concave, long or short, curved or straight, thick or thin, and wide or narrow (Kirton, 1964; Kauffman *et al.,* 1973). Thus the muscular animal was defined as the one which had a convex, bulging shape and the non-muscular animal as the one which had a concave, flat shape.

In addition to defining muscularity, De Boer *et al.* (1974) also defined conformation as the thickness of muscle plus fat relative to dimensions of the skeleton, and fleshiness as the thickness of muscle plus intermuscular fat relative to dimensions of the skeleton.

Several reasons for the importance of muscularity as a carcass characteristic have been considered in the literature. Increases in muscularity in meat animals is usually associated with higher M:B ratios (Dumont & Pouliquen, 1988), although this has been shown to not always be the case (Purchas *et al.,* 1991). The size and shape of meat cuts is directly affected by muscle thickness (Dumont, 1978). This permits the preparation of more attractive cuts from well-muscled carcasses and gives better prices in some markets, but the economic importance of this factor may vary from one country to another according to the cutting procedures. Dressing-out percentage has been shown to be higher for cattle and sheep that show better muscularity or conformation (Kauffman *et al.,* 1976; Kirton & Pickering, 1967; Purchas *et al.,* 1992). Meat quality, especially tenderness, may be influenced by better muscularity through an effect on muscle thickness (Dumont, 1978) as is seen in double-muscled beef animals. This appears to be a consequence of the decrease in connective tissue content with increasing muscle thickness.

Although the definition of muscularity by De Boer *et al.* (1974) was very clear and has been generally accepted, this characteristic is still most commonly expressed as subjective scores rather than as objective measurements. This may be because of difficulties in devising a suitable measurable index of average muscle thickness.

Purchas *et al.* (1991) proposed an objective muscularity index based on a measure of muscle depth relative to a skeletal dimension. An index of average muscle depth was obtained by taking the square root of an average cross-sectional area, which in turn, was assessed indirectly as the weight per unit length of a muscle. The most satisfactory measure of muscle length is often the length of an adjacent bone. Thus, an acceptable measure of average muscle depth based on simple objective measurements is the square root of muscle weight per unit length of an adjacent bone. If muscularity is expressed as the ratio of an average muscle depth to the length of an adjacent bone in order to correspond closely to the definition of De Boer *et al.* (1974), then muscularity will be predicted by the square root of muscle weight per unit length of an adjacent bone relative to bone length.

The general objective of this project was to evaluate this objective index of muscularity using sheep showing a range of muscularity levels as the experimental model. Animals used included rams from the Massey University high and low backfat selection lines of Southdowns where line differences in muscularity have been reported (Kadim *et al.*, 1989), and other groups of sheep and lambs known to have contrasting muscularity characteristics.

The specific purpose and objectives of this project were:

(1) To monitor changes in muscularity characteristics within the Southdown selection lines as they grow and develop (Chapter 3).
(2) To study the consistency of line differences in measures of muscularity in different anatomical regions (Chapter 3).
(3) To investigate relationships between muscularity differences between the Southdown lines and differences in the shape of the carcass and its skeletal framework (Chapter 3).
(4) To investigate relationships between muscularity differences between the Southdown lines and differences in the type, size and number of muscle fibres (Chapter 3).
(5) To investigate differences in muscularity and related characteristics between different breeds and sexes of sheep and also differences between groups in the pattern of change in muscularity with increasing carcass weight (Chapter 4).
(6) To examine relationships between objective measurements of carcass muscling and subjective muscularity or conformation scores (Chapter 5).
(7) To evaluate relationships between the objective muscularity index based on muscles around the femur and femur length (MUSC(FL)) and potential indirect predictors that can be measured more easily (Chapter 6).

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter information on the composition of growth of sheep, particularly as it relates to muscularity characteristics, will be reviewed. In the first part, carcass characteristics of importance to the meat industry, their analysis, and their patterns of change with growth will be considered.

The second part of the chapter reviews research work carried out on muscularity with respect to its definition, methods of evaluation, relationships with other carcass characteristics, and factors affecting it.

The final section will review information on relationships between muscularity and muscle fibre size and type.

Work carried out on sheep will be emphasised, but where only limited data on sheep are available, results for other species will also be considered.

2.2 PATTERNS OF GROWTH AND DEVELOPMENT IN THE SHEEP WITH RESPECT TO CARCASS COMPOSITION CHARACTERISTICS.

2.2.1 CARCASS COMPOSITION CHARACTERISTICS OF IMPORTANCE

It is difficult to specify which carcass characteristics are most important from the commercial point of view, but the main characteristics are usually those related to size and composition (Harrington & Kempster, 1989).

Williams (1972) described the muscle to bone ratio, the percentage of fat, the thickness of muscle layers, and the saleable meat distribution, as the main determinants of carcass quality. Carcass quality in this sense does not include quality characteristics of meat, such as colour, moistness and tenderness and these aspects are not considered in this section. Dumont (1976) listed the main carcass composition characteristics of commercial importance as carcass weight, carcass composition (including, muscle %, bone %, and fat %), muscle and fat distribution, and carcass conformation. Similar lists were given by Kempster *et al.* (1982) and Harrington & Kempster (1989). Purchas (1986) suggested that an adequate description of the body composition was provided by the dressing-out percent, fat percent, muscle to bone ratio, muscle and fat distribution, and muscle shape.

The carcass characteristics that will be considered in this section are dressing-out percentage, proportion of muscle, fat, and bone, distribution of muscle, fat, and bone, and carcass shape. These include most of those mentioned in the above lists although they are sometimes expressed in a different form.

1. ***Dressing-out percentage:*** This value is derived by expressing the weight of the commercial carcass as a percentage of pre-slaughter liveweight (Purchas *et al.*, 1989). Butterfield (1988) emphasised the importance of precisely defining the live and carcass weighing conditions and the dressing procedures, together with the provision of a clear definition of exactly what constitutes the carcass. When meat animals are sold on a liveweight basis, dressing-out percentage becomes important to the processor as it indicates the weight of carcass that can be expected from animals of a known liveweight, but it is of little concern to the processor who pays on the basis of carcass weight and is of even less concern to the retailer or consumer (Hall, 1988).

2. ***Proportions of muscle, fat, and bone:*** Carcass value per unit weight depends largely on the proportions of muscle, fat, and bone, which are usually expressed as percentages of carcass weight (Kempster *et al.*, 1982). These characteristics are also often reported as fat percentage and muscle to bone ratio (Purchas *et al.*, 1989). Thus, for producers, processors, retailers and consumers the superior carcass will have a high proportion of muscle, a low proportion of bone and an optimal level of fatness, or, alternatively, a high muscle to bone ratio with a low fat percentage (Fraser & Stamp, 1987; Kirton & Morris, 1989).

   The proportion of lean meat in the carcass is of major importance since this is the prime determinant of yield and commercial value (Harrington & Kempster, 1989). Leanness is the criterion by which most consumers judge quality and value for money (Garrett *et al.*, 1992).

Fat is the most variable tissue in carcasses of sheep, and usually when there is an increased percentage of fat in a carcass, there is a corresponding decrease in the percentage of lean meat and bone. Bone percentage relative to total carcass weight decreases slowly and continuously as weight increases (Butterfield, 1988).

As a result of these changes in percentage of each tissue relative to each other in the carcass, it can be seen that first muscle and then fat have the major influence on carcass composition, whereas bone at no stage exerts a dominant role in the determination of relative proportions of the three major tissues (Fraser & Stamp, 1987). On the other hand, variation in percentage of muscle in a carcass is brought about primarily by changes in fatness, and to a lesser extent by changes in the muscle to bone ratio.

3. ***Distribution of muscle, fat, and bone:*** Distribution of muscle, fat, and bone tissues between various body parts is usually expressed as individual muscle weights, fat depot weights, or bone weights relative to total muscle, total fat, or total bone, respectively (Purchas *et al.*, 1989).

   The distribution of these tissues throughout the carcass is of major importance because there are wide differences between cuts in their retail value (Kempster *et al.*, 1982). Bone weight distribution has less commercial importance than either lean or fat weight distribution, except possibly at the wholesale level for trade in carcass quarters or bone-in primal joints (Wolf & Smith, 1983). The amount and distribution of fat is critical in the overall value of a carcass. Kempster (1981) noted that fat in the body cavity (eg. kidney knob and channel fat) or excess subcutaneous fat trimmed during retail preparation is of little commercial value in comparison with that sold as a part of retail cuts (intermuscular or intramuscular fat). Results from anatomical studies with sheep have shown that muscle weight distribution is a fairly constant characteristic at a set weight and that there is little variation to exploit commercially (Jury *et al.*, 1977; Wolf, 1982).

4. ***Carcass shape:*** This characteristic has been defined by DeBoer *et al.* (1974) as carcass conformation in terms of the thickness of muscle and fat tissues relative to skeletal size, and as muscularity in terms of muscle thickness relative to skeletal size. Shape as such is a complex characteristic, but it represents one of

the measurements of interest for meat production studies (Kempster *et al.*, 1982).

Animals and carcasses that are considered to have superior conformation have traditionally had a higher commercial value (Kirton & Morris, 1989). If carcasses of superior conformation have a higher value, then they should either have a higher proportion of saleable meat, a higher proportion of meat in the higher priced cuts, or the shape must improve the saleability of the carcass through enhanced consumer appeal (Kempster *et al.*, 1982).

Results from several studies into muscle distribution (Taylor *et al.*, 1980; and Perry *et al.*, 1988) have shown that the importance of conformation or shape is much less than had previously been supposed, in that at the same total muscle weight the distribution of muscle between high and low value parts of the carcass was very similar in carcasses of good or bad conformation (Cuthbertson, 1975). However, the shape of a carcass or a carcass part in terms of its thickness relative to its length is important, not only because it has a bearing on the shape of cuts which may have considerable commercial value, but also because changes in shape may be associated with changes in fat percentage and muscle to bone ratio (Dumont, 1978). Timon & Bichard (1965) and Kirton & Pickering (1967) showed that superior lamb conformation as measured by subjective assessment was often associated with higher levels of fatness. Butchers aware of this association may still prefer carcasses of superior conformation and attach value to good carcass conformation for other reasons. However, such value as it has appears to relate to thicker muscles or to higher muscle to bone ratios rather than to an improved distribution of muscle weight (Harrington & Kempster, 1989). Muscularity and conformation as carcass characteristics are discussed in more detail in section 2.3 of this review.

2.2.2 METHODS OF ANALYSING GROWTH DATA

From the beginning of anatomical growth studies in farm animals early in this century, a number of different methods have been used to quantify growth and development. Some of the apparent confusion in the interpretation of growth data has arisen from conflicting views regarding the most appropriate methods to use.

In this section the three main methods which have been widely used in analysing the relative growth of body tissues are reviewed with respect to their advantages and their limitations. The methods involve the use of, first, tissue percentages and ratios, secondly, the allometric equation, and, thirdly, maturity coefficients.

2.2.2.1 *TISSUE PERCENTAGE AND RATIOS*

The combination of tissue percentages and ratios in describing the composition of a carcass or of a group of carcasses of similar weight are widely used in analysing animal growth data. This is especially seen when the composition of a carcass is expressed as fat percentage and muscle to bone ratio (TABLE 2.2).

The composition of a carcass expressed as proportions (or percentages) of the whole carcass is of limited value as a means of biological comparison as each change in the proportion of one tissue must be compensated by appropriate changes in the proportions of other tissues, which can lead to misinterpretations. This is because a treatment which has an effect, for example, only on the growth rate of fat, will produce a change in all the percentage values at a particular carcass weight, even though the muscle to bone ratio is not influenced. By using a combination of percentage values and ratios, this confusion can be overcome. Elsley *et al.* (1964) showed that statistical corrections for carcass weight differences when the effects of various treatments on carcass composition are being assessed must be made to allow for the differences in overall size and in fat content. This is because most carcass composition percentages and ratios change as carcass weight increases (TABLE 2.2).

In considering the mathematical and statistical operations that could be used on data, several researchers (Tulloh, 1963; Sokal & Rohlf, 1969) have pointed out that there are some dangers in using ratios and percentages. Tulloh (1963) demonstrated that the use of any of the following four commonly used methods of describing development may complicate an otherwise simple situation.

(a) The weight of the part (or organ or tissue) expressed as a percentage of body weight at various body weights or ages.

(b) The weight of the part expressed as a fraction of body weight at one age (or weight), compared with the fraction calculated at another age (or weight).

(c) The measurement of the part expressed as a percentage of its measurement at an earlier age or weight (usually at birth).

(d) The part expressed by a measurement in any one of the above three ways, in relation to a measurement of a standard part (instead of body weight). The standard part chosen such as bone weight is considered to be little influenced by external factors.

He concluded that it was best to base calculations on the original data rather than to transform them into ratios and percentages.

Sokal & Rohlf (1969) claimed that although ratios and percentages are widely used and well understood in much biological research, there are some serious drawbacks to their use in statistical work. They noted three specific disadvantages of ratios. The first was their relative inaccuracy due to additivity of the individual errors. The second was that their distributions can be skewed rather than normally distributed as required by the usual statistical tests. And the third was that they do not provide information on the relationship between the two variables whose ratio is being taken.

2.2.2.2 *THE ALLOMETRIC EQUATION*

The use of the allometric equation (Huxley, 1932) is based on the assumption that relative changes in component parts during growth are more dependent on the absolute size of the whole rather than on the time taken to reach that size (Elsley *et al.*, 1964).

It has the general form:

$$Y = a\,X^{b}$$

Where

Y is the weight of the component under study.

X is the weight of some suitable reference basis, e.g., body or carcass weight.

a is a constant.

b is the allometric growth coefficient (AGC).

The equation can be converted to logarithms (usually of base 10) and a linear regression equation is obtained with a slope equal to the AGC and an intercept equal to log a:

$$\text{Log } Y = \log a + b \log X$$

The two variables (X and Y) in this equation when it is used to analyse animal growth data, may either be two separate parts of the same animal, or Y may be a part of X (Tulloh, 1963).

Huxley (1932) pointed out that b (AGC) in the equation can be interpreted in simple meaningful terms as follows:

(1) Where Y is a part and X is the whole; then:
if $b = 1$, then Y remains the same proportion of X as X increases,
if $b < 1$, then Y becomes a decreasing proportion of X as X increases, and
if $b > 1$, then Y becomes an increasing proportion of X as X increases.

(2) Where Y and X are two separate parts of the body; then:
if $b = 1$, the relative growth rates are the same and the ratio of one tissue to the other remains the same as X increases (ie. Y:X is constant),
if $b < 1$, then as X increases, the ratio of Y to X diminishes, and
if $b > 1$, the ratio of Y to X increases as the weight of X becomes larger.

Butterfield & Berg (1966) used the terms high, average and low growth impetus to describe body components with AGC's significantly greater than, not different from, or less than one, respectively.

The allometric equation has been widely used as a means of describing changes in composition with animal growth. Reasons for its widespread use have been discussed in several publications and include:

1. It is a simple equation, and its parameters can be interpreted in simple meaningful terms as described above (Purchas, 1986).
2. It provides a very good fit for many sets of growth data as it fits certain curves as well as straight lines, but it will not fit data that show one or more inflexion points (Purchas, 1986).
3. Because the equation has a linear form, it is easy to apply linear regression procedures to determine the best fit and to assess the goodness of fit. Also, the

significant differences between treatments or groups can easily be evaluated using standard regression procedures (Tulloh, 1963).

4. Measurements compared need not be dimensionally similar (Davies, 1989a). For example, it can be used to describe the relationship between muscle weight and the cross-sectional area of the *longissimus* muscle.
5. For any growth study plotted without logarithmic transformation, the variation becomes greater with increasing absolute size. This is especially apparent when the growth range is wide, in which case some kind of logarithm transformation is important.

Other points, taken as limitations, may also be advantages:

1. It may apply only over a limited phase of growth because the allometric relationship becomes curved for extended periods of growth. Thus, Taylor (1978) noted that the range over which any allometric relation holds should be clearly specified.
2. It is non-additive because the sum of the parts when calculated from allometric equations may not equal the whole (Davies, 1989a).
3. The allometric relationship emphasises relative rates of growth at early stages compared with later stages so that linearity can be obscured at later stages (Taylor, 1978).
4. In calculating the allometric relationship between a part and the whole, there will always be a high correlation between the part and the whole if the part constitute a large percentage of the whole. (eg. the relationship between a group of muscles like those of the hind leg and total muscle) (Pomeroy, 1978).

2.2.2.3 *MATURITY COEFFICIENT*

Maturity is the final stage of development of an animal. It is the stage reached at the end of the growth curves where muscle and bone reach, for the first time, a steady state (Davies, 1989a). Butterfield *et al.* (1983a) defined an early maturing tissue as one which, at any stage of growth prior to maturity, achieved a greater proportion of its mature weight than the whole body had achieved of its mature weight. Conversely, a late maturing structure was defined as one which, at any stage of growth, prior to maturity, had achieved a smaller proportion of its mature weight than the whole body of its mature weight.

The degree of maturity of an animal is the ratio of an immature body weight and its mature weight (Davies, 1989a). Animals for which mature body weight is affected by genetic or treatment differences should be compared for body composition either at maturity, or at the same degree of maturity. McClelland *et al.* (1976) reported that differences in sheep body composition between breeds and between sexes at equal weight were explained by their different stages of maturity. Because of this, the concept of maturity has been used by Butterfield *et al.* (1983a), Thonney *et al.* (1987b), Perry *et al.* (1988), and Butterfield (1988) to describe the growth of the carcass tissues of meat animals including sheep.

The maturity coefficient (q) was first introduced by Butterfield *et al.* (1983a) as a result of their attempt to answer the question posed by Taylor (1978) about whether there may be an alternative form of equation to the allometric equation that would be additive in nature. It expresses the relationship of two variables Y and X in a quadratic equation of the form:

$$Y = p + qX + rX^2$$

Where

Y = weight of an organ divided by its own mature weight.

X = the weight of the total (animal or tissue) divided by its own mature weight.

When this quadratic curve is constrained to pass through the origin (0,0) and the point (1,1), then $p=0$ and $r=1-q$.

So the relationship may be rewritten:

$$Y = qX + (1\text{-}q)X^2$$

$$\text{or } Y\text{-}X^2 = q(x\text{-}x^2)$$

For statistical analysis it is convenient to transform to $Y^1=Y\text{-}X^2$ and $X^1=X\text{-}X^2$ so that the relationship becomes $Y^1=qx^1$, a straight line through the origin.

The maturity coefficient (q), in a similar way to the allometric growth coefficient, can be interpreted in simple terms as follows (Butterfield, 1988):

When $q = 1$, then $Y = X$ and therefore Y and X will mature at the same rate, and will grow at the same relative rates. That is, "average growth impetus" and the proportion of the part to the whole remains unchanged. Impetus as defined by Butterfield (1988) is a term which describes the relationship between the relative growth rate of an organ and the relative growth rate of the body. It can be measured from the 'Growth Coefficient' of Huxley (1932) or from the 'Maturity Coefficient' of Butterfield *et al.* (1983a).

if $q < 1$, the maturity coefficient represents a late maturing tissue and a greater rate of relative growth, i.e., "high growth impetus" relative to the maturity of live weight, and therefore the proportion of the part becomes an increasing proportion of the whole.

if $q > 1$, the maturity coefficient represents an early maturing tissue and a lesser rate of growth, i.e., "low growth impetus" relative to that of the whole animal and therefore the proportion of the part becomes a decreasing proportion of the whole.

The maturity coefficient was developed as a result of the fact that the allometric equation was not always an appropriate function to use for the reasons outlined above (Butterfield, 1988). Important properties of maturity coefficients include:

1. 'q' values are additive. Butterfield *et al.* (1983a) reported that a 'q' value can be calculated for the sum of a number of components from the sum of the individual q values simply weighted by actual weights of mature tissues. This differs from the AGC values which are non-additive.
2. The 'q' values represent a simple way of describing the growth patterns.
3. The 'q' value is capable of describing the relative growth of parts of the body which achieve a weight greater than their mature weight and then decline - such as some parts of the intestinal tract. It is in the description of the growth of these structures (which will have 'q' values greater than 2.0) that the maturity coefficient is unique, as it can efficiently describe such phenomena with a single 'q', whereas this is not possible with allometric coefficients (Butterfield, 1988).

The disadvantages of using maturity coefficients according to Butterfield (1988) include:

1. Maturity coefficients are suitable to describe the patterns of growth of dissected structures from about 20% of their mature weight up to maturity, but not for all

body structures (eg. brain and eyes) (Butterfield, 1988). This is because some carcass tissues, especially the musculature, in the early stages seemed to be governed by priorities not closely related to the maturing process.

2. It was shown by Kirton & Morris (1989) that the weight of mature animals within a breed depends on husbandry conditions. In practice, a mature weight value can be determined only by making certain assumptions, inferring a lack of precision (McClelland *et al.*, 1976).
3. Maturity coefficients were demonstrated by Butterfield (1988) to be unsuitable for describing the pathway to maturity of muscle to bone ratio, whereas allometric coefficients effectively described this phenomena. Thonney *et al.* (1987b) also pointed out that there are mathematical problems in attempting to express compositional maturities of one characteristic solely as a function of another using 'q' values.

Thonney *et al.* (1987b) summarised the difference between the allometric and maturity coefficient in noting that the price paid for additivity in 'q' is the inability to express relative growth easily, whereas the price paid for expressing relative growth easily in terms of the allometric equation is a loss of additivity.

2.2.3 PATTERNS OF GROWTH

During growth and development an animal changes in form and composition. A fundamental concept of growth according to Hammond (1932 & 1976) is that the shape of the growth curve is similar in all species and that the order in which the various parts and tissues develop is much the same, for it is based on the relative importance of the functions of the parts or tissues for survival of the animal. The order of growth and development thus was thought to follow an outward trend from the central nervous system, through bone, tendon, muscle, intermuscular fat and finally subcutaneous fat (Palsson & Verges, 1952).

Hammond *et al.* (1976) considered that the growth of a lamb, from conception to maturity, is not a simple change in size but a progressive change in the proportions of the various tissues, which results from the fact that, although each component grows along the same basic pattern, the time scales are different. Each component reaches the various stages in a different chronological order. Thus, as animal growth and development continues after birth, body composition and proportions continue to change (Hammond *et al.,* 1976). As an example, Hammond (1932) found in Suffolk sheep that the proportions of the head, neck, thorax, loin, shoulders, and leg joints as a percentage of the carcass weight + head was equal to 17.4, 8.0, 16.2, 7.8, 26.2, and 24.0, respectively, at birth while at 4 years old will be equal to 4.8, 5.9, 25.1, 17.8, 19.8, and 22.4, respectively. In summary, Hammond *et al.* (1976) noted that at birth, the head was relatively large; the legs were long, and the body was small, while in the mature animal the head was relatively small, the legs relatively short, and the body was large. Fraser & Stamp (1987) considered that such changes are brought about because the various parts grow at different rates. The major tissues of the animal body (bone, muscle, and fat) grow and develop at relatively different rates post-natally (TABLE 2.1 and 2.2). For almost all the studies included in Table 2.1, bone had the lowest growth impetus followed by muscle, and as both of these tissues had lower growth impetuses than the whole animal they decline as proportions of liveweight as the sheep proceeds to maturity. Fat with a high growth impetus constituted an increasing proportion of liveweight as the animal matures.

Davies (1989) also pointed out that changes in body proportions and composition are brought about by differential growth gradients existing between the different parts and tissues of the body. A gradient of increasing growth intensity was observed by Wallace (1948) and Palsson & Verges (1952) to pass upward from a centre of early maximum rate of growth in the lower limbs of the sheep to a centre of later maximum rate of growth in the loin. A further gradient of growth emphasis moved from the head towards the loin. Thus, in the leg after birth a gradient from low to high rates of relative growth runs from the lower parts such as the cannon bone to the upper parts such as the femur. Growth of the shoulder and hip is retarded before birth, by a reversal of the postnatal pattern. The concept of an axial cranio-caudal gradient of increasing growth, and a distoproximal gradient of increasing growth in the limbs was suggested first by McMeekan (1943) for pigs, and Palsson (1955) for sheep. Allometric studies of muscle growth of sheep by Lohse *et al.* (1971) and Jury *et al.* (1977) have confirmed this pattern of growth. Davies *et al.* (1984) demonstrated growth gradients within both muscle and bone in cattle, sheep and pigs.

The most accurate information on the composition of lamb or mutton carcasses is obtained by complete physical and chemical analyses (Hammond, 1932; Kirton *et al.*, 1962). Hammond *et al.* (1976) reported that the average chemical composition of commercial lamb carcasses on a fat-free basis was remarkably similar over a wide range of ages and weights. This conclusion was supported by the results of Kirton *et al.* (1959) and Kemp & Barton (1966). Similar results for whole body composition were found by Searle & Griffiths (1983) when they reanalysed data on the composition of the fat-free empty body from seven experiments involving 201 sheep from different breeds over a range of 3 to 570 days of age.

An example of changes in the chemical composition of the lamb carcasses was reported by Owen (1976) using data of Morgan & Owen (1973) for ram lambs raised on ad libitum feeding, and slaughtered at three different stages. The major chemical components of dry matter percent, fat percent, ash percent, and crude protein percent of the lamb carcasses were equal to 40.7, 52.5, 10.2 and 37.1, respectively, at a carcass weight of 9.1 kg, while at 16.1 kg the values were 44.6, 59.5, 9.0 and 31.2, respectively. Similar changes in chemical components of lambs with growth were shown by Kirton *et al.* (1959), and Kemp & Barton (1966) for carcass composition, and by O'Donovan (1974), Blaxter *et al.* (1982) and Searle & Griffiths (1983) for total body composition. The main conclusion drawn from these studies was that the water, ash, and crude protein all fell as a proportion of dry matter as the lamb grows, while the chemical fat content showed a marked increase.

In studies of meat animals, the primary concern is with the relative growth of muscle, fat and bone of the carcass, as shown in the work cited in TABLE 2.1 and 2.2 for lamb. Important changes that occur in these components with growth are as follows:

Bone growth:

The skeleton as a whole is an early maturing component of the body. Bone grows postnatally relatively more slowly than muscle and the whole carcass (TABLE 2.1). The implication of this is that lean to bone ratio is closely related to the size of the animal. This ratio increases, while the percentage of bone in the carcass declines (TABLE 2.2).

However, within the skeleton, individual bones vary in their rate of development (Hammond, 1932). The skull bones, for example, are relatively earlier maturing than the whole skeleton, whereas the ribs are later maturing. Davies *et al.* (1984) demonstrated in sheep that individual bones within the skeleton vary in their rate of development and that the growth ratio of each bone to total side bone weight growth also differed in their relative growth between prenatal and postnatal growth.

Muscle growth:

The proportion of total muscle in the body changes less than fat as the lamb grows (TABLE 2.2). Hammond (1932) showed that the proportion of muscle weight fell from 27 percent at birth to 24 percent at 41 weeks. Also, several other studies (e.g. McClelland *et al.,* 1976) have indicated a steady relationship between muscle weight and liveweight over narrower ranges of growth to maturity. It seems that it is probably only in advanced fattening that the proportion of muscle declines appreciably relative to liveweight (Butterfield, 1988).

Within the total, however, individual muscles show large differences in earliness of maturity. For example neck to forelimb muscles (q=0.73) and neck and thorax muscles (q=0.64) are relatively early maturing compared with the total muscle mass, whereas spinal muscles (q=1.15) are later maturing (Butterfield, 1988).

The concept that functional demands influence muscle growth during growth and development was proposed by the Hammond school. The suggestion that major changes in muscle weight distribution occur soon after birth has been confirmed in sheep by Lohse *et al.* (1971).

Growth patterns of muscle relative to total carcass or side weight or total muscle weight in sheep are given in TABLE 2.1. Also, the growth rate of individual muscles and muscle groups relative to total muscle weight in sheep has been studied by several workers including Lohse *et al.* (1971), Murray & Slezacek (1975), Jury *et al.* (1977), Butterfield *et al.* (1983b), and Butterfield *et al.* (1984).

Fat growth:

The adipose tissue of the lamb is later maturing than the body as a whole (Seebeck, 1966). The rate of increase of fat deposition is relatively greater than the other important carcass tissues and this is reflected in an increase in the percentage of fat in the carcass (see TABLES 2.1 and 2.2).

The relative growth of the different fat depots changes as fattening proceeds (TABLE 2.1). Subcutaneous fat has a higher relative growth rate than intermuscular fat, and kidney knob and channel fat grows at the same relative rate as total fat. The classical view of their order of development, as shown by Wood *et al.* (1980), is subcutaneous fat >omental fat >kidney knob and channel fat >intermuscular fat.

With regard to fat distribution within depots, Hammond (1932) indicated growth gradients of patterns of fat deposition from the distal ends converging in the abdominal region. Kempster (1981) reported Meat and Livestock Commission studies on sheep which showed low growth coefficients for fat in the distal limb joints with increasing coefficients centripetally on the limbs, and increasing further towards the rib and loin area. Fat growth coefficients in the flank and brisket areas tended to be the highest.

TABLE 2.1 Allometric growth coefficients (b) and maturity coefficients (q) showing how total muscle or individual muscle weights, total fat or fat depots weights, and total bone or individual bone weights changed relative to carcass weight for sheep from published studies. The values in brackets following some b values are the intercepts for the log/log relationship.

References and Comment	Dep.Variable(y) Indep. Variable(x)	b	q
Elsley *et al.* (1964). Suffolk crosses from birth to 40wks. Two sexes (n=18).	y=log10 total muscle wt.	1.10	
	y=log10 intermuscular fat wt.	1.82	
	y=log10 subcutaneous fat wt.	2.15	
	y=log10 total bone wt.	0.75	
	x=log10 total muscle + bone wt.		
Tulloh (1963). Mixed breeds. n=26 for muscle and fat and n=38 for bone.	y=log total carcass muscle wt.	1.02(-0.54)	
	y=log total carcass fat wt.	1.54(-1.84)	
	y=log total carcass bone wt.	0.72(-0.71)	
	x=log empty body wt.		
Seebeck (1966). Merinos and crossbreds. Rams, wethers, and ewes. Liveweight 13.5 to 35.5kg. (n=57).	y=log side muscle wt.	0.98	
	y=log total fat wt.	1.38	
	y=log total bone wt.	0.64	
	x=log jointed side wt.		

...**TABLE 2.1**/2 cont'd...

References and Comment	Dep.Variable(Y) Indep. Variable(x)	b	q
Jackson (1967). Scottish Blackface males from birth to 18 months (n=37).	y=log10 total muscle wt.	1.36	
	x=log10 total bone wt.		
Fourie *et al.* (1970). Southdown males from birth to 80wks (n=32). Similar results for Romney, SD X Rom, and females.	y=log total muscle wt.	0.95	
	y=log total fat wt.	1.39	
	y=log intermuscular fat.	1.24	
	y=log perinephric fat.	1.27	
	y=log subcutaneous fat.	1.75	
	y=log total bone wt.	0.71	
	x=log carcass wt.		
Lohse (1973). Peppin Merino males (n=32) from 1 to 730 days. Similar results for females.	y=log side muscle wt.	0.97	
	x=log carcass wt.		
Geenty *et al.* (1979). Wethers of 4 breeds, from 3 to 48wks (n=195).	y=log omental fat.	2.12	
	y=log kidney fat.	1.46	
	x=log fasted body wt.		

...**TABLE 2.1**/3 cont'd...

References and Comment	Dep.Variable(y) Indep. Variable(x)	b	q
Thompson *et al.* (1979). Six breeds, 2 sexes, and liveweights from 34 to 54kg (n=108).	y=log total muscle wt.	0.74(0.76)	
	y=log intermuscular fat.	1.51(-2.9)	
	y=log subcutaneous fat.	2.10(-5.2)	
	y=log total bone wt.	0.55(0.99)	
	x=log carcass wt.		
Broad & Davies (1980). Romney sheep from 80 days gestation to 5 years (n=32). Both sexes.	y=loge total side fat wt.	1.75	
	y=loge forequarter internal cavity fat wt.	1.06(-6.3)	
	y=loge forequarter subcutaneous fat wt.	2.21(-15.3)	
	y=loge forequarter intermuscular fat wt.	1.50(-8.2)	
	y=loge hindquarter internal cavity fat wt.	1.36(-7.5)	
	y=loge hindquarter subcutaneous fat wt.	1.81(-11.5)	
	y=loge hindquarter intermuscular fat wt.	1.44(-8.5)	
	x=loge carcass wet wt.		
Wood *et al.* (1980). Four breeds from 15 to 21 kg carcass wt. Two sexes (n=361).	y=log10 total muscle wt.	0.83	
	y=log10 subcutaneous fat.	1.99	
	y=log10 intermuscular fat.	1.01	
	y=log 10 kidney knob and channel fat wt.	1.68	
	y=log10 omental fat wt.	1.87	
	y=log10 total bone wt.	0.57	
	x=log10 total carcass wt.		

...TABLE 2.1/4 cont'd...

References and Comment	Dep.Variable(Y) Indep. Variable(x)	b	q
Jones (1982).	y=log total side fat.	1.22	
Suffolk crossbred	y=log subcutaneous fat.	1.36	
rams. Liveweight	y=log intermuscular fat.	0.93	
from 24 to 61.8 kg	y=log kidney fat wt.	1.16	
(n=38). Similar	y=log cavity fat wt.	1.11	
results for	x=log total side wt.		
females.			
Butterfield *et al.*	y=total muscle wt.		1.25
(1983a).	y=total fat wt.		0.07
Small and large	y=total bone wt.		1.41
Merino rams (n=39)	x=shorn full liveweight.		
from 18 kg to			
maturity.			
Butterfield *et al.*	y=total muscle wt.		1.27
(1984).	y=total fat wt.		0.15
Dorset Horn	y=total bone wt.		1.72
wethers and rams	x=shorn full liveweight.		
(n=39) from			
18 kg to maturity.			
Kempster *et al.*	y=log total muscle wt.	0.77	
(1987b).	y=log total fat wt.	1.82	
Lambs of several	y=log subcutaneous fat.	2.07	
breeds and crosses	y=log intermuscular fat.	1.50	
(n=1400) from early	y=log kidney fat.	2.11	
flocks at 3 live wt.	y=log total bone wt.	0.51	
over a range of 9kg	x=log total side wt.		
based on estimated			
adult body size from			

...**TABLE 2.1/5** cont'd...

References and Comment	Dep.Variable(y) Indep. Variable(x)	b	q
33 to 51kg. Similar results were obtained for the late flocks.			
Thonney *et al.* (1987b). Within sheep of 7 breeds, 2 sexes, and 4 stages of maturity (n=141).	y=loge total muscle wt. x=loge degree of maturity in liveweight.	1.04(2.46)	0.95
Taylor *et al.* (1989). Within rams of 8 breeds (n=72) and from 0.40 to 0.76 of maturity. Similar results for females.	y=log of total carcass muscle proportion.	-0.10	1.19
	y=log of total carcass fat proportion.	0.57	0.31
	y=log of total carcass bone proportion. x=log carcass wt.	-0.42	2.08
Thorgeirsson & Thorsteinsson (1989). Icelandic rams and ewes from birth to 74 wks (n=80). Values for 12kg carcass wt. Similar results obtained from 6 & 18kg carcass wt. group.	y=log total muscle wt	0.87	
	y=log total subcutaneous fat.	2.02	
	y=log total intermuscular fat.	1.66	
	y=log total bone wt x=log carcass wt. and (log carcass wt.)^2	0.63	

TABLE 2.2 Changes with increasing carcass weight for fat, muscle and bone percentages and for muscle to bone ratios for sheep from published studies.

References & Comment	Relationships of tissues with carcass wt.	Fat %	Muscle %	Bone %	M:B
Hammond (1932) Suffolk sheep from 11 wks to 5 yrs (n=36) and two sexes.	At carcass wt. of				
	13.6 kg	9.1	68.3	17.3	3.9
	18.8 kg	8.7	79.0	17.8	3.9
	46.5 kg	24.8	60.1	11.2	5.4
	49.2 kg	18.4	65.4	10.8	6.1
	67.8 kg	34.5	51.6	10.7	4.8
Hammond (1932) Suffolk rams from new born to 4 yrs (n=77).	At carcass wt. of				
	1.1 kg	4.5	48.8	33.3	1.5
	13.7 kg	8.9	68.6	17.6	3.9
	18.8 kg	17.7	66.6	13.2	5.0
	67.5 kg	28.6	59.5	9.0	6.6
Palsson & Verges (1952). Suffolk x 1/2 (Border Leicestor X Cheviot) with different planes of nutrition (high and low plane) and from new born to 41 wks.	At carcass wt. of				
	1.4 kg	2.4	47.1	34.0	1.4
	2.0 kg	4.8	47.5	30.6	1.6
	3.5 kg	4.7	55.4	27.2	2.0
	14.9 kg	22.2	51.3	16.8	3.1
	15.4 kg	21.0	53.0	16.6	3.2
	51.6 kg	43.1	37.8	9.3	4.1

...**TABLE 2.2/2** cont'd

References & Comment	Relationships of tissues with carcass wt.	Fat %	Muscle %	Bone %	M:B
Fourie *et al.*	At carcass wt. of				
(1970).	5 kg	17.7	58.6	12.9	4.5
Southdown sheep	10 kg	24.1	55.7	10.3	5.4
from birth to	20 kg	32.8	53.0	8.2	6.5
80 wks and two	30 kg	39.3	51.4	7.2	7.1
sexes (n=32).					
Similar results					
for Romney, and					
SD X Rom.					
McClelland *et al.*	As a percentage of				
(1976).	carcass wt.				
Sheep of 4 breeds,	9.5 kg	20.0	57.9	21.7	2.7
2 sexes and 4	13.3 kg	25.6	56.8	17.0	3.3
stages of maturity	17.5 kg	30.2	52.4	16.3	3.2
(n=65).	21.2 kg	34.0	51.2	14.7	3.5
Wood *et al.*	At carcass wt. of				
(1980).	14.7kg	28.5	57.7	13.8	4.2
4 breeds from	17.1kg	30.7	56.9	12.4	4.6
15 to 21 kg	19.3kg	32.4	55.3	12.3	4.6
carcass wt.	21.4kg	33.3	55.0	11.7	4.7
Two sexes (n=361).					

...**TABLE 2.2**/3 cont'd

References & Comment	Relationships of tissues with carcass wt.	Fat %	Muscle %	Bone %	M:B
Taylor *et al.*	At different estimation				
(1989).	of mature liveweight(g/kg).				
Rams of 8 breeds	26.9 kg	193	606	201	3.1
(n=72) and from	35.0 kg	233	598	169	3.5
0.4 to 0.76 of	43.1 kg	258	576	166	3.5
maturity.	51.1 kg	278	571	151	3.8
Thorgeirsson &	At carcass wt. of				
Thorsteinsson	1.9 kg	10.8	65.4	23.8	2.8
(1989).	16.5 kg	28.1	59.9	11.9	5.0
Icelandic male	33.1 kg	30.2	58.3	11.5	5.1
sheep from birth					
to 74 wks (n=80).					
Similar results					
for females.					

2.3 CARCASS MUSCULARITY

In this section four topics will be reviewed separately. The first two are concerned with the definition and evaluation of carcass muscularity, while the third considers relationships between carcass muscularity and other carcass characteristics. Finally factors affecting carcass muscularity are reviewed.

2.3.1 DEFINITION OF CARCASS MUSCULARITY

The terms "muscular" or "muscularity" have been used by animal breeders, butchers and consumers to describe the conformation or shape of farm animals (Hirzel, 1939; Palsson, 1939). Meatiness and fleshiness are two other terms that have been used in a similar way to muscularity in describing the degree of muscle development of live animals and carcasses (Yeates, 1952).

However, the term muscularity has been defined differently through the years, and, thus, it means different things to different people. Also, until recently there has been no generally accepted common language for describing this carcass characteristic in an objective way. This situation changed when a working group on carcass evaluation from the European Association for Animal Production established reference methods for the assessment of carcass characteristics including a definition of muscularity which facilitated objective measurement (De Boer *et al.*, 1974). They also differentiated between muscularity, conformation, and fleshiness.

Prior to this definition, muscularity had been defined in a number of general ways. Hedrick (1968) simply defined muscularity as the absence of fat because the yield of lean meat was considered the single most important factor determining carcass value.

Kirton (1964) noted that carcasses regarded by the meat trade as having good muscularity tended to be short in the leg and blocky in appearance, and to give the impression of having a larger amount of meat in the leg (a high-priced part of the carcass) than carcasses of poor muscularity.

More desirable muscling was also said by Martin *et al.* (1966) to be indicative of a higher ratio of muscle to bone, while according to Butler (1957) and Butterfield

(1963), a good muscling indicates that there are more of the right (high-priced) muscles. In other words, better muscled animals should have a better distribution of muscle (Berg & Butterfield, 1968).

Kauffman *et al.* (1973) reported that variations in the shape of the live animal or carcass are described as being either bulging or flat, convex or concave, long or short, curved or straight, thick or thin, and wide or narrow. They suggested that heavily-muscled animals having a convex, bulging shape should be defined as muscular and lightly-muscled ones having a concave, flat shape should be defined as non-muscular. Previously, Coop & Clark (1957) defined muscularity in terms of leg width relative to leg length, and Yeates (1959) defined the 'fleshing index' of a carcass as the extent to which it was heavier or lighter than the average for its length.

De Boer *et al.* (1974) defined muscularity as the thickness of muscle relative to dimensions of the skeleton. Conformation, in contrast, was defined as the thickness of muscle plus intermuscular fat plus subcutaneous fat relative to dimensions of the skeleton, and fleshiness as the thickness of muscle plus intermuscular fat relative to dimensions of skeleton. Kempster *et al.* (1982) reported that, based on the above definitions, conformation can be regarded as essentially being muscularity when meat animals were compared at equal fatness. Purchas (1990) noted that this distinction between muscularity and the other terms helped to overcome widespread misunderstandings and to clarify the issues when grading or classification schemes have sought to incorporate measures of shape.

Kempster *et al.* (1982) claimed that the De Boer definition of muscularity and other carcass characteristics had been widely adopted and used. However, in spite of this clear definition, meat producers, breeders and scientists still used some other terms to define muscularity and the associated carcass characteristics. Kadim *et al.* (1989) used total side muscle weight relative to body length, or weights of individual muscles relative to the length of adjacent bones as indexes of muscularity. Madsen *et al.* (1992) defined beef carcass muscularity in terms of an index incorporating the *M.longissimus* area (measured between the 13th thoracic and 1st lumbar vertebrae) and the weights of six important cuts (full rib, sirloin, inside, full rump, knuckle and tenderloin) from the hind-quarter at given carcass weight. Anon (1982) stated that the term 'muscling' can be defined as a visual assessment of muscle to bone ratio. Purchas (1986) noted that, generally, improvements in muscularity were associated with increased muscle to bone ratios, but that this was not always the case. Fisher & Bayntun (1981) considered that the most important commercial aspect of conformation or carcass shape was probably its relationship with the ratio of the weights of saleable meat to bone. By using a simple simulation model Purchas *et al.* (1991) demonstrated that muscularity as defined by De Boer *et al.* (1974) could change without changes in M:B ratio. They concluded that both these characteristics should be measured and reported for carcass composition studies.

2.3.2 EVALUATION OF CARCASS MUSCULARITY

This topic will be reviewed separately for subjective and objective methods of evaluation. Emphasis will be placed on work involving sheep, but studies with cattle and pigs will also be considered where only limited data on sheep are available.

Most reported carcass muscularity measurements have been as subjective scores (Colomer-Rocher *et al.*, 1980; Kirton *et al.*, 1983) despite the clear definition of muscularity provided by De Boer *et al.* (1974). Purchas *et al.* (1991) suggested that the lack of objective measures may be because of perceived difficulties in obtaining a satisfactory single index of average muscle depth due to the wide variation in depth both within and between muscles.

2.3.2.1 *SUBJECTIVE EVALUATION*

Visual assessment to give a muscularity score (with or without the assistance of instrumentation), has always been essentially the only means used to identify differences between carcasses for muscularity and conformation (Newman, 1993). It is a quick, cheap and convenient method and, in the absence of more precise predictors, is suitable for use in commercial abattoirs. It has become a principal component of the classification and grading schemes in many countries (Kirton, 1989). Muscularity as used in grade standards is an estimate of muscle shape and thickness (De Boer, 1984). Kempster *et al.* (1982) reported that the overall or leg conformation is also used as the assessment of the relative distribution of muscling in the carcass or in the leg, respectively. These traits are dependent upon muscle thickness, depth, and length, and to a variable extent, upon both subcutaneous and intermuscular fat depots (De Boer, 1984). However, Pomeroy (1975) reported that such assessments suffer from a number of disadvantages common to most systems of subjective judgement. These include: the variable experience of the assessors; the difficulty of standardization of assessments made by different people; choosing definitions of the differences between steps on the scoring scale; the problem of choosing the optimum number of steps in the scoring scale; and difficulties in controlling the environmental conditions during assessments. For example, the level of lighting and the angle from which the carcasses are viewed, and the appearance of other carcasses in the same batch can influence the judgements made (Kempster *et al.*, 1982).

In a number of classification systems, standard sets of photographs and/or silhouettes have been prepared to assist graders make subjective assessments and to improve the consistency of visual appraisal (Kempster *et al.*, 1982). These are particularly helpful when assessors are regularly exposed to carcasses representing only a narrow part of the whole range of the scales (Gatherum *et al.*, 1961), or to improve repeatability over time (Pomeroy, 1975). Harries *et al.* (1974) also showed that the performance of novice judges could be improved by the use of such standards.

The number of points on scales for muscularity and conformation vary between countries or applications with 5-7 point scales being most common (Kempster *et al.*, 1982). A 15-point scale, with five basic classes each with three subdivisions, has been proposed as the standard for the assessment of experimental cattle in E.A.A.P. countries (De Boer *et al.*, 1974), while in New Zealand the export classification system for lamb carcasses has only two muscling classes and the system for beef carcasses has three classes (NZMPB, 1992). In Australia, five muscling categories for beef carcasses are assessed visually (Hall, 1988).

Starke & Joubert (1961) reported that visual appraisal, even in the case of experienced judges, does not ensure a true picture of carcass assessment as objective measurements. However, Pomeroy (1975) concluded, after reviewing visual assessment techniques, that it was a useful technique for assessing carcasses under commercial conditions providing its inherent limitations were recognised, and providing adequate training backed by photographic standards was given to those undertaking the assessment.

Newman (1993) reported that the performance of assessors was influenced by physical, psychological and environmental effects and that whilst individual assessors performed well for short periods, it was impossible to perform consistently at optimum performance for long. He noted that the performance both within and between graders for assessing beef carcasses visually was variable and the difference between the worst and the best was large. Under commercial 'pressures' there was a significant fall-off in performance after a relatively short period of time (20-30 min). Harries *et al.* (1974) studied the reliability of visual appraisal techniques on intact sides of beef by testing judges for discrimination and consistency, and by comparing their assessments with the results of subsequent dissection. The judges tended to disagree with each other in the scoring of the conformation characteristics, but expert judges gave more stable scores than trainee or butcher judges. De Boer & Nijeboer (1973) studied the suitability of using stereo-diapositive (standardized photographs) for test scoring in comparison to real beef carcasses. For fleshiness and fat covering there was a small but non-significant difference in scoring level between the real carcasses and the diapositives, but the photographs were almost as effective as real carcasses in checking scoring results of different judges. The scoring of diapositives by the same judges did not show important differences between persons and successive scores of fleshiness by the same judge were closely correlated ($r = 0.97$). In spite of a wide range of variation, no significant differences occurred between averages. They concluded that the lack of a routine for judges makes it necessary to check on their level of scoring, as it may be affected by a variety of circumstances such as seasonal fluctuations of fleshiness.

In one experiment in which six very experienced judges were asked to complete the traditional score card for 21 beef carcasses, Williams (1972) reported that there was not a high level of agreement between the judges, particularly for assessments of fat covering. However, there was better consistency for eye muscle or muscular development scores. Coefficients of concordance values (W) were between 40 to 69%. Williams (1972) also compared the traditional type score cards for beef and lamb visual assessment, which allocated up to 20 points for each characteristic, with an experimental score card system which was based on a 7-point scale for each characteristic, with each point having a matching description. When the two scoring systems where compared with 20 lambs and eight judges of varying experience, the 7-point system was shown to be more efficient and there was a marked improvement in consistency of judgement.

2.3.2.2 *OBJECTIVE EVALUATION*

Several methods have been tested to evaluate carcass muscularity and conformation in attempts to make the systems entirely objective (Hirzel, 1939; Hammond, 1952). Savell & Cross (1991) discussed the debate as to whether the muscling in meat animal carcasses was assessed more effectively from the cross-sectional area of a major muscle (e.g., *M.longissimus*) or by observing or measuring the shape and contour of the round (conformation or muscle profile). The determination of muscling by an evaluation of conformation was shown to be confounded by fatness.

2.3.2.2.1 *MEASUREMENTS TAKEN ON THE CROSS-SECTION OF THE M.longissimus*

Area and dimensions of the cross-section of the *longissimus* muscle and various combinations and ratios (e.g., A/B and EMA/carcass length) have been used extensively as indices of muscling in the carcass and have been studied over many years as predictors of carcass lean content (Palsson, 1939; Walker & McMeekan, 1944; Kempster *et al.*, 1976; Eldridge, 1989). Kempster *et al.* (1982) pointed out that the use of such measurements on cut carcasses is impractical in most commercial situations for a number of reasons related to butchery practice and animal slaughter speeds. These measurements are usually taken by ruler, planimeter, or by tracing the area from the cut surface between ribs 12 and 13 or between ribs 6 and 7 (Kempster *et al.*, 1982) or by video image analysis (Cross *et al.*, 1983). Photographic methods were reported by Schoonover & Stratton (1957) to be less subject to error. Significant differences between right and left sides in eye muscle area of beef carcasses reported by Carpenter & Palmer (1961) appeared to be due mainly to cutting errors (Hedrick *et al.*, 1965). Henderson *et al.* (1966) compared various methods and found good correlations among different operators, but agreed with earlier workers as to the importance of cutting errors. Results from several studies with lamb and beef (Cole *et al.*, 1960; Timon & Bichard, 1965; Latham *et al.*, 1966; Kempster *et al.*, 1976) have shown that relationships between measurements of the eye muscle and measures of carcass lean have generally been poor (moderate to low, and lower with lean percentage than lean weight), which surprises some who expect the area of a big muscle such as the *M.longissimus* to be well correlated with leanness. However, as it does account for some of the variation in carcass lean yield, and is relatively easy to obtain, and because better, simpler and more direct measures of muscling have not been devised, it continues to be advocated along with other simple measures for use in estimating carcass lean content (Hedrick, 1983).

2.3.2.2.2 *LINEAR MEASUREMENTS*

Linear carcass measurements (for example, width, length and depth) and various combinations and ratios of linear measurements have been used to evaluate muscularity and conformation (Kempster *et al.,* 1982). Palsson (1939) considered length of leg to be the best index of muscle development in sheep, but Walker & McMeekan (1944) considered the length of leg to be only moderately adequate. Measurements taken with a calibrated stick, tapes, or calipers are more repeatable (Brannang, 1975) than subjective scores, and are also more consistent as methods for comparing carcasses at different locations (Brannang, 1975). There are disadvantages, however, as the time and labor required to take such measurements can limit their use on the slaughter floor (Boggs & Merkel, 1979). Palsson (1939), Walker & McMeekan (1944), Coop & Clark (1952) and Robinson *et al.* (1956) used the ratio of width of gigots to length of leg (G/F) as an index of blockiness. The accuracy of the measurement is reasonably high and when used with sheep carcasses for the assessment of conformation it showed a series of declining values, convenient for discriminating between conformation grades in each of three weight categories (Robinson *et al.,* 1956).

2.3.2.2.3 *WEIGHT TO LENGTH RATIOS*

Weight in relation to length has been proposed as an objective measure of carcass blockiness, but again this has not been taken up widely (Kempster *et al.,* 1981; Kempster *et al.,* 1986). The simplest ratio was the hot carcass weight divided by carcass length (Yeates, 1952). This ratio developed in Australia by Yeates (1952, 1959) was termed the 'fleshing index', and was employed in the initial Australian beef carcass appraisal system. It was later adapted by Thwaites *et al.* (1964) for use with lamb and mutton carcasses. The gross fleshing index was based on the weight that a carcass varies from the average at any particular length to give positive or negative indexes in pounds. To facilitate the calculation, a simple 'slide-rule' was developed which, with length and weight known, allowed fleshing index to be read off (Yeates, 1959). The carcass length used by Yeates and co-workers for sheep was from the point of the pubic symphysis to the middle of the first rib. This index describes the amount of lean and fat which a carcass carries relative to its length and affords a quick and accurate description of its fleshing (Thwaites *et al.*, 1964). However, Yeates *et al.* (1975) noted that the fleshing index does not discriminate between the relative development of muscle and fat. Maximum development of the former is desirable, while over- or under-fatness should be penalized during appraisal because the aim is to achieve a high fleshing index without overfatness.

In a study to evaluate the lamb and mutton carcass grading system in the Republic of South Africa, Bruwer *et al.* (1987) described the carcass mass/carcass length ratio (kg/cm) in lamb as the carcass thickness. This was found to be a more reliable predictor of the visual evaluation of conformation than the carcass mass/leg length ratio (kg/cm) (leg thickness) at all ages. They found it to be a suitable objective measurement for conformation in a practical situation.

2.3.2.2.4 *PROFILE DIMENSIONS*

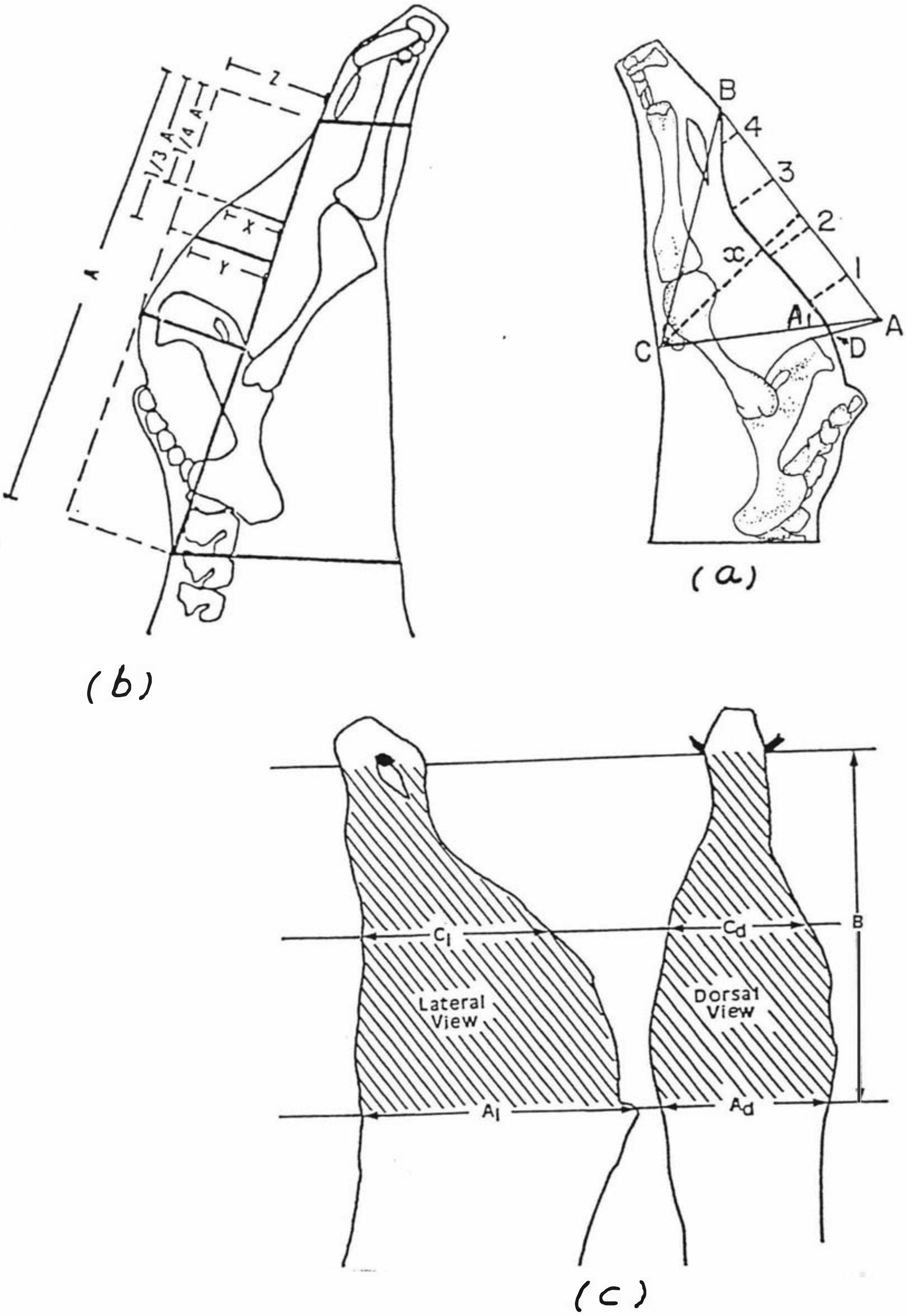
In New Zealand, two objective measurements, the depth of the hind limb (X) and area of the hind limb (ABC) between anatomically defined points (Figure 2.1a) were found by Bass *et al.* (1977) to give a good relationship with meat percentage for 230 crossbred steers. These measurements (Figure 2.1a) involved the insertion of a steel pin along the line of the caudal edge of the cut surface of the symphysis pubis (A - A1). The angle of the pin, which protruded 12cm from the carcass surface, was determined by the edge of the symphysis pubis. A rule was then extended from the free end of the pin (A) to the tuber calcis (B). The middle of the patella (C) was also located so that the area of triangle ABC could be calculated. The distance from the line A-B to the surface of the carcass immediately below the line A-B was measured at regular intervals of 10cm from A to B. These measurements allowed the area (Z) of the carcass within triangle ABC to be estimated. The other measurement taken was the greatest width (X) of the hindquarter perpendicular to a line running from the mid-point between A and B to point C. In another study with 98 steers from ten different sire breeds, Bass *et al.* (1981) found these two objective measurements to be better than visual carcass conformation systems in predicting carcass muscle weight. An additional 18.8% and 11.5% of the variation was accounted for in predicting total muscle weight by including area and the depth measurements after adjusting for the hindquarter weight. However, only 10.0% and 6.9% of extra variation was accounted for by the area and depth respectively, after adjusting for hindquarter weight and hindquarter fat. It was suggested that the area measurements had the advantage that they could be included in a national carcass classification system (Bass *et al.*, 1981) although it was not explained how they could be routinely measured.

FIGURE 2.1 Three objective measurements of thigh conformation used with beef carcasses.

(a) Measurements taken on the left side of beef carcass as reported by Bass *et al.* (1977).

(b) Measurements of thigh conformation in young bull carcasses as reported by Sorensen (1984).

(c) Measurements taken on beef carcasses using video image analysis as reported by Eldridge (1989).



Results produced by rather similar methods have been reported by Sorensen (1984) using measurements X, Y, and Z (Figure 2.1b) to assess the muscularity in the posterior part of the thigh of young bulls. Ratios between these measurements together with the carcass length and weight gave good correlations to subjective carcass conformation and muscle/bone ratio. For example, R^2 values obtained by a combination of carcass weight, carcass length, weight/carcass length and thigh measurements X/Z were 0.59 for muscle/bone ratio and 0.74 for conformation score.

Another study using similar methods to assess measurements of beef muscle shape (conformation), by a video image analysis system was reported by Eldridge (1989). In this system, the measurements of muscle shape were based on the degree of convexity of the butt (Figure 2.1c), and the carcasses were viewed laterally and then turned through 90^o to be viewed dorsally. The image of the carcass was analysed by defining the area of interest (AOI) of each carcass and then thresholding the image to convert it to a silhouette. The parameters measured on the image of each carcass for both lateral and dorsal views included area of carcass within AOI, horizontal dimensions of carcass at the base of the AOI (A_l,A_d), the vertical dimension of the AOI (B), and the horizontal dimension at 1/2 the height of AOI (C_l,C_d). These parameters were identified by defining the upper and lower points of AOI as the base of the hook and the point of separation of the tail (between the sacral and coccygeal vertebra), respectively. The results from 162 carcass images in relation to one objective measurement (eye muscle area/carcass length), and carcass muscle shape scored visually by 2 teams of trained assessors (A and B) were given by Eldridge (1989). For the group of carcasses weighing <250 kg, the correlation between Area Butt, Width thigh (C_l, lateral view), width thigh (C_d, dorsal view), and C_l*C_d and team A were 0.00, 0.23, 0.21, and 0.23, respectively, and between these parameters and team B were 0.30, 0.60, 0.50, and 0.57, respectively. Similar correlations were given by the assessor teams in relation to these parameters for the group of carcasses weighted >250 kg, but, in this case, the values were higher for the team A and lower for the team B. They concluded that, based on these preliminary results, the carcass parameters could be useful in assessing carcasses <250 kg for muscle shape by using a video image analysis system. They also noted how the results highlighted the variation between assessors in grading for muscle shape.

A different approach was used by Fisher (1975) in a study of steers of one breed (Hereford). Photographic negatives of the dorsal and lateral views of 30 carcasses were obtained and profile areas measured from projected images on a specially designed imaging table. Relations between fore- and hindquarter areas in the two views were adjusted to the cubic dimension, and the weights and volumes of tissues were computed. The results showed in general that the correlations relating both of the profile areas with lean weights (r = 0.64-0.71) were less than those given with fat weight. The variation in total lean weight explained by side weight alone was 60.0%, and by dorsal area or lateral area was 44.2% and 47.0%, respectively. He concluded that neither of the profile areas was of much value in explaining the variation in lean weight especially when the variation in fat was as large as it was in this experimental group.

Dumont (1989) examined in detail the conformation of the ham (proximal pelvic limb) in 65 pigs comprising entire and castrated males, females, and four breeds including the highly-muscled Pietrain. Photographic diapositives of the medial and dorsal views were projected and 'transverse apparent diameters' were constructed on the traced profiles at 26 equidistant points, and perpendicular to, the line joining the calcaneal tuber to the cranial edge of the symphysis pubis. Multivariate analysis of centred-data techniques were used to identify interrelations of the most discriminating widths in relation to the ham muscle-to-bone ratio.

The results showed that the variation of width was larger for the dorsal view. The relationships between the different widths with muscle to bone ratios were generally higher for the dorsal view and differed between the levels. He concluded that the best measurements of "conformation" were located at the distal third of the ham and did not correspond to those levels for which the correlation with the muscle to bone ratio was maximum, which was closer to the middle part of the ham toward the body.

Similar objective studies of profile measurements have not been reported in lamb experiments.

2.3.2.2.5 *OTHERS*

Purchas *et al.* (1991) proposed an objective muscularity index based on an index of muscle depth relative to a skeletal dimension. The muscle depth index was derived by taking the square root of the average muscle cross-sectional area, which was obtained by dividing muscle weight by its length (or the length of an adjacent bone). The muscle depth index was then divided by bone length to provide a measure of muscularity. Purchas (1993) noted that this approach for muscularity measurement was most satisfactory for parts of the carcass where the muscles totally surround the bone (for example, the muscles surrounding the femur and the humerus) as this ensures that the square root of the area is an index of muscle depth and not width. Measures on the *longissimus* muscle may be unsatisfactory because the width of that muscle is not constrained by the presence of other muscles.

Fisher (1990) calculated a shape index of beef carcasses based on the roundness of cross-sections by dividing the square root of their areas (measured on bandsawn slices) by their perimeters. Thus, higher shape-index values indicated deeper or thicker tissues. The carcass slices were obtained from three animals of similar muscularity, but contrasting fatness, by feeding the three members of a set of monozygous triplet heifers different dietary energy levels. The shape index was practically identical in all three carcasses in the very lean region of the ischium (proximal pelvic limb), but the fatter carcasses had higher index values in the fatter caudal rib and loin regions. Therefore, those slices which were similar for the three carcasses were from sites where thickness was due mainly to muscle and bone depth and relatively independent of fat thickness.

2.3.3 RELATIONSHIPS BETWEEN CARCASS MUSCULARITY AND OTHER CARCASS CHARACTERISTICS

Only limited information on relationships with muscularity is available, so this section will also include some results on relationships with the closely related characteristics of conformation and muscle to bone ratios.

2.3.3.1 *DRESSING-OUT PERCENTAGE*

Kauffman *et al.* (1976) showed that beef breed types with better conformation at the same level of fatness tended to dress-out better. They observed that as degree of muscling changed from angular (muscling group 1) to muscular (muscling group 5), dressing-out percentage increased from 64.8 to 72.5 and thoracic cavity capacity decreased from 13.7 to 6.2 units. This association appeared to be due to differences in the size of the body cavity and weight of internal organs. The latter decreased from 4.3% for muscling group 1 to 2.0% for muscling group 5 (Kauffman *et al.*, 1976). Similar results were found for lambs with leggy and blocky conformation by Kirton & Pickering (1967), with a higher proportion of offal (stomachs being 83-103g higher and full intestines being 178-390g higher) and lower omental fat (27-121g) in the leggy conformation lambs at a similar carcass weight. Kadim *et al.* (1989) found that a high-backfat line of Southdown rams which had higher muscularity had, at the same carcass weight, higher dressing-out percentages (2.2% higher) and lighter weights of several internal organs (foregut empty, intestines, liver, heart, and kidneys). Results from a carcass evaluation of three terminal sire breeds for crossbred lamb production reported by Webster *et al.* (1990) showed that, at the same fat class, there were no significant differences between Suffolk, Texel and Charollais-cross lambs in dressing-out proportion, but that Texel lambs tended to be of poorer conformation than those sired by the other two breeds.

Raimondi (1961) reported that muscular hypertrophy in Piedmont cattle was associated with a higher than normal dressing-out percentage due to thinner hides and reduced viscera, in addition to a greater muscle development compared to normal cattle. Similar results were found by Purchas *et al.* (1993) with higher levels of muscularity for Piedmontese X Friesian and Belgian Blue X Friesian bulls than Friesian bulls. At similar carcass weights, mean dressing-out percent was significantly higher for the Piedmontese X Friesian (57.80%) than the Belgian Blue X Friesian (56.70%), with the means for each of these groups being more than 2.5 percentage points above the Friesian group.

Williams *et al.* (1989) selected sixty-six medium-framed crossbred steers representing two muscle thickness scores (No. 1 and No. 2 evaluated visually as outlined in the official U.S. standards) and showed that, at similar liveweights, No. 1 steers had a higher ($P<.05$) dressing-out percentage (2.8% higher). The authors also showed that this higher dressing-out percentage for the No. 1 steers was maintained after hot fat trimming to 6.4 mm.

Differences in dressing-out percentage between cattle breeds that showed differences in muscularity have been investigated by More O'Ferrall *et al.* (1986). They showed that Blonde D'Aquitaine-X and Limousin-X steers had almost 3 percentage points better dressing-out (57.5%) than the Friesian (54.7%), and, in heifers, the Limousin crosses had a 3% better dressing-out than Friesian and 1% better than Blonde crosses at a similar age.

2.3.3.2 *CARCASS MUSCLE PERCENTAGE*

The proportion of muscle in the carcass is of major importance since this is a prime determinant of yield and commercial value. Variations in percentage of muscle in a carcass are brought about primarily by changes in fatness, and usually to a lesser extent by changes in the muscle to bone ratio (Butterfield, 1974). However, the emphasis in this section will be on the relationships between muscularity and muscle to bone ratio.

Berg & Butterfield (1966) reported that good muscularity "conformation" of normal animals implies a higher muscle/bone ratio even when the values are adjusted to a common level of total muscle, fat, muscle plus bone or carcass weight, respectively.

Jackson & Mansour (1974) found similar muscle/bone ratios between groups of lamb carcasses chosen for good and poor conformation without adjusting the data to any covariate. These results differed from the results obtained by Kirton *et al.* (1983) where the well-muscled lamb carcasses were found to be significantly superior in muscle/bone ratio to poorly muscled carcasses at the same carcass weight. In the report of Kadim *et al.* (1989), animals from the high-backfat lines, which had higher muscle/bone ratios at constant side weight than the low-backfat line, also had higher muscularity (in terms of muscle weight per unit length) at a common carcass muscle plus bone weight.

Kempster and Cuthbertson (1977) reported results from a survey of commercial lamb carcasses involved 421 castrated male lambs of the main types of British breeds. They showed differences between breed-type groups in conformation score, lean percentage, bone percentage and lean to bone ratio at constant side subcutaneous fat percentage. The conformation values were highest for Intermediate and Suffolk crosses (4.30 and 4.08, respectively) and lowest for Blackfaced Mountain and Welsh Mountain breeds (3.60 and 3.28, respectively). The corresponding values for the muscle/bone ratio for Intermediate breed was 3.80, for Suffolk crosses was 3.37, but for the Blackface Mountain was 3.52, and for Welsh Mountain was 3.71. It is clear from these results that at constant side subcutaneous fat percentage, the breed with the highest conformation score may have had higher (Intermediate) or lower (Suffolk) muscle/bone ratios than those breeds which had lower conformation scores. The higher conformation score and muscle/bone ratio for the Intermediate breed was because of the higher lean percentage while the Suffolk crosses had a high conformation score but lower muscle/bone ratio due to a higher bone percentage. Similarly, Kempster *et al.* (1981) reported from two breed-comparison trials involved 1478 and 920 crossbred lambs that breeds with better conformation (muscularity) do not necessarily have higher muscle/bone ratios. Suffolk crosses, for example, have relatively low muscle/bone ratios in relation to their conformation score whereas Texel crosses have a high muscle/bone ratio but do not have sufficiently high conformation scores to identify that advantage.

Kempster (1978) reported similar results in an experiment with cattle based on 753 steer carcasses from 17 breed types. These results indicated that, although there was a definite trend for breeds with better conformation to have higher muscle/bone ratios at a constant carcass subcutaneous fat percentage, certain breeds and crosses did not conform well to this trend.

Colomer-Rocher *et al.* (1982) reported results from a trial involving dissection of the right hind-quarter of 129 steer carcasses from 10 sire breeds which were classified on a seven-point conformation scale according to the shape of the tuber ischii-tuber calcis profile of the hind quarter. At a constant carcass weight and hind quarter fatness, carcasses in the convex classes had more muscle and higher muscle/bone ratios than those in concave classes, while bone percent was higher in the concave classes. The muscle content of the hind quarter increased by 0.59 kg and the bone decreased by 0.13 kg per conformation class, with a corresponding increase in the muscle/bone ratio of 0.07.

For 125 cow carcasses over four years of age evaluated for muscling score by Muller *et al.* (1989), the edible portion percent after trimming fat to 1.27 cm was highest (74.99%) in the better-muscled Choice group and lowest (71.99%) in the Utility muscling group. The better-muscled groups had significantly lower percentages of bone and fat trim and a better ratio of edible portion to bone than the poor-muscled groups. In double-muscled cattle, Dumont (1982) reported that muscle/bone ratios are higher than for normal animals as a result of more muscle and less bone.

Purchas *et al.* (1991) reported, on the basis of a theoretical model, that although muscularity and muscle/bone ratio characteristics often change together, there are situations where differences in muscularity are not accompanied by differences in muscle/bone ratio and vice versa. This evidence agrees well with the above experimental results where close relationships have been shown in some studies but not in others.

2.3.3.3 *LINEAR MEASUREMENTS*

Evidence has accumulated for many species of meat animals to show that carcasses classified to be superior in muscularity (conformation) are those carcasses identified as having shorter legs, shorter trunks, and being plump, blocky and very thickly fleshed throughout (Barton & Philips, 1950; Kirton & Pickering, 1967; Bowman & Hendy, 1972; Jackson & Mansour, 1974).

Jackson & Mansour (1974) showed that the carcasses in a good-conformation class, although slightly heavier, tended to have shorter length measurements (for carcass and hind-leg lengths) and greater hind-leg width and circumference than the poor-conformation class. Hind-leg measurements were all significantly different between the two conformation classes. Russel (1961) reported from data on complete dissection of lamb carcasses covering the normal range of weights and grades found in New Zealand at that time, that animals with longer bodies and legs had more muscular tissue than animals of the same carcass weight with shorter bodies and legs. Similar results have been reported in sheep by Kirton & Pickering (1967) and Fourie *et al.* (1970), but in all these cases the shorter carcasses, which showed at the same time a blocky conformation, contained more fat.

Kirton *et al.* (1983) reported on an experiment with lamb carcasses in which experienced meat industry personnel selected lamb carcasses categorised as either well-muscled, average-muscled or poorly-muscled. The well muscled carcasses had, at the same carcass weight, the shortest carcass length, leg length, cut leg length and tibia-tarsus length. Similar results were found in a comparison between the well-muscled Suffolk breed and the Finnish-Landrace which was classified as inferior in muscularity (Lirette *et al.*, 1984).

In an experiment designed to study the effects of selecting animals for high or low backfat depths (assessed ultrasonically at position C over the *longissimus* muscle at the last rib) on carcass characteristics, Kadim *et al.* (1989) reported greater carcass or leg length for the low backfat line, which also was more poorly muscled. The low backfat line was also narrower at the shoulder (WF), behind the shoulder (WTh), and at the legs (G).

Among carcasses of similar weight and fatness, differences in shape can arise from the same weight of lean being laid down over long bones (giving poor conformation) or shorter bones (giving better conformation) (MLC, 1975).

2.3.3.4 *EYE MUSCLE AREA AND DEPTHS*

The cross-sectional area and the depths of the *longissimus* muscle have been used extensively as indicators of muscling in meat animals by researchers, the meat industry, and breed improvement associations because this part of the carcass is the last to reach its full development according to growth gradient theory (Hedrick, 1983). Thus, the degree of muscle development could be estimated best by observing the cross-sectional area at the last rib. Because the meat yield improves by a third of a yield grade for each additional square inch of ribeye, it has been considered as one of the important carcass characteristics used to predict yield grade in cattle (Thonney, 1990). However, because ribeye area gives only a two-dimensional measurement of a three dimensional object, it may not be as good an estimator of the amount of muscle as of the shape of the muscle. Therefore, when cattle have been selected for conformation, they have been selected for fat cover and for muscle shape but not for the amount or proportion of muscle (Thonney, 1990).

In lambs of constant carcass weight Kirton & Pickering (1967) showed that carcasses selected for blocky conformation had significantly higher eye-muscle area than carcasses of leggy conformation. Kirton *et al.* (1983) reported that well-muscled carcasses, which were selected visually by experienced meat industry personnel, had similar widths (A), but deeper depths (B = 12.3% greater) and larger cross-sectional areas of *M.longissimus* (22.0% greater) than the poorly muscled carcasses. From an experiment with Icelandic sheep, Thorgeirsson & Thorsteinsson (1989) reported that short-legged type sheep have substantially larger eye-muscle areas (A x B) than the long-legged type sheep at equal carcass weight. Southdown sheep selected for high-backfat depths have been shown to have shorter bodies, higher muscularity, and deeper (B) cross-sectional areas of *M.longissimus* than those selected for low-backfat (Kadim *et al.*, 1989). Kempster *et al.* (1987a) studied the characteristics of crossbred lambs by ten sire breeds when compared at the same estimated carcass subcutaneous fat proportion, and found that the Southdown and Suffolk crossbred lambs, although they had the highest conformation score, their *M.longissimus* widths (A = 53.9 and 58.1 mm, respectively) and depths (B = 26.3 and 27.1 mm, respectively) were lower than the Texel crossbred lambs (A = 59.4 mm and B = 27.9 mm) which had similar conformation scores.

Tyler *et al.* (1964) obtained larger ribeyes for beef carcasses of high Choice than for low Good conformation at the same carcass weight. Similar results were obtained by Kauffman *et al.* (1970) when they compared steer carcasses possessing Prime average conformation with another group possessing Standard plus conformation.

Ward *et al.* (1992) found in sheep that the addition of either ultrasonic or carcass measures of rib eye area or depth (B) to carcass weight led to a significant improvement in the prediction of carcass leg muscle:bone ratio or index of muscularity, measured from an index of muscle depth relative to a skeletal dimension, but a significant breed effect still existed. This led to a suggestion that rib eye muscle dimensions are not strongly related to hindquarter muscularity.

In general, sorting on the basis of higher conformation or muscularity will contribute to larger cross-sectional areas of *longissimus* and to deeper depths (B), but selection on the basis of larger cross-sectional areas of *longissimus* may not increase the amount of carcass muscle, but it may improve the conformation or muscularity of the carcass.

2.3.3.5 *MUSCLE DISTRIBUTION*

Although it is generally believed that an animal with good muscularity or conformation produces a relatively high proportion of more valuable meat or has more meat in the right places, Berg & Butterfield (1968) presented evidence that differences in conformation or muscularity are not caused by differences in muscle weight distribution.

Bergstrom (1978) reported that the only explanation for good muscularity based on visual appraisal can be factors other than the actual muscle weight distribution, such as thickness of the muscle layer in relation to the dimensions of the skeleton. Butterfield (1963) claimed that good conformation based on visual appraisal was brought about by variation in the distribution of fat rather than muscle.

Research work on muscle growth has shown that the relative proportions of various muscle groups differ very little between various breeds, types and nutritional regimes (Lohse *et al.*, 1971; Wolf, 1982; Jones *et al.*, 1983; Butler-Hogg & Whelehan, 1987; Thonney *et al.*, 1987b). At the same time, there is increasing evidence that fat distribution is the major contributor to differences in conformation (Kirton, 1964; Timon & Bichard, 1965; Kirton & Pickering, 1967; Jackson & Mansour, 1974; Kirton *et al.*, 1983; Kadim *et al.*, 1989). Data from MLC (1975) showed that differences in carcass shape were primarily due to differences in overall fatness, to the variable distribution of fat and to variation in the thickness of muscles, but not to differences in muscle distribution.

2.3.4 FACTORS AFFECTING CARCASS MUSCULARITY

Few studies have reported the effects of factors on carcass muscularity, so this section will review studies on factors affecting conformation or muscle/bone ratios as well, due to their relationships with muscularity. Factors to be considered include slaughter weight and age, sex, breeds, and nutrition.

2.3.4.1 *SLAUGHTER WEIGHT AND AGE*

Hedrick (1968) reported that it is impossible to separate the effects of weight and age because under normal feeding conditions these two factors will be closely related. Butterfield (1988) in his book also noted that muscle tissue has a much faster relative growth rate than bone tissue, and that considerable change in whole-body muscle/bone ratio occurs in growing sheep during postnatal period.

The muscle/bone ratio of lambs increases at a decreasing rate with increasing carcass weight (Hammond, 1932; Fourie *et al*., 1970 and Sents *et al*., 1982). In cattle, Berg & Butterfield (1966) reported that as carcass weights increased there was a slow increase in the muscle/bone ratio of about 0.03 for each 10 kg increase in carcass weight. Berg (1982) also reported that in a normal calf at birth the muscle relative to bone may be in the order of 2:1 whereas at a slaughter weight of approximately 500 kg the ratio may be 5:1.

Wallace (1948) studied the growth of lambs before and after birth and showed that the flesh/bone ratios before birth were 2.93, 4.12, 3.37 and 2.63 at gestational ages of 56, 84, 112 and 140 days, respectively, and after birth the ratios were 4.91, 5.81, 7.70 and 7.90 at ages of 62, 112, 200 and 332 days, respectively. This data showed that the muscle/bone ratio increased linearly with age after birth, but not before birth.

Further results from the literature showing how muscle/bone ratio increases with increasing carcass weight are presented in Table 2.2 in this review.

2.3.4.2 *SEX*

Kirton & Morris (1989), in reviewing the effects of sex on patterns of change during growth and development, noted that heifers and steers were similar, but that bulls increase proportionately more in forequarter muscles, which are usually somewhat lower in economic value than hindquarter muscles. Thus entire males have carcasses of different shape from castrates or female, as well as being more muscular.

Owen (1976) in his book noted that ewes reach a lower mature size than rams, due to the effect of oestrogen in restricting the growth of the long bones of the body. He also stated that male sex hormones stimulate muscle growth to give the entire male a higher muscle to bone ratio than wethers.

Ahmad & Davies (1986) reported from an experiment with Merino X Border Leicester lambs that rams contained on average more muscle, more bone and less fat than wethers of similar liveweight, and that wethers contained less fat and more muscle than ewes, but the muscle to bone ratio was highest for ewes (3.95), lowest for wethers (3.52) and intermediate for rams (3.79). Wood *et al.* (1980) showed that the muscle/bone ratios for wether lambs was 4.47 and for ewe lambs was 4.56 when compared at the same carcass weight. At the same carcass weight, the rams of the purebred Dorset Down lambs was significantly lower in muscle/bone ratio than ewes of the same breed (Butler-Hogg *et al.*, 1984). Similar results were reported by Fourie *et al.* (1970); Butler-Hogg & Brown, (1986) and Dransfield *et al.* (1990). In cattle, Kempster *et al.* (1982) reported that, at an equal level of fatness, bulls will be superior to steers in muscle to bone ratio because the steers are less mature, but there seems to be little difference between steers and heifers in a similar comparison.

Thonney *et al.* (1987a) pointed out that studies of the effect of sex on composition required that comparisons be made at the same proportion of mature body size rather than at the same carcass weight, as the sexes differ in size at maturity. Thus clear conclusions are difficult to draw because few studies of this sort have been conducted.

2.3.4.3 *BREEDS (BETWEEN AND WITHIN BREEDS)*

Boccard (1981) stated that, as an animal grows, its muscle/bone ratio increases to a plateau at maturity following a pattern that is relatively independent of growth rate and that is largely determined by breed.

Anous (1989) showed that the muscle/bone ratio in the hind limb of ram lambs of Rava, Ile-de-France, Charmois, Rouge-de-l'Ouest, Vende¯enne, Suffolk, Charolais, Romanov, Tarasconnais, Southdown and various crossbreeds varied, from three units for breeds with poor conformation (but comparable fatness) to about six units for breeds with good conformation. These results showed that each one of the pure breeds was distinguished from the others by a specific muscle/bone ratio (Anous, 1989).

Butler-Hogg & Whelehan (1984) used Texel and Scottish Blackface rams ranging in age from 6 months to 4.5 years. They showed that the Texel, the breed with the greater mature size, was heavier, leaner and had a higher muscle/bone ratio at the same age. Similarly, Cameron & Drury (1985) reported from a sire breed trial comparing Texel, Charollais and Charnoise that the Texel crosses had proportionately more lean than the Charmoise due to their higher muscle/bone ratios while the Oxford crosses had the lowest muscle/bone ratio. At constant liveweight the progeny of Dorset Downs, Oxford, Ile-de-France, Oldenburg and Texel sires differed significantly in lean/bone ratio (Wolf *et al.,* 1980). The proportion of lean in the carcass of the Texel cross lamb was 3.7 percentage points above the mean for all breeds due to high muscle/bone ratios. Similar results were reported by Kempster & Cuthbertson (1977) in a survey covering the main British lamb types when the data was adjusted to the overall mean subcutaneous fat percentage. The Suffolk crossbred group had the second highest conformation score but the lowest lean/bone ratio.

Two studies have been reported by Thorgeirsson & Thorsteinsson (1989) involving the comparison of different conformation types within Iceland sheep that were chosen on the basis of metacarpal length and body weight to represent long-legged (L) and short-legged (S) types. In both studies the L-type had considerably heavier bones, and lower muscle/bone ratios. Kadim *et al.* (1989) reported from a study involving selection for high or low backfat depths within the Southdown breed that rams from the high backfat-line had a 6% higher muscle/bone ratio and a higher muscle weight per unit length than animals from the low backfat-line, when adjusted to a constant side muscle plus bone weight and carcass weight, respectively. Purchas *et al.* (1991) also calculated muscularity indexes from the data of Kadim *et al.* (1989) and additional data from lighter animals of the same selection lines. They found that for both weight groups muscularity was significantly higher for the high-backfat line after variations in carcass weight had been adjusted for by covariance.

2.3.4.4 *NUTRITION*

In beef calves at the same muscle plus bone weight a low plane of nutrition retards muscle development, semi-starvation depletes muscles with a markedly lesser effect on bone, and realimentation leads to compensation whereby muscle and bone relationships are restored (Berg & Butterfield, 1968).

In his book on sheep production Owen (1976) stated that the results from several studies on various species have demonstrated that the carcass is far less affected by undernutrition than was once thought, particularly the fat free body proportions. The amount of fat, relative to the rest of the body, can be reduced by feed restriction during growth, but it is difficult to demonstrate any important effect on muscle/bone ratio in carcasses compared at the same total fat-free weight. In an experiment involving 24 Merino X Border Leicester lambs fed two energy diets at initial liveweights of around 22.0 kg and grown to a terminal full liveweight of 35 kg, Ahmad & Davies (1986) reported that, at the same liveweight, lambs on a high-energy-diet had higher muscle/bone ratios (3.93) than those on a low-energy diet lambs (3.59) due to significantly higher bone percentage in the low-energy-diet lambs. Similar results have been reported by Seebeck & Tulloh (1968) in cattle. Two groups of Angus steers were used in this study. In group A, the animals grew continuously and were slaughtered at 250, 281, 316, 356, and 400 kg, and in group B, the animals grew like group A but were then subjected to a further growing-phase until they reached weights 15% above the group A killing weights. They were then subjected to a 13% loss of body weight by restricted feeding before slaughter. Comparison of group A and group B animals at the same side weight showed that body weight loss led to lower muscle/bone ratios (3.92 vs 3.29 for group A vs group B). This was accompanied by a significant increase in the proportion of bone in the carcass, but only a slight decrease in the proportion of muscle. In a similar experiment with 35 Merino wethers, Aziz *et al.* (1992) found that lambs losing weight had more bone weight than those of the same carcass weight gaining weight.

Seebeck (1973) reported that with undernutrition the muscle/bone ratio declined in cattle because of the greater loss in muscle weight compared to bone weight. Also, since bone length either increased or remained the same while muscle bulk decreased, Seebeck (1973) and Seebeck & Tulloh (1968) both concluded that shape of muscle must have changed to become more slender. Young & Sykes (1985) used 72 female lambs aged 56 days and weighing 20 kg, and showed that, relative to continuously grown control animals, lambs restricted from feed to maintain a constant body weight for 56 days before realimentation, had a femur bone weight 8.7% greater and length 8.1% greater, while *M.semitendinosus* length was 4.8% greater and *M.semitendinosus* weight was 15.0% less. The relationships between the *M.semitendinosus* and femur bone in terms of muscle/bone ratio and muscle weight/bone length were also significantly different between the control and the restricted groups. The restricted animals had a lower muscle/bone ratio (0.471) and muscle weight/bone length (0.291) than the control animals (0.606 and 0.372, respectively). The calculated muscularity in terms of muscle depth to bone length (Purchas *et al.,* 1991) was 0.154 for the control group and 0.125 for the restricted group.

Based on studies with rats, Hooper (1978) suggested that there was a close relationship between the growth of bone and the muscle attached to that bone such that the growth in length of the bone act as a pacemaker of muscle growth. Burwell (1986) reported after reviewing the growth of bone that nutrition can affect the growth of bone dimensions. Tulloh & Romberg (1963) demonstrated that slow-growing sheep had more slender bones than fast-growing sheep at the same weight. The high plane of nutrition, which let the lambs gain weight as rapidly as possible, showed a significantly bigger increase in bone weight per unit of body weight and per unit of bone length than did the bones of the low plane group which gained at half the daily rate. Searle *et al.* (1989) studied the effect of nutrition on skeletal dimensions during growth in sheep. They fed 15 cross-bred (Border Leicester X Merino) castrate male sheep ad libitum from 2 days to 27 months of age, while 15 similar sheep were fed half the average amount consumed by the first group at the same age. The results showed that the unrestricted animals were consistently wider at the shoulders but smaller in leg length and chest depth when the groups were compared over the range common to both (16 - 44 kg). Palsson & Verges (1952) reported similar evidence with young sheep which had grown slowly having longer legs than genetically similar animals of the same weight, which had grown rapidly.

Palsson & Verges (1952) studied the effects of the plane of nutrition on growth of lamb carcasses, by comparing lambs on two planes of nutrition and making comparisons at the same carcass weight regardless of age. At the same carcass weight (30 lb), lambs from the high-high plane group had higher values for femur weight and femur thickness index than those in the low-low group. The total muscle in the leg and femur length which were used to calculate the muscularity index were highest for the low-low and lowest for the high-high plane. The muscle/bone ratio was higher for the low-low lambs (4.27) than for the high-high group (3.89), but the latter group had higher muscularity (calculated from total muscle depth in the leg to femur length as described by Purchas *et al.,* 1991) value (0.884) than the low-low planes (0.831). These results differ from those of Young & Sykes (1985) where the restricted animals had a lower muscle/bone ratio. This may have resulted from the difference in femur weight which was higher in the restricted animals of Young & Sykes (1985) but lower in the low-low plane group of Palsson & Verges (1952).

The above studies have shown in general that body weight loss which resulted from low planes of nutrition led to slightly lower muscle/bone ratios and a more consistent decrease in muscularity as a result of increasing bone percentage and bone length and, as a result, a slight decrease in the proportion of muscle as well.

2.4 MUSCLE FIBRE-SIZE AND FIBRE-TYPE CHARACTERISTICS AND THEIR RELEVANCE TO MUSCULARITY

In this section changes in muscle fibre number, size, length, and type during growth and development are described first, and then other factors affecting these characteristics are reviewed. Emphasis will be on relevant information from sheep and other meat animal species, but research with humans, mice, rats and chickens will also be considered. However, as the emphasis in this review is on the muscularity, only information relating muscle fibre-size and fibre-type characteristics to muscularity or associated characteristics will be reviewed.

Several classification systems have been described for the identification of skeletal muscle fibre types (Davies, 1989b). In this section, the classifications described in Table 2.3 will be adopted, especially the system of Cooper *et al.* (1970) with red, intermediate and white fibres as it has been widely used in muscle studies of meat animals. Where appropriate other systems of classification have been converted to this one. For example; alpha white, alpha red and beta red will be referred to as white, intermediate and red fibres, respectively.

Table 2.3 An outline of muscle-fibre-type classification systems, showing the alternative terms used.

	Classification system		First use
Slow-oxidative	Fast-oxidative -glycolytic	Fast-glycolytic	Peter *et al.* (1972)
Type I[a]	Type II	Type II	Dubowitz&Pearse (1960)
Red[b]	Intermediate	White	Cooper *et al.* (1970)
Beta red	Alpha red	Alpha white	Ashmore & Doerr (1971)

[a] Used if study based only on myosin ATPase.

[b] Used if study based on metabolic enzymes.

2.4.1 CHANGES DURING GROWTH AND DEVELOPMENT (NUMBER, SIZE, LENGTH and TYPE)

Skeletal muscles in meat animals exist as a mass of multinucleate cells known as muscle fibres. They are formed by the fusion of mononuclear precursor cells called myoblasts (Wilson *et al.,* 1992). Nuclei in muscle fibres do not divide, but as the muscle enlarges extra nuclei are recruited from the remaining mononucleate population (Swatland, 1984), which, in the postnatal animal, are known as satellite cells. Such cells have the capacity to replicate and thus can be considered to be a reserve of nuclei that can fuse with the fibre (Campion *et al.,* 1981). Goldspink (1977) identified three distinct and inter-related processes in muscle growth as being precursor cell proliferation; cell fusion; and protein accumulation within the fused fibres.

Ashmore & Addis (1972) and Sivachelvan & Davies (1981) both found that fibre hyperplasia (increase in total myofibre number within various skeletal muscles) was essentially completed by birth in sheep and that post-natal growth was due mainly to fibre hypertrophy. Goldspink (1980) stated that, during hypertrophy, muscles grow by increases in length and cross-sectional size. Fibre length increased through serial addition of sarcomeres, largely at the ends of the fibre, while increases in diameter resulted from proliferation of myofibrils (Goldspink, 1980). The latter was associated with incorporation of satellite cells into the fibre, thereby increasing the number of nuclei per fibre (Swatland, 1984; Cheek, 1985). Williams & Goldspink (1971) reported that the increase in limb length postnatally is accompanied by an increase in the length of fibres of individual muscles of the limb and it has been shown that this is associated mainly with an increase in the number of sarcomeres in series along the myofibrils, and hence along the length of the fibres.

After reviewing several studies, Goldspink (1980) reported that although there were changes in the proportions of fibre types with age, there was no change in the total number of fibres within muscle. These individual muscle fibres can be identified and evaluated using histochemical methods to indicate the activity of enzymes such as succinic dehydrogenase, adenosine triphosphatase in the alkaline range (ATPase) and phosphorylase (Ashmore & Doerr, 1971). Ashmore *et al.* (1972) examined histochemically the prenatal development of muscle fibres using *M.semitendinosus* in the fetal lamb from 50-145 days of gestation. They found that the initial fibres formed were those destined to become type I fibres. They were followed by the development of those destined to be type II fibres. The initial type I fibres showed myosin ATPase activity at 50 days of gestation, and type II fibres showed activity at 70 days of gestation. These fibres were organized so that type I fibres served as a structural framework around which type II fibres developed.

Joubert (1956) studied the growth of muscle fibre size in sheep using *M.longissimus*, *M.rectus femoris* and *M.gastrocnemius* and showed that the mean fibre diameter in these muscles increased from 9.3 µm in new born lambs to 49.2 µm in mature sheep, with no increase in the number of fibres after birth. Similar results were found by White *et al.* (1978) in sheep when they used the *M.vastus lateralis, M.vastus medialis, M.rectus femoris and M.vastus intermedius* in which fibre diameter of both type I (red) and type II fibres increased from birth to five years of age. In relation to the type of the muscle fibre, they found that the number of type II fibres decreased while that of type I fibres increased with increasing age in *M.vastus lateralis, M.vastus medialis and M.rectus femoris.* However, Moody *et al.* (1980) found that the number of red fibres decreased while the number of intermediate and white fibres increased in *M.longissimus* of sheep during an increase in liveweight from 31.8 to 50 kg. The muscle fibre diameter for the three fibre types also increased with increasing liveweight. Marinova *et al.* (1984) reported that in sheep *M.longissimus* the proportion of intermediate fibres increased and the proportion of red fibres and white fibres decreased with increasing liveweight from 25 to 35 kg, with similar data being obtained for the *M.supraspinatus.* Solomon *et al.* (1981) found no differences in the percentage of muscle fibre types in *M.longissimus and M.semimembranosus* of lambs as slaughter weight increased from 32 to 41 kg, but muscle fibre size increased with increased weight.

In cattle, Spindler *et al.* (1980) showed that the red, white and intermediate fibre types from samples of the *M.biceps femoris* doubled in mean cross-sectional area during growth from 28 to 392 days in calves, while the proportion of white fibres slightly increased and the proportion of red fibres slightly decreased. Dreyer *et al.* (1977) also found in cattle that the percentage of red fibres declined and that of white fibres increased in *M.semimembranosus and M.semitendinosus* with age especially between birth and 12 - 16 months. Tuma *et al.* (1962) found that the mean fibre diameter in *M.longissimus* increased from 53.9 µm at 6 months of age to 71.4 µm at 90 months of age.

In pigs, slaughtered at 25 and 100 kg liveweight, Kiessling *et al.* (1982) reported that fibre size within *M.longissimus and M.semimembranosus* samples increased with age, and that there was an 8 - 10% decrease in the number of red and intermediate fibres and a corresponding increase in the white fibres.

The results from the above reported studies regarding the proportion of all muscle fibre types are conflicting. Some show an increase and other a decrease with increasing age or weight, but in general most studies showed an increase in the proportion of white or intermediate muscle fibres with increasing age or weight. Also there is full agreement between studies on an increasing size of muscle fibres with age or weight. Thus, the conclusion from this section and that from section 2.3.4.1 on factors affecting carcass muscularity is that, with increasing age or weight, muscularity increases as the result of increasing muscle fibre size and an increasing proportion of white muscle fibres.

2.4.2 FACTORS AFFECTING MUSCLE FIBRE SIZE, NUMBER AND TYPE

Several factors affect muscle fibre characteristics as well as muscularity in meat animals. However, as the previous section showed, muscle fibre characteristics change between different stage of development and between different muscles, so comparisons should be made within one muscle at a set stage of development. This means that reviewing comparisons within and between breeds is difficult due to different stages of maturity. Factors reviewed here are genetics, sex, nutrition, exercise, stretch and anabolic substances.

2.4.2.1 *GENETIC EFFECTS*

Staun (1972) pointed out that muscle fibre size and number together with the amount of extracellular material (e.g fat and connective tissue) determine muscle size or weight, but that in order to increase meat production it was desirable to select for increases in fibre number due to physiological limits to fibre size. In sheep, Solomon *et al.* (1981) found that *M.longissimus* and *M.semimembranosus* from Suffolk X (Finnish - Southdown) lambs had significantly more white fibres and fewer intermediate fibres than the Suffolk X (Suffolk - Rambouillet) lambs when compared at the same liveweight. The red fibres were significantly larger only in the *M.semimembranosus* of the Suffolk X (Finnish Landrace - Southdown) lambs. They concluded that breed may affect the transformation from intermediate to white fibres and suggested that this may be advantageous for increasing muscularity. This suggestion was based on the argument that muscle size was directly related to the degree to which intermediate fibres transform into white fibres. Supporting evidence for this conclusion comes from the work of Ashmore *et al.* (1972) and Bartlett *et al.* (1980).

Genetic effects on muscle fibre size and type between breeds of cattle (Dreyer *et al.*, 1977; Spindler *et al.*, 1980; Johnston *et al.*, 1981) and pigs (Staun, 1963) have also been reported, but most of these studies have not related the differences between muscle fibre characteristics to the differences in muscularity. Therefore, whenever possible, the differences in muscle fibre characteristics between breeds or within breeds will be supported by some indirect studies that showed differences in muscularity between the same breeds that have been used to study muscle fibre characteristics.

Dreyer *et al.* (1977) found that *M.semimembranosus* and *M.semitendinosus* from Friesland cattle had a higher proportion of white muscle fibres, a lower proportion of red muscle fibres and larger fibre diameters than Afrikaner cattle. Spindler *et al.* (1980) reported after using samples from the *M.biceps femoris* that Holstein steers had smaller muscle fibre diameters than Hereford or Angus steers at the same age, and that Angus steers had a higher proportion of white fibres and a lower proportion of intermediate fibres than the other two breeds. Kempster *et al.* (1982) showed that based on various reports, the Angus breed had higher muscularity as indicated by having higher muscle:bone ratio than Hereford or Holstein breeds.

Johnston *et al.* (1981) reported that differences between Angus and Simmental steers varied between *M.semimembranosus, M.semitendinosus and M.biceps femoris.* Whereas *M.semimembranosus* from Angus steers had significantly larger intermediate and white fibres, no effects were found on the numbers or percentages of each fibre type. The *M.semitendinosus* from the Simmental-cross steers had both a larger number and a higher percentage of red fibres with fewer intermediate fibres than Angus cattle, but breed had no significant effect on fibre diameter. The *M.biceps femoris* from Simmental cross steers had significantly more fibres with a higher percentage of red fibres, a lower percentage of intermediate and white fibres and significantly larger intermediate fibres than the Angus. May *et al.* (1977) showed that the *M.longissimus* from Limousin X Angus crosses had more white fibres and slightly fewer intermediate fibres than Simmental X Angus or Hereford X Angus crosses, while fibre diameters did not differ between breeds. May *et al.* (1977) concluded that, since animals with a high percentage of Limousin blood are usually thought to be classified as heavily muscled, the increased percentage of white fibres may be partially responsible for this phenomenon. Comparing *M.longissimus, M.semitendinosus and M.triceps brachii-lateral head* samples between Charolais and Angus calves breed at 25 day old, Bartlett *et al.* (1980) showed that, for all muscles, Charolais calves had a significantly greater total number of myofibres as well as significantly greater numbers of white and red myofibres per muscle cross sectional area. However, when the muscle fibre type was expressed as a percentage of total myofibres, Angus calves had greater white and intermediate fibre percentages while Charolais calves had a greater red fibre percentage. Bartlett *et al.* (1980) concluded that young Angus calves show rather mature muscular development and that these cellular parameters might be used to estimate mature muscularity.

Tatum *et al.* (1990) compared the carcass composition of cattle breeds and its relationship with the fibre characteristics of *M.longissimus* in an experiment with 45 steers from matings of Piedmont, Gelbvieh and Red Angus sires with British and European crossbred dams that were slaughtered after 124, 166 or 208 days of feeding from an age of 291 days. The results showed that the Piedmont steer carcass, which had the largest *M.longissimus* area, the highest yield of separable muscle and the highest muscle/bone ratio, also had the highest percentage of white muscle fibres, the lowest percentage of intermediate muscle fibres and the smallest cross-sectional area of red muscle fibres in *M.longissimus*.

Holmes & Robinson (1970) reported that muscular hypertrophy (double muscling) in domestic cattle (an inherited disorder of skeletal muscle growth) was related to a change from intermediate to white muscle fibre type. Dumont (1982) reported that the muscularity of double-muscled cattle resulted from an increased number and size of muscle fibres and was associated with intramuscular connective tissue which was finer and wider meshed than normal animals. Similar results were found by Hendricks *et al.* (1973) when they compared several muscles of double-muscled and normal phenotype Angus bulls. The double-muscled animals had, in addition to higher muscle fibre number, a slightly higher percentage of white fibres, fewer red fibres and larger white fibres.

Ouhayoun & Beaumont (1968) found that the muscles of the culard (double-muscled) animals had a larger number of fibres than muscles of normal animals. Swatland & Kieffer (1974) showed that fetuses of hypertrophied animals (double-muscled) had more fibres in several muscles than the fetuses of normal animals. Similar results were found by Gerrard & Judge (1993) when they compared the *M.semitendinosus* samples from the fetuses of double-muscled and normal cattle. Ashmore & Robinson (1969) found that double-muscled animals had a higher percentage of large white muscle fibres than normal animals.

There are few reports of within-breed differences in muscle fibre characteristics for sheep (Kadim *et al.*, 1993), cattle (Hendricks *et al.*, 1973) or pigs (Nostvold *et al.*, 1979), but more work on line differences in chickens have been investigated (Aberle & Stewart, 1983).

Kadim *et al.* (1993) indicated an effect of selection for backfat depth on muscle fibre characteristics in *M.semitendinosus* of Southdown rams, such that at the same weight, the high-fat line sheep possessed significantly higher proportions of red fibres, with non-significant decreases in the proportions of intermediate and white fibres. Mean fibre diameters within fibre type did not differ significantly between the lines. However, at a constant side weight Kadim *et al.* (1989) found that the high-fat line had significantly greater muscle/bone ratios, and higher muscularity (in terms of muscle weight per unit length). The work with double-muscling described above (Hendricks *et al.,* 1973) is a good example of a within-breed effect. However, the results from Kadim *et al.* (1993) showed contrasting results from the point of view of muscularity from those studies done within double-muscled and normal cattle.

Seideman *et al.* (1989) compared the carcass and muscle characteristics of pigs from a lean selected strain and an obese selected strain at about 110 kg liveweight and found that the carcasses from lean pigs had larger *longissimus* muscle cross-sectional areas than carcasses of obese pigs. The proportions of all fibre types and the cross-sectional areas of red and white muscle fibres of the *M.longissimus* from lean and obese pigs were not different, but the intermediate fibres from the lean pigs were smaller ($P<0.10$) than obese pigs. The area occupied by each fibre type as a proportion of total fibre area in the *longissimus* muscle of lean and obese pigs represented 7 and 10% for intermediate fibres and 84 and 79% for white fibres, respectively. They concluded that the larger *longissimus* muscle area of the lean strain resulted from total muscle fibre hypertrophy, as, overall, lean pigs tended to possess fewer fibres per unit of area than obese pigs. Staun (1963) studied the genetic effects of two breeds (Duroc and Yorkshire pigs) after selection for or against fatness and failed to show any significant differences between breeds or lines of the Yorkshires in terms of the total number of muscle fibres or in fibre diameter, but did show an increase in the number of muscle fibres in the low-fat line of the Duroc pigs in *M.longissimus*. They suggested that when pigs with a thin layer of backfat are selected for breeding, these pigs also possess genes for a large area of *M.longissimus* which, in turn, results in an increase in the number of muscle fibres. That this phenomenon was so pronounced in the Duroc breed was thought to be due to selection within this breed for several generations. Observations on fast-growing lean pigs (Yorkshire) and slow-growing obese pigs (Ossabaw) by Ezekwe & Martin (1975) indicated that the greater muscle growth in the Yorkshire pigs was achieved by greater fibre numbers and size. In another selection experiment with pigs, a control line, a line selected for high rate of gain and low fat thickness, and a line selected in the opposite direction, were compared by Nostvold *et al.* (1979). The high gain *M.longissimus* had a significantly higher percentage of intermediate fibres and a lower percentage of white fibres than the low gain line, but no significant line differences were observed for red fibre frequencies at a constant weight. Also, at the same weight, the low gain line had smaller muscle fibres for all fibre types, but with significant differences for the white fibres only.

In chickens, the broiler-type has been selected specifically for growth and muscularity while layer-type birds have been selected for egg production. Aberle & Stewart (1983) compared *M.sartorius* samples from these types of chickens at the same body weight and found that both types had similar proportions of the various fibre types, but broilers had greater numbers of fibres than layers and larger type II myofibres (white fibres). Type I myofibres (red fibres), however, were larger in the layers. The percentage of intermediate type myofibres decreased and that of white type myofibres increased during growth, but these changes occurred at a younger age in broiler-type birds. They concluded that the greater muscularity and the more rapid growth of the broiler-type birds were caused by more rapid myofibre hypertrophy and the presence of more myofibres. Similar results have been reported by Ashmore & Doerr (1971) in that type II intermediate fibres myofibres transformed to type II white fibres myofibres during normal development of the chicken. Ashmore *et al.* (1972) suggested that selection of animals for increased muscularity causes a correlated increase in the proportion of white muscle fibres, especially in the broiler-type birds.

Smith (1963) also reported from a selection study with chickens involving a random-bred meat-type line (R), a growth selected meat-type line (S), an egg-type line (L) and their crosses. At hatching, the *M.sartorius* from the R-type line had a greater fibre number and slightly smaller fibre size than the L-type line of similar body weight, but at 10 weeks of age, the large-bodied R-type line had considerably larger muscle fibres than the small-bodied L-type line. The reciprocal crossbreds were approximately equal to the parental means for both fibre size and number at hatching and for fibre size at 10 weeks of age. The results also showed that the growth-selected meat-type line (S) possessed slightly smaller and, therefore a greater number of fibres at hatching than did the random-bred line, but at 10 weeks of age S-type had significantly larger muscle fibres than R-type. Smith (1963) concluded that, although large-bodied chickens had more and larger muscle fibres at broiler age than small-bodied chickens, fibre size was apparently of greater importance than fibre number in determining muscle size. A similar conclusion was drawn by Handel & Stickland (1987 & 1988) in a study with Large White pigs selected on the basis of their weight at birth. The results indicated that muscle fibre number at birth was an indicator of potential for postnatal muscle growth.

In conclusion, the above studies have shown that differences in fibre size and fibre type profiles are distinguishable between breeds and between lines within breeds. As well, for doubled-muscled cattle and some within-breed comparisons, increases in the number of fibres, and the size and percentage of white fibres in better-muscled animals, also exist. Thus, when the meat animals are bred for the purpose of producing a greater amount of muscle, the proportion of white fibres increases at the expense of red fibres. It seems likely that the larger diameter of white fibres is the reason for the increased amount of meat in those carcasses with a higher proportion of those in the muscles.

2.4.2.2 *SEX EFFECTS*

Hammond (1932) found that the untyped muscle fibres of sheep were largest in males, intermediate in castrates and smallest in females when compared at equal age. He added that the larger muscle fibres in rams corresponded to a larger body size and weight of muscle. These results were supported by the Moody *et al.* (1970) who showed that rams had larger fibres because they grew faster and were heavier at the same weight. Moody *et al.* (1980) showed that the diameter and percentage of red fibres from *M.longissimus* samples was higher for ram than wether lambs, and higher for wether than ewe lambs at the same weight. There were no effects of sex on intermediate or white fibre diameters or percentages. Nicastro *et al.* (1985) showed that wether lambs had a significantly higher percentage of intermediate fibres in *M.longissimus* and a significantly lower percentage of white fibres than ewes. In contrast, Solomon *et al.* (1981) found that ewe lambs had a significantly higher percentage of intermediate fibres than wethers in *M.semimembranosus*.

In cattle, fibres of *M.biceps femoris* from Hereford, Angus and Holstein heifer and steer twin calves were shown by Spindler *et al.* (1980) to be larger in heifers than steers at the same age. In Angus and Hereford steers, the white muscle fibre occurrence was significantly higher than in heifers. In contrast, Johnston *et al.* (1981) found that *M.longissimus* samples from steers tended to have significantly more red fibres and a lower percentage of white fibres (47.6 vs 49.9) than heifers at the same age. Sex, however, did not have a significant influence on fibre diameter. Young & Bass (1984) compared bulls and the steers at the same weight using *M.longissimus*, *M.splenius and*

M.sternomandibularis, and showed that castration of cattle was associated with an increase in the occurrence of white fibres in the *M.longissimus and M.splenius* at the expense of intermediate fibres with no change in the occurrence of red fibres. Fibres were larger in bulls than in steers, and this was particularly true for the intermediate fibres. This difference in fibre area was more clear in the *M.splenius* than in the *M.longissimus*. They concluded that this difference between steers and bulls presumably reflects the development of neck and shoulder muscles in bulls. Seideman *et al.* (1986) found that *M.longissimus* from bulls had a larger area and a higher percentage area of red and intermediate fibres, but a lower white fibre percentage and percentage area compared with steers at the same age. Similar results were reported by Dreyer *et al.* (1977) from *M.semimembranosus* and *M.semitendinosus* samples of bulls and steers at the same age. The bulls had a higher percentage of red muscle fibres, and a lower percentage of white muscle fibres with a larger mean fibre diameter than steers.

The effect of sex on porcine muscle fibre type, diameter and number was studied using *M.longissimus* by Miller *et al.* (1975). Gilts had significantly larger fibres than barrows, but no other effects were found between sexes.

In humans, Miller *et al.* (1993) found that women had 45, 41, 30 and 25% smaller muscle cross-sectional areas for the *M.biceps brachii, M.total elbow flexors, M.vastus lateralis and M.total knee extensors*, respectively. The men had significantly larger type I fibre areas and mean fibre areas than the women in *M.biceps brachii* and significantly larger type II fibre areas and mean fibre areas in *M.vastus lateralis*.

All the experimental work with different sexes mentioned in this section and in section 2.3.4.2 has shown that male meat animals have a more muscular shape and this results mainly from an increase in muscle fibre size and from more and larger red fibres with fewer white fibres.

2.4.2.3 *NUTRITION EFFECTS*

The influence of nutrition on muscle fibre size and type is evident from studies with sheep (Joubert, 1956), cattle (Yeates, 1964), pigs (McMeekan, 1940) and laboratory animals (Goldspink, 1964). These studies have indicated that a low plane of nutrition produced an atrophy of muscle fibres, while a high plane of nutrition resulted in an enlargement of muscle fibre diameter.

Joubert (1956) found that starvation decreased the diameter of muscle fibres in sheep compared at the same age (samples taken from *M.longissimus, M.rectus femoris and M.gastrocnemius*), but not at the same carcass weight. These results also indicated that muscle fibre diameters decreased when sheep were placed on a submaintenance plane of nutrition and increased when the total muscle mass of the carcass increased due to supermaintenance feeding. Hight & Barton (1965) also found that the diameter of *M.longissimus* fibres decreased on a low plane of nutrition for mature ewes adjusted to the same weight. Asghar & Yeates (1979) showed that lambs slaughtered at the same age as a control group, but kept on a submaintenance feeding, had a significantly lower fleshing index (measured according to Thwaites *et al.*, 1964), smaller *M.longissimus* eye area and smaller *M.longissimus* fibre diameters than the control group, but lambs kept on a maintenance diet had a non-significantly smaller mean fibre diameter than lambs on the control feeding. They concluded that loss in body weight was necessary to cause a pronounced decrease in the diameter of the muscle fibres.

Evidence on the effects of nutrition on the proportion of muscle fibre types in muscles of meat animals has not been reported widely. In sheep, Nicastro *et al.* (1985) studied the histological properties of *M.longissimus* from lambs fed two protein sources (soybean meal and distillers dried grain with solubles) and three protein levels (12.5%, 15.7% and 18.9%). The results showed that lambs fed soybean meal protein had larger white fibres and significantly smaller diameters of red and intermediate fibres than lambs fed grain. The results also showed that lambs fed the 12.5% protein level exhibited a significantly higher percentage of intermediate fibres and a greater diameter of white fibres. However, the authors did not investigate the possibility of a weight effect on these results. Moody *et al.* (1980) postulated that increased energy in lamb rations appeared to cause a physiological shift in *M.longissimus* samples from intermediate to white fibres for lambs slaughtered at the same weight. Nordby *et al.* (1987) studied the effects of maternal undernutrition during pregnancy (fed 30 days prior to breeding and throughout gestation) on growth, muscle cellularity and fibre type in lambs. The results showed that feeding ewes 70% of their requirements during this period resulted in lambs at a slaughter weight of 58.5 kg with heavier *M.semitendinosus* weights, larger muscle fibre diameters and similar muscle areas to lambs from adequately fed ewes. At the same time, no differences in muscle weight, area and fibre diameter were observed in the *M.extensor carpi radialis*, and no influence of ewe diet was observed for proportions of muscle fibre types. They concluded that low feeding levels during gestation of ewes had no detrimental effects on the carcass or muscle fibre characteristics of their lambs at slaughter.

Yeates (1964) studied the effects of nutrition on muscle fibre area and diameter in two groups of adult cattle. A first group consisted of two pairs of identical twin steers, one of each twin having been starved for 7 months until they lost approximately 200 kg. Animals of a second group were brought from a drought-feeding experiment, in which they were reduced to a state of extreme emaciation. There was a decrease in cross-sectional area of *M.longissimus* in starved adult cattle compared with fed controls of the same age, associated with a reduction in the mean diameter of the muscle fibres. With regain of liveweight, a complete recovery of both cross-sectional area of the muscle and of fibre diameter was observed. Johnston *et al.* (1981) reported that there were significantly fewer intermediate fibres and significantly more white fibres in the *M.longissimus* of the grain-fed cattle than those fed grain plus grass. In general, as energy level in the ration decreased the percentage of intermediate fibres increased and the percentage of white fibres decreased at slaughter ages for the high and low energy levels of 16 and 20 months, respectively. Similar results were reported by Seideman *et al.* (1986) who found that cattle fed a low-energy diet had a significantly higher percentage of *M.longissimus* red fibres, larger white fibres and a greater percentage area of red fibres than cattle fed a high-energy diet compared at the same age. However, these results could reflect a weight effect as they were not adjusted to the same weight.

Staun (1972) compared three groups of pigs fed equal amounts of energy, but different daily amounts of protein supplement until they were slaughtered at 90 kg liveweight. Muscle fibre size of *M.longissimus* and *M.semitendinosus* increased with increasing levels of protein supplement. Area of *M.longissimus* and weight of *M.semitendinosus* have increased according to fibre development. Kiessling *et al.* (1982) studied the effect of nutritional level on the number and size of muscle fibres in *M.longissimus and M.semimembranosus* of pigs at 100 kg liveweight. The low-energy diet caused a significant decrease in the intermediate fibre number in both muscles, and a significant increase in the red fibre number in *M.semimembranosus*, compared with a high-energy diet. At the same time a significant decrease in the diameter of the intermediate fibres in *M.semimembranosus* with a non-significant slight increase in the diameters of red and white fibres was observed. In another experiment with pigs, Stickland *et al.* (1975) investigated the change in the size and number of muscle fibres in *M.flexor digiti V brevis* samples from the fore-foot of 10-day-old and 1-year-old well-nourished pigs, as well as from 1- and 2-year-old animals that were severely energy-deficient and protein-deficient. The results showed that the normal 1-year-old animals had much larger muscle fibres than the pigs in any of the other groups, but failed to show any significant differences between the numbers of fibres in the muscles of pigs in any of the four severely energy-deficient and protein-deficient groups when compared with the control 10-day or 1-year old groups.

The effect of severe dietary protein restriction on skeletal muscle fibre number and area in weanling rats related in a reduction of skeletal muscle growth (Timson & Dudenhoeffer, 1985). It was concluded that this was due to a reduction in the growth rate of individual muscle fibres with no change in fibre number or the proportion of type I (red) fibres.

Dwyer & Stickland (1992) studied the effects of undernutrition throughout gestation on muscle fibre number in the guinea pig and tested whether this effect was due to the relative proportions of fibre types in the muscles or the anatomical location of the muscles. Thus, *M.biceps brachii* (fast, cranial and proximal), *M.soleus* (slow, caudal and distal) and *M.extensor digitorum longus* (fast, caudal and distal) were examined for controls and undernourished animals. The result showed that at the same age a 40% reduction in maternal intake resulted in a significant reduction in neonate body and muscle weights, M.biceps and *M.extensor digitorum longus* fibre numbers, but did not affect M.*soleus* fibre number. They concluded that the effect of nutrition on muscle fibre number is a function of the fibre types in that muscle. Fast muscles suffer a disproportionate reduction in fibre number with undernutrition due to the relatively high contribution to total fibre number made by fast twitch fibres, which develop secondarily to slow twitch fibres (Ashmore *et al.,* 1972). Slow muscles, with a greater proportion of primary fibres, are less affected by undernutrition.

The general conclusion reached from the above studies is that poor nutrition reduces muscle fibre size but not number, while good nutrition is especially necessary for the growth of white muscle fibres.

2.4.2.4 *EXERCISE EFFECTS*

The effect of exercise on muscle fibre size and type has been studied in several species including humans (Ewing *et al.,* 1990), horses (Essen-Gustavsson & Lindholm, 1985), pigs (Fitts *et al.,* 1973), cats (Giddings & Gonyea, 1992), Guinea pigs (Maxwell *et al.,* 1973) and rats (Seiden, 1976).

The work done by Goldspink & Howells (1971) and Goldspink & Ward (1979) on athletes, which involved normal types of exercise, running, and weight-lifting, showed that there was no increase in the number of muscle fibres and that the increase in musculature was due to an increase in muscle fibre size. Goldspink (1980) in reviewing this topic noted that some forms of exercise are much more effective in producing muscle fibre hypertrophy than others, and that certain kinds of exercise may induce hypertrophy of one type of fibre rather than another. Results from humans have demonstrated that intense endurance training caused an increase in the percentage of intermediate fibres while the percentage of white fibres decreased (Anderson & Henriksson, 1978). They suggested that there was a gradual conversion of part of the white fibres into intermediate fibres. However, Ewing *et al.* (1990) did not find significant changes in fibre type percentage in the right knee extensors and flexors of men trained on an isokinetic dynamometer over a 10-week period.

In the horse, Essen-Gustavsson & Lindholm (1985) found a higher proportion of intermediate fibres and a lower proportion of white fibres in the middle gluteal muscle of well-trained active horses as compared to inactive horses. Lindholm *et al.* (1982) also reported that the percentage of intermediate fibres increased in racehorses from 31% before the racing season to 38% at the end of the season, while the percentage of white fibres decreased from 56% to 49% and the percentage of red fibres remained unchanged.

Fitts *et al.* (1973), however, found no differences in the distribution or size of three muscle fibre types in miniature pigs following 3 and 7 months of sprint or endurance training.

In laboratory animals, the effect of weight lifting exercises by mice on muscle fibre size has been studied by Goldspink (1964). In this work the animals were required to pull down a food basket which was attached to a pulley system. A known weight was attached at the other end of the pulley system and thus the amount of work performed by the animals in obtaining their food could be estimated. The results demonstrated an increase in mean diameter of some fibres of *M.biceps brachii*, but a general increase in size of all fibres was not seen. Seiden (1976) found that by imposing a regimen of forced swimming on adult male rats, the muscle weight and fibre cross-sectional diameter of *M.extensor digitorum longus* increased by 41%.

The concept that an exercise-induced increase in muscle mass arises from increases in fibre cross-sectional area without increases in muscle fibre number has been studied by Giddings & Gonyea (1992) using cats. Ten adult cats performed weight-lifting exercises, and *M.flexor carpi radialis* weights from the exercised and control forelimbs were compared for muscle fibre hyperplasia. This work confirmed previous work (Gonyea & Ericson, 1976) in demonstrating that muscle fibre hyperplasia contributes to muscle enlargement following long-term exercise. They suggested from their work that *de novo* fibre formation rather than longitudinal fibre splitting was the major mechanism contributing to muscle fibre hyperplasia in this model.

In conclusion, an increase in muscularity following exercise is due to an increase in diameter of fibres of muscles that have been frequently exercised and from a conversion of some of the white fibres into intermediate fibres. There is some evidence that an increase in muscle fibre number occurs following long-term exercise. However, the type of exercise performed must be considered.

2.4.2.5 *EFFECT OF STRETCH OVER THE SKELETAL FRAME*

Increasing the work load on a muscle fibre has been found to stimulate and cause a sudden increase in muscle fibre size by the production of more myofibrils (Goldspink, 1980). These correlated events are not fully understood, but, simple disuse of muscles without stretch appears to have the opposite effects to that of exercise (Sivachelvan & Davies, 1986).

Hypertrophy and atrophy of muscle fibres as a result of an experimental treatment have been described by Gutmann & Hajek, (1971); Gauthier & Dunn, (1973); Vaughan & Goldspink, (1979) and Hoffmann, (1980) using different species. These authors reported that a muscle will decrease in size if it is denervated, tenotomised or immobilized, and will increase in size if synergistic muscles are either incapacitated by denervation or tenotomy, or are removed.

Williams & Goldspink (1971) found that immobilization of the limbs of growing mice using plaster casts resulted in a considerable reduction in the number of sarcomeres in series and therefore in shorter muscle fibres, while Tabary *et al.* (1972) reported that immobilization of adult muscles in their extended position results in an increase in the number of sarcomeres in series along the fibres.

Gutmann *et al.* (1971) reported that compensatory hypertrophy of skeletal muscle induced by functional elimination of synergistic muscles was mainly the result of stretch brought about by the action of the antagonistic muscles. They studied this method using *M.extensor digitorum longus and M.soleus* of growing rats. Thus, to achieve compensatory hypertrophy of *M.extensor digitorum longus*, the synergistic *M.tibialis anterior* was cut at its peripheral tendon and removed *in toto*; to achieve compensatory hypertrophy the M.soleus, *M.gastrocnemius* and *M.plantaris* were cut at the distal end of their common tendon. The results showed an increase in diameter of all muscle fibres of different histochemical types and an increase in muscle weight especially for *M.extensor digitorum longus* which still appeared to undergoing compensatory hypertrophy after 3 months. Similar experiments were carried out by Guth & Yellin (1971) using rat soleus or plantaris muscles. After removing these muscles, the remaining muscles exhibited a substantial increase in the percentage of red fibres, which reflected presumably an increase in the workload on the muscles.

Sivachelvan & Davies (1986) used seven newborn lambs with one hindlimb bound to the body, such that the hip was fully flexed and the stifle and hock were fully extended. They found that muscles and bones tended to be heavier on the contra-lateral side in the hindlimb and on the ipsilateral side in the forelimb with the particular exception of the hip bone and the muscles extending the hip, and therefore stretched, on the bound side. *M.semitendinosus* of the bound limb weighed nearly twice as much as that of the control animals. It was concluded from this study that the enlargement of *M.semitendinosus* was due to stretch and that the stretched muscle maintained the same shape as the control muscle by increasing proportionately to length the transverse areas of its fibres as well as its connective tissue components, thereby increasing its mass.

2.4.2.6 *EFFECTS OF ANABOLIC SUBSTANCES*

The anabolic agents to be reviewed here can be classified as to whether they are oestrogenic, androgenic or progestrogenic in action, whether they are endogenous or exogenous to farm animals, and whether they are steroid or non-steroidal compounds (Lamming & Peters, 1987).

There are few studies on the effects of anabolic agents on the muscle fibre types and size of meat animals, and therefore, little is known about the effects these substances have on the muscle fibres of meat animals.

Beermann *et al.* (1990) studied the dose-dependent effects of porcine somatotropin on muscle fibre characteristics of skeletal muscle growth in growing barrows and gilts. Eighty crossbred pigs weighing 46 kg were assigned randomly to receive a range of daily subcutaneous injections until they weighed 100 kg. The results from *M.semitendinosus* samples indicated that the weight of this muscle increased significantly in a linear manner with increasing somatotropin dose. Percentage of white and intermediate fibres was not changed, but cross-sectional area of white and intermediate fibres was increased in parallel with muscle weight. From these results, it was concluded that exogenous porcine somatotropin increased skeletal muscle mass through the radial hypertrophy of individual muscle fibres without altering histochemical fibre type. Similar results were found by Solomon & Dunn (1988) with growing pigs and by Beermann *et al.* (1987) with porcine growth hormone. The muscle fibre type proportions were not altered by porcine GH administration. In another experiment, Krausgrill *et al.* (1990) studied the effects of exogenous porcine growth hormone on *M.semitendinosus* muscle fibres of pigs growing from 60 to 90 kg. At 90 kg slaughter weight the proportion of red fibres was not affected by growth hormone administration, but the percentage of intermediate fibres was reduced significantly and that of the white fibres was increased significantly. Lefaucheur *et al.* (1992) studied the effects of exogenous porcine somatotropin administered to Large White barrows during the growing (30 to 60 kg body weight) and finishing (60 to 100 kg BW) period on growth performance and muscle fibre characteristics. The weights of *M.longissimus* and *M.semitendinosus* were increased significantly in somatotropin-treated pigs with a similar increase in *M.longissimus* area. The administration of somatotropin also resulted in a similar increase in muscle fibre size for all fibre types in both *M.longissimus* and *M.semispinalis*, but not on fibre type percentages in *M.longissimus*, although the percentage of white muscle fibres was significantly increased in *M.semisipinalis*. In lambs, Beermann *et al.* (1987) studied the effect of cimaterol (beta-adrenergic agonists) on muscle growth and on muscle fibre size and type. A significantly greater increase (22% to 32.8%) in weights of *M.biceps femoris, M.semimembranosus and M.semitendinosus* and *in M.longissimus* cross-sectional area (26% to 32%) occurred in treated lambs. The greater muscle weights were found to be the result of increased radial growth or hypertrophy of both type I and type II fibres. The effect of cimaterol on muscle fibre type was found to be only in *M.semitendinosus* in which the percentage of type I fibres was significantly decreased. They also showed that the induced hypertrophy of *M.semitendinosus* by cimaterol was a result of greater increase in both protein and RNA content. This suggested that cimaterol elicits a rapid increase in muscle RNA and protein accretion without concurrent incorporation of satellite cell nuclei. Beermann (1993) concluded from reviewing the effect of beta-adrenergic agonists on skeletal muscle growth that chronic beta-agonist treatment causes muscle hypertrophy rather than hyperplasia and that type II fibres account for the greater portion of hypertrophy when compared with type I fibres, but the response is not equal or not seen in all muscles. He also concluded that long-term treatment may cause an increase in the proportions of type II fibres. However, in cattle, Gerrard & Judge (1993) showed a greater increase ($P<0.5$) in muscle fibre number from the cross-sections of *M.semitendinosus* of the double-muscle fetuses compared with the fetuses of the normal cattle. This was associated with greater growth factor activity in the serum of double-muscled fetuses during early fetal development. Greater growth factor activity may play a role in bovine muscle fibre hyperplasia.

Seideman *et al.* (1986) compared intact bulls, bulls implanted with Synovex-S, bulls implanted with Ralgro and castrates, and showed that at the same age, the bulls implanted with Ralgro had significantly more red and intermediate fibres and a lower proportion of white fibres in *M.longissimus* than steers, but did not differ from the intact bulls or bulls implanted with Synovex-S. The average areas of red and intermediate fibres of *M.longissimus* from intact bulls and bulls implanted with Ralgro were significantly larger than corresponding fibre types from steers, but no significant differences were found for the white fibres. Similar results were also found for the percentage area of red and intermediate fibres as for the average area, but the muscle from steers had a significantly larger white fibre percentage area than the muscle from intact bulls and bulls implanted with Synovex-S and Ralgro.

Three groups of cattle from Friesian and Charolais-cross Friesian (bulls, steers and steers implanted with both resorcylic acid lactone and trenbolone acetate) were studied by Clancy *et al.* (1984) to investigate the effects of anabolic agents on the fibre characteristics of *M.longissimus*. At 26 months of age, implanted steers had 26% more intermediate fibres and 8% less white fibres than the untreated steers, and the bulls had 33% more intermediate fibres and 20% less white fibres than the implanted steers, while the percentage of red fibres did not vary significantly between groups. The mean cross-sectional areas of the red fibres did not differ between the implanted steers and bulls but was significantly greater than that of the untreated steers. At the same time, although the intermediate fibres from the treated steers did not differ significantly from the other two groups, the treatment did bring about an increase in fibre area. Also, the mean area of the white fibres in the implanted steers was similar to that of the untreated steers and significantly smaller than that of the bulls.

In conclusion, any increase in muscle weight and cross-sectional area produced by an anabolic treatment is due to an increase in the area of all muscle fibres, but especially of white and intermediate fibres. Generally there is an increase in the proportions of intermediate and white muscle fibre and a decrease in red fibre proportion.

CHAPTER THREE

CHANGES IN MUSCULARITY AND CARCASS COMPOSITION OF SOUTHDOWN RAMS SELECTED FOR HIGH- AND LOW-BACK FAT DEPTH WITH GROWTH FROM BIRTH TO MATURITY

INTRODUCTION

Differences in carcass quality characteristics between rams from the Massey University backfat selection lines of Southdowns have been studied previously at carcass weights of c. 29 kg (Kadim *et al.*, 1989) and c. 14 kg (Abdullah, 1989). Results of these studies have shown that the high-backfat line had higher muscularity, (Purchas *et al.*, 1991) more fat, less bone, similar muscle and a higher red muscle fibre percentage in *M.semitendinousus* (Kadim *et al.*, 1993) than the low-backfat line at similar carcass weights.

Studies assessing changes in muscularity and other carcass characteristics with growth of animals selected for increased or decreased fatness were not found in the literature. However, positive associations between fatness and muscularity have been reported previously for sheep (Kirton *et al.*, 1983; Butterfield *et al.*, 1983a; Butler-Hogg & Whelehan, 1984; Bass *et al.*, 1984) and pigs (Wood *et al.*, 1983).

The objectives of the experiment reported here are:

1. To study differences between the Southdown backfat selection lines in the way in which muscularity and associated composition characteristics change with growth.
2. To study the consistency of line differences in measures of muscularity and other composition characteristics in different anatomical regions.

3. To investigate relationships between muscularity differences between the lines and differences in the shape of the carcass and its skeletal framework.
4. To investigate the relationship between muscularity differences between the lines and differences in the type, size and number of muscle fibres.

MATERIALS AND METHODS

Animals and experimental design

The 80 Southdown rams used in this study came from a selection programme that was initiated at Massey University in 1976 to establish high- and low-backfat lines of Southdown sheep (Purchas *et al.,* 1982). The programme was based on selection for either increased (high-line) or decreased (low-line) weight-adjusted backfat depths as assessed by ultrasound (Purchas & Beach, 1981). The Southdown rams used in the seven slaughter groups were aged between 1 and 833 days (Table 3.1) and included representatives from those born in two years (1989, n=36; 1990, n=44). These rams were allocated at random within a line to the weight group within the same year of birth after selecting two sires from each line for breeding.

Two sires within each line were used each year (the sires used were not the same in the two years), but for the animals used in this study it was not known which of the two possible rams was the sire of individual animals. The rams were all raised on pasture alone, under typical commercial conditions. All animals were slaughtered during the spring/summer period (Table 3.1). Further details on the Massey University backfat selection lines have been provided by Kadim *et al.* (1989).

TABLE 3.1 The experimental design showing the birth year, age at slaughter, weight at slaughter and time of slaughter.

Group No.	Year born	Line	No. of Animals	Mean age (days)	Mean carcass weight (kg)	Time of slaughter
1	1990	1	6	1	1.5	Aug, Sept 90
		2	6	3	1.9	
2	1990	1	6	39	6.0	Sept, Oct 90
		2	6	40	6.5	
3	1990	1	6	112	10.7	Dec 90
		2	6	106	10.7	
4	1989	1	6	408	18.4	Sept, Oct 90
		2	6	403	16.5	
5	1989	1	6	532	28.6	Jan, Feb 91
		2	6	535	26.1	
6	1989	1	6	838	35.7	Dec 91
		2	6	838	34.1	
7	1990	1	4	829	38.7	Dec 92
		2	4	829	35.1	
All		1	40	372	19.0	
		2	40	372	17.9	

Slaughter procedures and measurements on carcass and non-carcass components

Lots of four or six animals within each weight group were slaughtered and dressed on any one day following normal commercial procedures, with a captive bolt pistol being used to stun the animals. Animals were fasted for a period of 17 hours prior to slaughter.

Non-carcass components including liver (without gallbladder), spleen, lungs & trachea, empty foregut, empty intestine, heart, kidney, kidney fat, omental fat and testes, were weighed immediately after removal from the body following slaughter, except the foregut and the intestine which were emptied, washed under cold running water, and allowed to drip-dry before being weighed.

After slaughter the carcasses were held at 1-3^{o}C within a plastic bag for 24 hours. Following this period, the carcasses were weighed and a number of linear measurements were made. These included body length (LB) (Moxham & Brownlie, 1976; defined and shown in Appendix 1: Table A1.1 and Figure A1.1) leg length (T), gigot width (G), maximum shoulder width (WF), and width behind the shoulder (WTh) (Palsson, 1939; defined and shown in Appendix 1: Table A1.1 and Figure A1.1).

The carcasses were then sawn down the middle of the vertebral column and divided into shoulder, rack, loin, and leg cuts (Appendix 1: Figure A1.2). The shoulder cut was removed by a cut along the caudal edge of rib 7, and the leg by a cut between the last and second-to-last lumbar vertebrae. The separation of rack and loin cuts between ribs 12 and 13 was as described by Kadim *et al.* (1988).

These cuts were weighed and then several linear measurements were made on the cut surfaces as follows: *M.longissimus* area (EMA), width (A), depth (B), fat depths C and J, (Palsson, 1939), tissue depth GR, and fat depths L3 and S2 (Kirton & Johnson, 1979). These measurements are defined and shown in Appendix 1: Table A1.1 and Figure A1.3. On the leg cut, the measurement of leg length was made from the distal tip of the tarsal bones to the cranial end of the exposed cut through the pelvic bone.

The leg, shoulder and rack cuts from the right side of each carcass were sealed in plastic bags and frozen at -20^{o}C for further dissection.

Because of the small body size of new born lambs, several measurements were not made on carcasses of group 1. These included fat depths C, J, L3, and S2, tissue depths GR, EMA, muscle water and fat percentage and the muscle fibre type measurements.

Dissection procedures and measurements

Following a period of frozen storage (c. 7 days), dissection was commenced after taking one side at random from the freezer and thawing it for 12 hours at room temperature. The leg and rack cut from each side was dissected into muscle, bone, subcutaneous fat and intermuscular fat following the procedures of Brown & Williams (1979). Only the foreleg from the shoulder cut was dissected into individual muscles and bones. All parts were weighed immediately after dissection. Dissection included the separation of several individual muscles from the leg and the foreleg following the procedures described by Fourie (1962). The bone from each cut and several individual bones from the leg, rack and foreleg were also scraped clean and weighed before sealing in plastic bags and freezing, pending further measurements. Two intermuscular fat depots (IMFD) were also dissected from between the muscles (Appendix 1: Figure A1.2). The prescapular IMFD was dissected from the shoulder cut after removing the subcutaneous fat, *M.brachiocephalicus* and *M.omotransversarius*, and the popliteal IMFD was dissected from the leg cut after removing the *M.biceps femoris* and *M.semitendinosus*. A total central transverse section (10 mm thick) from *M.semitendinosus* was taken for the estimation of muscle fibre number, and a sample of *M.longissimus* in the region of rib 12 (c. 50g) was taken for intramuscular fat and water measurements.

Bone measurements

These included the total weight of bone plus cartilage in the leg and rack, and several linear and area measurements from the metacarpal, the eighth rib, the radius & ulna, the scapula, the humerus, the pelvic bones, the tibia and the femur.

After approximately 1 - 3 months, all bones were removed from the freezer, thawed and reweighed. Linear measurements were taken with calipers to an accuracy of 0.1 mm and the circumference of each bone was measured with a fine cotton string. The circumferences of the femur, tibia, radius & ulna, humerus and metacarpal bones were measured at the narrowest points on the shaft, and the maximum length for those bones were measured from distal and proximal extremities. Tibia and femur transverse areas of bone were measured by sawing across the bone at mid length, removing the marrow, smoothing with a sharpening stone, and then stamping the cross-sectional bone area on to paper using ink. The bone area was calculated by subtracting the empty marrow cavity area from the total area. Areas were determined using a digitising tablet and the VERSACAD programme.

Other measurements that were taken on individual bones (Appendix 1: Figures A1.4, A1.5, A1.6 and A1.7) were as follows:

Femur bone:

A/ Transverse width of the greater distance of the trochanter of the head.
B/ Sagittal width of the head.
C/ Transverse width between the medial and lateral epicondyles.
D/ Sagittal width from the trochlear groove to the intercondylar fossa.

Tibia bone:

A/ Transverse width of the medial and lateral condyles.
B/ Sagittal width from the tibial tuberosity to the popliteal notch.
C/ Transverse width between the medial and lateral malleoli.
D/ Sagittal width across the cochlea.

Humerus bone:

A/ Transverse width between the major and minor tubercles.
B/ Sagittal width between the head and apex of the greater tubercle.
C/ Transverse width between the medial and lateral epicondyles.

Scapula bone:

A/ Maximum length from the supraglenoid tubercle to the dorsal border of the scapular cartilage.
B/ Circumference of the glenoid angle (scapular neck).
C/ Maximum height at the acromion from the cranial/dorsal edge of the scapula to the surface of the neck of the scapula.

Pelvic bone:

A/ Maximum length from the tuber coxae to the caudal part of the tuber ischii including the cartilage at each end.
B/ Circumference of the shaft of the ilium.

Eighth rib:

A/ Direct distance from the head to the distal end (costal cartilage not included).
B/ Maximum projection of the rib from the line connecting the head to the distal end (Rib curvature).

Muscle fibre measurements

The left *M.semitendinosus* from 63 carcasses (excluding carcasses of group 7 and most of group 1) was removed and placed on ice within 1 to 2 hours of slaughter. A central sample (10mm X 5mm X 5mm) from these muscles was removed and frozen in isopentane cooled in liquid nitrogen within 2 to 3 hours post-mortem. After mounting the samples on a cryostat chuck and allowing to equilibrate to -20^{o}C, (c. 30 min) transverse sections of 10 µm thickness were cut, mounted on slides and stained for succinate dehydrogenase (SDH) using the Nitro Blue Tetrazolium method of Nachlas *et al.* (1957). Based on the staining activity, fibres were identified as high, medium or low activity which were specified as red, intermediate and white fibres. Fibre-type proportions were estimated by scoring all types of fibres in a fixed square area (600 µm X 600 µm) using a projection microscope (magnification power was 64X, with 4X for the microscope and 16X for the lens) to count any fibres inside the square, including all fibres touching two sides of the square (upper and right side), but leaving out any fibres touching the other two sides of the square. The size of the square that the image was projected on to was 153mm X 153mm. The average number for two squares were recorded to calculate the percentage of each fibre. Mean fibre area was calculated by dividing the area of the square by the total number of fibres present.

The 10 mm thick transverse section from the middle of each right *M.semitendinosus* collected at the time of dissection was traced on to paper to give a cross-sectional area (A1); and then stored in 10% Formalin. After 2 - 6 months, the areas (A2) of these fixed sections were re-traced and then a block (13 X 13 mm^{2}) of fixed sample was cut (A3) and wax embedded. After measuring the area (A4) of the wax embedded block, transverse sections of 10 µm thickness were cut, mounted on slides, and stained with Haematoxylin for 3 min. The number of fibres in a fixed square (390 µm X 390 µm) area (A5) was then measured using a projection microscope as described above (magnification power was 100X, with 4X for the microscope and 25X for the lens). The projected square was calibrated with a 1mm stage micrometer each time.

The mean fibre area in fresh muscle was calculated as:

Mean fibre area = A5/(No. of fibres in A5) X A3/A4 X A1/A2

The number of fibres in A1 (fresh muscle) was calculated as:

No. of fibres = (No. of fibres in A5) X A4/A5 X A2/A3

Mean values for A1 to A5 within groups are given in Appendix 3.

Muscle chemical analysis - fat and water determination

Samples of *M.longissimus* at the level of the 12th rib were used to determine intramuscular fat and water content. Samples were thawed partially by microwave for 30s and then diced into small pieces with a knife. After mixing thoroughly, triplicate samples (10 - 14g each) were weighed out on to tared aluminium foil and freeze-dried for 4 days.

The water content was calculated from the loss in weight with freeze-drying, and the fat content was estimated initially from two freeze-dried meat samples by SOXHLET extraction for about 9 hours with petroleum ether (B.P. 40 to 60°C) (A.O.A.C., 1970). The third sample was not extracted if the two samples were within 20% or 0.5 of a percentage point, whichever was the smaller.

Calculation of derived indexes

Muscularity as described by Purchas *et al.* (1991) and outlined in Appendix 2: Table A2.1) and muscle to bone ratio respectively, were calculated for various sets of muscle weights and bone lengths (for muscularity) or bone weights (for M:B) as follows:

(1) The weight of five leg muscles (*M.semimembranosus, M.semitendinosus, M.biceps femoris, M.quadriceps femoris and M.adductor*) to femur length or weight (MUSC(FL); M:B(FW)).

(2) The weight of muscles surrounding tibia (*M.gastrocnemius, M.lateral extensor, M.peroneus longus, M.peroneus tertius and long extensor group, M.flexor group, M.tibialis anterior, and M.soleus*) to tibia length or weight (MUSC(TL); M:B(TW)).

(3) The weight of *M.gluteus* in the leg to pelvic bone length or weight (MUSC(PL); M:B(PW)).

(4) the total leg muscle weight to leg length or total leg bone weight (MUSC(LegL); M:B(LegBW)).

(5) The weight of three shoulder muscles (*supraspinatus; infraspinatus + deltoideous*) to scapula length or weight (MUSC(SL); M:B(SW)).

(6) The weight of three shoulder muscles (*supraspinatus; infraspinatus + deltoideous*) to scapula + cartilage length (MUSC(S&CL)).

(7) The weight of muscles around the radius and ulna to radius and ulna length or weight (MUSC(R&UL); M:B(R&UW)).

(8) The weight of three muscles around the humerus (*biceps brachii, triceps brachii, and brachialis*) to humerus length or weight (MUSC(HL); M:B(HW)).

Other indexes of shape as described in Appendix 2: Table A2.1 included:

(1) the ratio of eye muscle depth (B) to width (A) (B:A ratio).

(2) the ratio of eye-muscle area (EMA, cm^2) raised to the power of 1.5 and carcass weight (EMA ratio).

(3) the ratio of carcass weight (kg) to carcass length (m) cubed (CWT/L^3).

Statistical methods

The general-least-squares procedures within the SAS computer programme (SAS Institute Inc., 1987) was used to evaluate the significance of line, carcass weight and their interactions.

Multiple comparisons between predicted means were made using the "PDIFF" option within the "LSmean" statement in the "GLM" procedure of the SAS programme (SAS Institute Inc., 1987).

Different variables were analysed using one of the following three methods:

(1) To examine the relative growth of body or carcass components, allometric growth coefficients (Huxley, 1932) were calculated for each line and compared by regression analysis. Curvilinearity in the allometric relationship was tested as follows (Dr R.W.Purchas and Mr A.B.Pleasants, personal communication 1994):

The equation indicating a linear relationship between the relative growth rates of x and y is

$$1/y \, . \, dy/dt = k \, . \, 1/x \, . \, dx/dt \qquad \text{[Equation 1]}$$

Where k = allometric growth ratio (AGR)

If k is a linear function of x

Then $$k = a + bx \qquad \text{[Equation 2]}$$

and by substitution into equation 1 and cancelling dt

$$dy/y = a(dx/x) + b(dx)$$

and by integration of both sides

$$\ln y = a \ln x + bx + \text{constant} \qquad \text{[Equation 3]}$$

By fitting a multiple regression equation with lny as the dependent variable and lnx and x as the independent variables, estimates of a and b are obtained that can be used with equation 2 to calculate values of k (the AGR) at specific values of x. If logarithms to the base 10 are used (as was the case in the current study) equation 3 becomes

$$\log_{10}y = a \log_{10}x + (b/2.30259)x + \text{constant}$$

because $\log_{10}y = \ln y/\ln 10$
and $\ln 10 = 2.30259$

Component weights at selected carcass weights were estimated using the logarithmic regressions from which the growth coefficients were derived.

(2) For the analysis of ratios (eg., muscularity and M:B ratios) a regression of the ratio against $\log_{10}$ carcass weight was used.

(3) Quadratic regression equations were used to analyse the relationship between muscle fibre characteristics and carcass weight, and linear regression equations were used to analyse the changes in chemical composition data and dressing-out percentage with increasing carcass weight because the quadratic component was not significant.

When the above three models were used, the full models including interactions were initially used, but any variables found to be statistically non-significant ($P>0.10$) were deleted from the model before predicted values were calculated.

Testing of differences between regression coefficients and specified values was carried out by the GLM procedure of the SAS computer programme and the significance of the regression coefficient was tested by t-test using the following formula (Sokal & Rohlf, 1969):

$$t_s = (b-1)/s_b$$

Where b = the slope of the regression coefficient.

S_b= the standard error of the estimated slope.

RESULTS

The means for all measurements of carcass composition within the seven weight groups are given as background information in Appendix 3.

The three methods to analyse the data were as follows:

(1) Allometric equations were used to analyse the patterns of change in weights of non-carcass components, carcass linear dimensions, bone weights and dimensions, and all component weights obtained by dissection of the leg, rack and shoulder cuts. This was because it provided a good fit of the data and because the AGR's can be interpreted in simple meaningful terms as outlined in Chapter 2, section 2.2.2.2.

When the second term in the allometric equation (i.e x) was significant ($P<0.05$), the coefficient is shown in the appropriate Tables as b_2. Values of b_2 can be used with b_1 to calculate AGR's at any value of x as indicated in the Materials and Methods section, and b_2 also indicates whether the AGR was increasing or decreasing as x increased. Thus, if $b_2>0$, the AGR increased with increasing x, and if $b2<0$, then the AGR decreased with increasing x.

(2) For ratios, such as all muscularity indexes and M:B ratios, semi-log equations were used to assess changes with increasing carcass weight. These gave a better fit than when carcass weight was not in the log form. The regression coefficients provide an estimate of the change in the ratio per unit proportional change in carcass weight.

(3) Changes in muscle fibre measurements with increasing carcass weight and for intramuscular fat, water and dressing-out percentages were analysed using linear and quadratic regression models. These provided better fits than the semi-log regressions.

Non-carcass components measurements

Predicted values of the non-carcass components at a carcass weight of 25 kg are shown in Table 3.2. The values for all non-carcass components, except kidney fat and testes, were higher for rams from the low-backfat line than the high-backfat line. The liver, spleen, heart and omental fat were all significantly higher by 10.8%, 13.0%, 11.9%, and 14.8%, respectively, in the low-backfat line and the testes was significantly higher by 8.7% in the high-backfat line.

The allometric growth ratios for the liver, spleen, lungs & trachea, empty intestine, heart, and kidney were all less than one, indicating that these characteristics became a decreasing proportion relative to carcass weight as carcass weight increased. The kidney fat, omental fat and testes had allometric growth ratios greater than one, indicating that these characteristics became a greater proportion relative to carcass weight as carcass weight increased.

The pattern of growth showed a parallel increase for all measurements for both lines with the exception of empty intestine weight, which showed a higher slope for the low-backfat line with a cross-over at 10 kg carcass weight.

It should be noted that the "effect" under "line effect" in Table 3.2 (and also in similar subsequent Tables) refers to the line effect on the intercept in the general least-squares models. In the case of variables such as empty intestine weight where there was a significant line effect on the slope (b_1), this does not mean that the line difference at the predicted values (at 25 kg in this case) was necessarily non-significant. No attempt was made to estimate the significance of line differences at other values of x for those variables where b_1 differed between the lines.

Table 3.2 also shows that the log/log relationships of the liver, spleen, empty foregut, empty intestine, kidney fat, and omental fat were not linear as indicated by the significant values for b_2. The positive sign of b_2 for the fat characteristics indicated that AGR's for these characteristics increased with increasing carcass weight and the negative sign for the liver, spleen, empty foregut, and the empty intestine indicated that the AGR's decreased with increasing carcass weight.

TABLE 3.2 Predicted weights of non-carcass components at a carcass weight (CW) of 25kg for Southdown rams from high- and low-backfat selection lines ranging in carcass weight from about 1.5kg (birth) to 40kg. Double-log regression equations were used to calculate allometric growth ratios (AGR) and predicted weights.

	Line effect			Allometric Growth Ratio[b]		Pattern Of Change	R^2%
	High	Low	Effect[a]	b_1 (high/Low)[c]	b_2		
Predicted component at a carcass weight of 25kg:							
n	40	40					
Liver (g)	869	974	*	1.0643	-0.0078^{***}	Parallel	94
Spleen (g)	79.5	91.4	**	1.2376	-0.0112^{***}	Parallel	97
Lungs & trachea (g)	492	529	+	0.6422	---	Parallel	93
Empty foregut (g)	1581	1684	NS	1.5635	-0.0134^{***}	Parallel	97
Empty intestine (g)	1874	2078	NS	$1.3258/1.4528^{***}$	-0.0189^{***}	Div(10)[d]	97
Heart (g)	208	236	***	0.6993	---	Parallel	96
Kidney (g)	147	153	NS	0.6261	---	Parallel	95
Kidney fat (g)	363	354	NS	0.4014	0.0332^{***}	Parallel	94
Omental fat (g)	686	805	*	1.4591	0.0109^{**}	Parallel	97
Testes (g)	390	356	*	1.7113	---	Parallel	92

[a] Significance of the line effect from the general least-squares model.

[b] The least-squares equations included either only one covariate (log carcass weight), in which case the AGR = b_1, or carcass weight (CW) as a second covariate when it was significant ($P<0.05$), in which case AGR = $b_1 + (b_2 \times 2.30259)(CW)$.

[c] Log carcass weight was highly significant as a covariate for all variables ($P<0.001$). Separate values of b_1 for high and low lines are given only when there was a significant difference between lines in the slope ($P<0.05$).

[d] The value in brackets is the approximate value of x where y was equal for the two groups. Values diverged on either side of this cross-over point.

NS=$P>0.10$; +=$P<0.10$; *=$P<0.05$; **=$P<0.01$; ***=$P<0.001$.

Carcass linear dimensions measurements

The results for carcass linear dimensions are shown in Table 3.3. At 25 kg carcass weight, the low-backfat line carcasses were significantly longer by 55 mm and had significantly longer hind legs (T) by 8 mm, but significantly narrower shoulders (WF) by 11 mm and width behind the shoulder (WTh) by 11 mm.

M.longissimus at the 12/13 rib had a greater area ($P<0.1$) and was deeper (B) for the high-backfat line, but was not quite as wide.

Fat depth (C), fat depth (L3) and fat depth (S2) were all significantly higher by 2.68, 5.27 and 3.49 mm, respectively, in the high-backfat line carcasses than the low-backfat carcasses, but tissue depth (GR) was non-significantly higher by 1.41 mm and fat depth (J) was higher by 1.5 mm, which was significant only at the 10% level of probability.

Table 3.3 also shows that the allometric growth ratio values for the whole carcass linear dimension measurements were less than one because linear measurements are being related to a weight. A value of 0.33 is expected for isometric growth.

Table 3.3 shows that the measurements on *M.longissimus*, tissue depth GR, and the fat depths J and S2 were characterized by a parallel pattern of growth for both lines while the carcass dimension measurements and fat depths C and L3 were characterized by an early diverging growth and always had higher slopes for the high-backfat line, with the exception of body length (LB) and leg length (T) measurements which had higher slopes for the low-backfat line.

The log/log relationship for all characteristics shown in Table 3.3 except the depth and the area measurements of the *M.longissimus* were not linear as indicated by the level of significance of the second covariate (carcass weight). The negative signs (LB, T, G, A) for the b_2 values indicate that the AGR's were decreasing with increasing carcass weight and the positive signs (mainly measures of fatness) indicate that the AGR was increasing with increasing carcass weight.

TABLE 3.3 Predicted shapes of carcass linear dimensions at a carcass weight (CW) of 25kg for Southdown rams from high- and low-backfat selection lines ranging in carcass weight from about 1.5kg (birth) to 40kg. Double-log regression equations were used to calculate allometric growth ratios (AGR) and predicted components.

	Line effect			Allometric Growth Ratio^b		Pattern Of Change	R^2%
	High	Low	Effect^a	b_1 (high/Low)^c	b_2		
<u>Predicted values at a carcass weight of 25kg:</u>							
Body length (LB)(mm)	1004	1059	***	0.3215/0.3518***	-0.0021***	Diverging	98
Leg length (T)(mm)	174	182	**	0.2622/0.2887**	-0.0023***	Diverging	97
Width behind shoulder (mm)	204	193	**	0.3626/0.3204***	0.0019***	Div(10)^d	99
Gigot width (G)(mm)	256	255	+	0.4460/0.4692*	-0.0043***	Div(25)^d	98
Maximum shoulder width(mm)	236	225	**	0.3630/0.3350**	0.0012**	Diverging	99
M.longissimus:							
Depth (B) (mm)	34.77	33.06	+	0.3675	---	Parallel	92
Width (A) (mm)	60.65	62.94	+	0.3903	-0.0041***	Parallel	93
Area (cm^2)	17.85	16.48	+	0.5121	---	Parallel	79
Fat depth (C) (mm)	5.98	3.30	***	0.3291/-0.0811**	0.0268***	Div(6)^d	84
Tissue depth (GR) (mm)	12.34	10.93	NS	-0.5252	0.0419***	Parallel	82
Fat depth (L3) (mm)	14.57	9.30	***	0.1257/-0.1772*	0.0276***	Div(7)d	82
Fat depth (J) (mm)	7.58	6.08	+	-1.1268	0.0590***	Parallel	78
Fat depth (S2) (mm)	9.27	5.78	***	0.4253	0.0156*	Parallel	70

[a,b,c,d] See footnotes to Table 3.2.

NS=P>0.10; +=P<0.10; *=P<0.05; **=P<0.01; ***=P<0.001.

Measurements on the leg, rack, and shoulder cuts

Tables 3.4 to 3.6 give the predicted characteristics at 2096g, 498g and 757g muscle & bone weights for the leg, rack and shoulder cuts, respectively. These are the predicted weights of these three cuts in a 25kg carcass weight.

All muscle and fat characteristics measured from the leg cut (Table 3.4) were higher in the high-backfat line at the same leg muscle plus bone weight, but only leg weight, *M.semimembranosus, M.biceps femoris,* total subcutaneous fat, popliteal intermuscular fat depot, and total leg fat were significantly higher ($P<0.05$). However, individual bone measurements from this cut with total leg bone were significantly higher in the low-backfat line.

All characteristics measured from the rack cut (Table 3.5) were also higher in the high-backfat line except total bone weight which was essentially the same in both lines, but rack weight, subcutaneous fat weight and total fat weight were the only characteristics significantly higher ($P<0.05$). Similar results were found for the characteristics measured from the shoulder cut (Table 3.6), but only shoulder weight, *M.infraspinatus+deltoideus* and prescapular intermuscular fat depot were significantly higher in the high-backfat line and *M.brachialis* was significantly higher in the low-backfat line. Individual bone measurements of the humerus and radius & ulna bones were also significantly higher in the low-backfat line which gives a similar results to those obtained from individual bone measurements of the leg cut.

Tables 3.4 to 3.6 also show that the AGR's with respect to muscle+bone weight for the three cut weights and all individual muscle weights or total muscle weights in the leg, rack and shoulder were higher than one, except *M.quadriceps femoris* and total distal muscle from the leg cut, and *M.brachialis* and total muscles around the radius bone from the shoulder cut. Fat measurements from the three cuts also showed values greater than one, but total leg bone, total rack bone and individual bone measurements from the leg and shoulder cuts had values less than one. Thus, relative to muscle+bone weight in these cuts, fat, and to a lesser extent, muscle was becoming an increasing proportion and bone a decreasing proportion.

Changes in composition for all three cuts were parallel for the two lines with the exception of total leg muscle, total leg bone, femur weight, femur length, rack weight, rack intermuscular fat weight, rack total fat weight, *M.biceps brachii,* *M.infraspinatus+deltoideus* weight in the shoulder, humerus weight and humerus length all of which showed diverging double log regression lines. These all had higher slopes in the high-backfat line, except *M.biceps brachii*, femur weight and length, and humerus weight and length which had a higher slope in the low-backfat line.

Tables 3.4 to 3.6 show that the second covariate (muscle + bone weight) of the double log regression line was significant for most leg, rack, and shoulder characteristics. The b_2 values included both positive and negative examples with no apparent pattern for different dissected components, although b_2 was negative for most muscle weights and for all individual bone measurements.

TABLE 3.4 Predicted leg characteristics at a total leg muscle and bone weight of 2096g for Southdown rams from high- and low-backfat selection lines ranging in carcass weight from about 1.5kg (birth) to 40kg. Double-log regression equations were used to calculate allometric growth ratios (AGR) and predicted values.

	Line effect			Allometric Growth Ratio[b]		Pattern Of Change	R^2%
	High	Low	Effect[a]	b_1 (high/Low)[c]	b_2		
Predicted values at a leg muscle & bone weight of 2096g:							
Leg weight (g)	2959	2790	**	0.9990	0.0000233**	Parallel	99
M.semimembranosus (g)	245	235	*	1.1973	-0.0000311**	Parallel	99
M.semitendinosus (g)	93.2	92.3	NS	1.1445	---	Parallel	99
M.biceps femoris (g)	231	215	***	1.0965	---	Parallel	99
M.quadriceps femoris (g)	320	299	+	0.9964	---	Parallel	97
M.adductor (g)	95.3	101.7	NS	1.2348	-0.0000554**	Parallel	97
M.gluteus (g)	190	185	NS	1.1415	---	Parallel	99
Total distal muscle (g)	244	236	+	0.9613	---	Parallel	99
Total subcutaneous fat (g)	387	305	**	1.3265	-0.0000805*	Parallel	95
Total intermuscular fat (g)	302	289	NS	1.0453	---	Parallel	97
Popliteal intermuscular fat depot (g)	23.0	20.4	*	0.9991	0.0000567*	Parallel	96
Femur bone weight (g)	95.6	104.1	***	0.7722/0.8404*	-0.0000332*	Diverging	96
Femur bone length (mm)	144	150	***	0.2220/0.2851***	---	Diverging	95
Tibia bone weight (g)	75.9	79.1	*	0.66111	---	Parallel	99
Tibia bone length (mm)	157	161	**	0.23783	---	Parallel	97
Total leg fat (g)	699	599	**	1.0911	0.0000693**	Parallel	96
Total leg muscle (g)	1746	1721	NS	1.1109/1.0916***	-0.00000729**	Div(1400)[d]	99
Total leg bone (g)	348	379	***	0.6899/0.7574***	---	Diverging	99

[a,d] See footnotes to table 3.2.

[b] The least-squares equations included either only one covariate (log leg muscle + bone weight), in which case the AGR = b_1, or leg muscle + bone weight (LM+B) as a second covariate when it was significant ($P<0.05$), in which case AGR = $b_1 + (b_2 \times 2.30259)(LM+B)$.

[c] Log leg muscle + bone weight was highly significant as a covariate for all variables ($P<0.001$). Separate values of b_1 for the high and low lines are given only when there was a significant difference between lines in the slope ($P<0.05$).

NS=P>0.10; +=P<0.10; *=P<0.05; **=P<0.01; ***=P<0.001.

TABLE 3.5 Predicted rack characteristics at a total rack muscle and bone weight of 498g for Southdown rams from high- and low-backfat selection lines ranging in carcass weight from about 1.5kg (birth) to 40kg. Double-log regression equations were used to calculate allometric growth ratios (AGR) and predicted values.

	Line effect			Allometric Growth Ratio[b]		Pattern Of Change	R^2%
	High	Low	Effect[a]	b_1 (high/Low)[c]	b_2		
Predicted values at a rack muscle & bone weight of 498g:							
Rack weight (g)	824	748	**	0.9979/0.9308**	0.000237***	Diverging	99
Subcutaneous fat (g)	115	86	**	1.0231	0.000852***	Parallel	94
Intermuscular fat (g)	162	136	NS	1.097/0.9112***	0.000373***	Div(167)[d]	95
Total muscle (g)	390	389	NS	1.1106	-0.0000803***	Parallel	99
Total fat (g)	288	224	*	1.1013/0.9019***	0.000574***	Diverging	96
Total bone (g)	110	111	NS	0.7568	0.000150***	Parallel	99

[a,d] See footnotes to table 3.2.

[b] The least-squares equations included either only one covariate (log rack muscle + bone weight), in which case the AGR = b_1, or rack muscle + bone weight (RM+B) as a second covariate when it was significant ($P<0.05$), in which case AGR = $b_1 + (b_2 \times 2.30259)(RM+B)$.

[c] Log rack muscle + bone was highly significant as a covariate for all variables ($P<0.001$). Separate values of b_1 for the high and low lines are given only when there was a significant difference between lines in the slope ($P<0.05$).

NS=$P>0.10$; *=$P<0.05$; **=$P<0.01$; ***=$P<0.001$.

TABLE 3.6 Predicted shoulder characteristics at a total shoulder muscle and bone weight of 757g for Southdown rams from high- and low-backfat selection lines ranging in carcass weight from about 1.5kg (birth) to 40kg. Double-log regression equations were used to calculate allometric growth ratios (AGR) and predicted values.

	Line effect			Allometric Growth Ratio[b]		Pattern Of	
	High	Low	Effect[a]	b_1 (high/Low)[c]	b_2	Change	R^2%
Predicted values at a shoulder muscle & bone weight of 757g:							
Shoulder weight (g)	3510	3342	**	1.0074	0.000146***	Parallel	99
M.biceps Brachii (g)	26.9	27.3	NS	1.0969/1.1344*	---	Div(500)[d]	99
M.triceps Brachii (g)	156	158	NS	1.0515	---	Parallel	99
M.brachialis (g)	17.4	18.6	**	0.9971	-0.0000761**	Parallel	99
M.supraspinatus (g)	98.4	96.8	NS	1.1622	-0.0000723**	Parallel	99
M.infraspinatus+deltoideus(g)	135	122	***	1.189/1.1438**	0.0000490**	Diverging	99
Muscles around the radius bone (g)	134	134	NS	0.9626	---	Parallel	99
Prescapular intermuscular fat depot (g)	81.3	62.1	***	-0.6147	0.0011***	Parallel	85
Humerus bone weight (g)	73.4	78.7	***	0.8844/0.9210*	-0.0000897***	Diverging	99
Humerus bone length (mm)	121	125	***	0.2882/0.3103**	-0.0000379***	Diverging	98
Radius&Ulna bone weight (g)	59.4	61.9	**	0.7634	-0.0000372*	Parallel	99
Radius&Ulna bone length(mm)	155	158	*	0.2522	---	Parallel	98

[a,d] See footnotes to table 3.2.

[b] The least-squares equations included either only one covariate (log shoulder muscle + bone weight), in which case the AGR = b_1, or shoulder muscle + bone weight (SM+B) as a second covariate when it was significant ($P<0.05$), in which case AGR = $b_1 + (b_2 \times 2.30259)(SM+B)$.

[c] Log shoulder muscle + bone weight was highly significant as a covariate for all variables ($P<0.001$). Separate values of b_1 for the high and low lines are given only when there was a significant difference between lines in the slope ($P<0.05$).

NS=$P>0.10$; *=$P<0.05$; **=$P<0.01$; ***=$P<0.001$.

Bone weight and dimensions

In this section, line differences in relative bone growth were assessed by allometry using bone length as the dependent variable because most bone measurements were lengths or circumferences so that deviations from isometric growth were shown by the coefficient, b, deviating from unity. The AGR of bone weight with bone length should be multiplied by 0.333 in order to compare it with the other values.

Predicted bone weights and dimensions at specific bone lengths for the two lines from the double-log regression equations are presented in Table 3.7.

Predicted bone weight and circumference for the metacarpal and radius & ulna bones at lengths of 100 mm and 165 mm, respectively, were the same for the two lines of rams. Similar results were also found for the eighth rib weight and scapula bone weight and circumference, but the curvature of the eighth rib, the sagittal width of the scapula neck and the weight and circumference of the pelvic bone were all significantly higher relative to bone length (4.8%, 3.8%, 3.6% and 2.6%, respectively) in the high-backfat line.

At a constant length of 120 mm, the measurements from the humerus bone for circumference and proximal end depth of the high-backfat line were both significantly larger in addition to being slightly but not significantly heavier than for the low-backfat line.

The tibia bone weight, circumference and the bone transverse area were all significantly higher relative to bone length in the high-backfat line by 3.3%, 4.2% and 11.0% respectively, and the width and the depth measurements from the distal end of the tibia bone were lower in the high-backfat line by 3.5% and 4.1%, respectively, when compared at the same length of 170 mm. Similar results were found for the same measurements obtained from the femur bone when adjusted to the length of 150mm, but the bone weight and circumferences were non-significantly higher in the high-backfat line. The width and the depth of the proximal end and the depth of the distal end were also significantly lower in the high-backfat line by 5.2%, 2.3% and 3.8%, respectively.

Table 3.7 also shows for most characteristics that the pattern of growth was parallel for both lines with the exception of weight and the transverse area of the femur bone which diverged from 138 and 128 mm, respectively. In each case the slope was higher for the high-backfat line. The proximal end width of the tibia bone was the only characteristic to show a converging pattern of growth, with the low-back fat line having a greater slope.

For most characteristics shown in Table 3.7, the second covariate (bone length) was significant ($P<0.05$), but most b_2 were negative indicating that the AGR decreased with increasing bone length. The exceptions included most measures of circumference (except the femur) indicated that the AGR increased with increasing bone length.

Simple AGR values from the double-log model are shown in Table 3.8. A common slope for both lines was assumed for the purpose of calculating the AGR's in this Table.

Table 3.8 shows that the bone weight of the eighth rib, scapula and humerus and the bone circumference of the radius & ulna, humerus and femur were the only bone shape measurements to grow proportionately faster than bone length with the rest growing proportionately more slowly than bone length.

The slopes of the regressions were significantly higher or lower than unity (1 or 3) for most bone shape measurements, but in four cases, namely the metacarpal circumference, the eighth rib weight and curvature, and radius & ulna circumference, they were not significantly lower or higher than 1 or 3 for circumferences and weights, respectively.

TABLE 3.7 Predicted bone weights and dimensions at specific bone lengths for Southdown rams from high- and low-backfat selection lines ranging in carcass weight from about 1.5kg (birth) to 40kg. Double-log regression equations were used to calculate allometric growth ratios (AGR) and predicted bone weights and dimensions.

	Line effect			Allometric Growth Ratio[b]		Pattern Of Change	R^2%
	High	Low	Effect[a]	b_1 (high/Low)[c]	b_2		
<u>Metacarpal characteristics at a length of 100mm:</u>							
Bone wt. (g)	31.20	31.60	NS	5.1643	-0.0128^{***}	Parallel	97
Bone circumference (mm)	47.54	47.21	NS	0.9362	---	Parallel	89
<u>Eighth rib characteristics at a length of 150mm:</u>							
Bone wt. (g)	14.93	14.14	NS	3.1011	---	Parallel	91
Rib curvature (mm)	50.83	48.41	**	0.9825	---	Parallel	95
<u>Radius&Ulna characteristics at a length of 165mm:</u>							
Bone wt. (g)	69.78	69.45	NS	3.9534	-0.0037^{**}	Parallel	99
Bone circumference (g)	57.22	56.81	NS	0.0975	0.0030^{**}	Parallel	95
<u>Scapula characteristics at a length of 125mm:</u>							
Bone wt. (g)	59.51	58.05	NS	3.1022	---	Parallel	
Bone circumference (mm)	54.19	54.61	NS	0.4487	0.0016^{**}	Parallel	97
Sagittal width of neck (mm)	27.55	26.50	**	0.4813	0.0043^{***}	Parallel	98
<u>Humerus characteristics at a length of 120mm:</u>							
Bone wt. (g)	71.39	69.48	NS	3.0865	---	Parallel	99
Bone circumference (mm)	52.57	50.52	***	0.1966	0.0041^{***}	Parallel	98
Bone proximal end width (mm)	42.70	42.74	NS	0.9450	---	Parallel	98
Bone proximal end depth (mm)	46.18	45.08	**	1.0676	---	Parallel	97
Bone distal end width (mm)	31.33	31.27	NS	1.3910	-0.0033^{***}	Parallel	91
<u>Pelvic bone characteristics at a length of 180mm:</u>							
Bone wt. (g)	88.45	85.27	*	3.4911	-0.0020^{***}	Parallel	99
Bone circumference (mm)	48.19	46.93	*	0.5564	0.0010^{*}	Parallel	97

Tibia characteristics at a length of 170mm:							
Bone wt. (g)	92.45	89.39	*	3.4254	-0.0023^{*}	Parallel	99
Bone circumference (mm)	52.28	50.11	***	0.2863	0.0019^{*}	Parallel	96
Bone transverse area (cm^2)	1.46	1.30	*	1.7197	---	Parallel	76
Bone proximal end width (mm)	38.20	38.07	+	$1.3749/1.4452^{*}$	-0.0021^{***}	Converging	97
Bone proximal end depth (mm)	46.20	46.87	+	1.5671	-0.0028^{***}	Parallel	96
Bone distal end width (mm)	17.17	17.77	***	1.3076	-0.0030^{***}	Parallel	87
Bone distal end depth (mm)	32.52	33.85	***	1.5040	-0.0032^{***}	Parallel	90
Femur characteristics at a length of 150mm length:							
Bone wt. (g)	104.24	103.16	NS	$3.7862/3.3992^{**}$	-0.0032^{*}	$\mathrm{Div}(138)^{d}$	97
Bone circumference (mm)	59.56	58.08	+	2.7248	-0.0047^{**}	Parallel	93
Bone transverse area (cm^2)	1.67	1.54	**	$2.4807/1.9789^{**}$	---	$\mathrm{Div}(128)^{d}$	90
Bone proximal end width (mm)	21.30	22.41	**	-1.3772	0.0056^{***}	Parallel	65
Bone proximal end depth (mm)	47.83	48.91	*	2.7150	-0.0058^{***}	Parallel	92
Bone distal end width (mm)	44.55	45.75	NS	4.1688	-0.0114^{***}	Parallel	64
Bone distal end depth (mm)	47.30	49.10	**	4.0019	-0.0108^{***}	Parallel	79

[a,d] See footnotes to table 3.2.

[b] The least-squares equations included either only one covariate (log bone length), in which case the AGR = b_1, or bone length (BL)as a second covariate when it was significant ($P<0.05$), in which case AGR = $b_1 + (b_2 \times 2.30259)(BL)$.

[c] Log bone length was highly significant as a covariate for all variables ($P<0.001$). Separate values of b_1 for the high and low lines are given only when there was a significant difference between lines in the slope ($P<0.05$). NS=$P>0.10$; +=$P<0.10$; *=$P<0.05$; **=$P<0.01$; ***=$P<0.001$.

TABLE 3.8 Shape parameters (a and b allometric coefficients with regression coefficients) for the weight and circumference of the bones relative to their length, in Southdown rams from high- and low-backfat selection lines ranging in carcass weight from about 1.5kg (birth) to 40kg.

Dependent variables (Log bone)	Log bone length effect	Intercept(lines) high-low[a]	b	b=3.0[b] b=1.0	R^2%
Metacarpal wt. (g)	***	-0.0017	2.622	***	96
Metacarpal cir. (mm)	***	0.0031	0.936	NS	89
Eighth rib wt. (g)	***	0.0235	3.101	NS	91
Eighth rib curvature (mm)	***	0.0212^{**}	0.983	NS	95
Radius&Ulna wt. (g)	***	0.0040	2.817	***	99
Radius&Ulna cir. (mm)	***	0.0016	1.018	NS	94
Scapula wt. (g)	***	0.0108	3.102	*	98
Scapula cir. (mm)	***	-0.0131	0.826	***	97
Humerus wt. (g)	***	0.0118	3.087	*	99
Humerus cir. (mm)	***	0.0136^{**}	1.168	***	97
Pelvic wt. (g)	***	0.0192^{*}	2.839	***	99
Pelvic cir. (mm)	***	0.0098	0.885	***	96
Tibia wt. (g)	***	0.0161^{*}	2.730	***	99
Tibia cir. (mm)	***	0.0172^{***}	0.874	***	95
Femur wt. (g)	***	0.0038	2.538	***	96
Femur cir. (mm)	***	0.0150^{***}	1.222	***	93

[a] The significance of the difference in intercept between the high- and low-back lines.

[b] The t-test was used to assess whether the allometric coefficients (b) deviated from unity. b=3.0 used with bone weight as the weight was a cube length and b=1.0 used with bone circumference.

*=P<0.05; **=P<0.01; ***=P<0.001.

Muscularity indexes, M:B ratios, and other ratios

Predicted values of all shape ratios in Table 3.9 and all muscularity indexes and M:B ratios in Table 3.10 and 3.11 were higher for rams from the high-backfat line than the low-backfat line, when the data was adjusted to a constant log carcass weight. These line effects were all significant ($P<0.05$) except for EMA ratio, MUSC(LegL), MUSC(R&UL), M:B(R&UW) and M:B(HW).

The results in Tables 3.9 to 3.11 and Figures 3.1 to 3.3 also showed that with increasing carcass weight, all ratios and indexes increased proportionally, and for most of these ratios there was a parallel increase for both lines. For the CWT/L3 ratio, MUSC(FL), MUSC(PL), M:B(PW) and M:B(SW) ratios, however, the two lines diverged from an early age. The M:B ratio from the whole leg and muscularity calculated from the full scapula (bone+cartilage) were the only two indexes for which the regression lines crossed over, with cross-over points at 14 and 10 kg carcass weight, respectively. This indicates that the low-backfat line rams were higher in these two indexes just after birth but not during later stages of growth.

Table 3.12 shows in three parts the relationships amongst measures of muscularity, amongst measures of M:B ratios, and between M:B ratios with muscularity from the leg and the shoulder cuts in terms of simple correlations. The results from the relationships amongst muscularity indexes in the top part of Table 3.12 show that the muscularity from the muscles around the femur and the tibia and muscularity from the muscles around the femur and the scapula were the most closely related to each other. The middle part of Table 3.12 show the results from the relationships between muscularity and M:B ratios which indicated that the muscularity from the muscles around the femur and the humerus were the most closely related to all measures of M:B ratios, and that the muscularity based on total leg muscle relative to leg length and muscles around the scapula relative to scapular length were the poorest. The lowest part of Table 3.12 show the results from the correlation between all M:B ratios which indicate that the M:B ratio from the muscles around the femur and the tibia and also the M:B ratio from the total leg muscle and bone and M:B ratio from the muscles around the femur were the most closely related to each others.

TABLE 3.9 Predicted shape ratios at a carcass weight (CW) of 25kg for Southdown rams from high- and low-backfat selection lines ranging in carcass weight from about 1.5kg (birth) to 40kg. Regression equations of the shape ratio against log carcass weight were used to calculate predicted ratios at 25kg carcass weight.

	Line effect			Regression coefficient with[b]	Pattern Of	
	High	Low	Effect[a]	Log CW (High/Low)[c]	Change	R^2%
Predicted values at a carcass weight of 25kg:[e]						
B:A ratio	0.584	0.533	***	0.0967	Parallel	47
EMA ratio	2.871	2.690	NS	-1.8501	Parallel	66
CWT:L^3	25.6	21.7	***	9.6421/5.0842**	Diverging	59

[a,c] See footnotes to Table 3.2.
[b] The least-squares equation included only one covariate (log carcass weight).
[e] To predict the value of the ratios from the regression equation the carcass weight was used on a gram basis.
NS=P>0.10; **=P<0.01; ***=P<0.001.

TABLE 3.10 Predicted muscularity values (MUSC) and M:B ratios for several parts of the leg at a carcass weight (CW) of 25kg for Southdown rams from high- and low-backfat selection lines ranging in carcass weight from about 1.5kg (birth) to 40kg. Carcass component against log carcass weight regression equations were used to calculate predicted ratios.

	Line effect			Regression coefficient with[b]	Pattern Of	
	High	Low	Effect[a]	Log CW (High/Low)[c]	Change	R^2%
Predicted values at a carcass weight of 25kg:[e]						
MUSC (FL)	0.603	0.555	***	0.1770/0.1450*	Diverging	86
MUSC (TL)	0.254	0.247	***	0.0576	Parallel	76
MUSC (PL)	0.199	0.183	***	0.0451/0.0330*	Diverging	76
MUSC (LegL)	0.248	0.245	NS	0.0717	Parallel	67
M:B (FW)	11.71	10.63	***	6.1070	Parallel	91
M:B (TW)	3.51	3.31	***	1.5721	Parallel	91
M:B (PW)	2.74	2.40	***	1.1911/0.9681*	Diverging	84
M:B (LegBW)	5.60	5.04	***	3.0965/2.4941**	Div(14)[d]	91

[a,c,d] See footnotes to Table 3.2.
[b,e] See footnotes to Table 3.9.
NS=P>0.10; *=P<0.05; **=P<0.01; ***=P<0.001.

TABLE 3.11 Predicted muscularity values (MUSC) and M:B ratios for several parts of the shoulder at a carcass weight (CW) of 25kg for Southdown rams from high- and low-backfat selection lines ranging in carcass weight from about 1.5kg (birth) to 40kg. Carcass component against log carcass weight regression equations were used to calculate predicted ratios.

	Line effect			Regression coefficient with[b]	Pattern Of Change	R^2%
	High	Low	Effect[a]	Log CW (High/Low)[c]		
Predicted values at a carcass weight of 25kg:[e]						
MUSC (S&CL)	0.241	0.224	***	0.0401/0.0209***	Div(10)[d]	61
MUSC (SL)	0.371	0.349	***	0.0634	Parallel	71
MUSC (R&UL)	0.195	0.192	NS	0.0350	Parallel	72
MUSC (HL)	0.354	0.346	*	0.0828	Parallel	79
M:B (SW)	4.51	3.95	***	1.2665/0.8414*	Diverging	71
M:B (R&UW)	2.44	2.39	NS	0.8962	Parallel	87
M:B (HW)	3.00	2.93	NS	1.1252	Parallel	82

[a,c,d] See footnotes to Table 3.2.

[b,e] See footnotes to Table 3.9.

NS=P>0.10; *=P<0.05; ***=P<0.001.

TABLE 3.12 Simple correlations (r%) between muscularity indexes, M:B ratios with muscularity indexes, and between M:B ratios for several parts of the leg and the shoulder cuts for Southdown rams of both lines.

Item	MUSC(R&UL)	MUSC(HL)	MUSC(SL)	MUSC(FL)	MUSC(TL)	MUSC(PL)	MUSC(LegL)
MUSC (R&UL)	---	93	84	93	94	84	78
MUSC (HL)		--	89	93	94	84	78
MUSC (SL)			--	95	86	87	71
MUSC (FL)				--	96	93	80
MUSC (TL)					--	88	78
MUSC (PL)						--	75
MUSC (LegL)							--

	M:B(R&UW)	M:B(HW)	M:B(SW)	M:B(FW)	M:B(TW)	M:B(PW)	M:B(LegBW)
MUSC (R&UL)	91	89	72	89	91	82	87
MUSC (HL)	91	97	76	92	94	87	91
MUSC (SL)	81	85	83	84	84	81	84
MUSC (FL)	91	91	78	94	96	91	93
MUSC (TL)	87	88	75	89	94	85	88
MUSC (PL)	84	86	80	88	88	93	86
MUSC (LegL)	79	79	64	82	81	78	84

	M:B(R&UW)	M:B(HW)	M:B(SW)	M:B(FW)	M:B(TW)	M:B(PW)	M:B(LegBW)
M:B (R&UW)	--	94	81	94	95	90	93
M:B (HW)		--	80	94	95	90	91
M:B (SW)			--	79	81	84	80
M:B (FW)				--	96	93	96
M:B (TW)					--	93	95
M:B (PW)						--	92
M:B (LegBW)							--

FIGURE 3.1 A scatterplot of muscularity (femur) against log carcass weight as an example of a diverging pattern between the two lines. Linear regression lines with 99% confidence limits are shown separately for high (solid line and circles) and low (dashed line and filled triangles) backfat selection lines for Southdown rams.

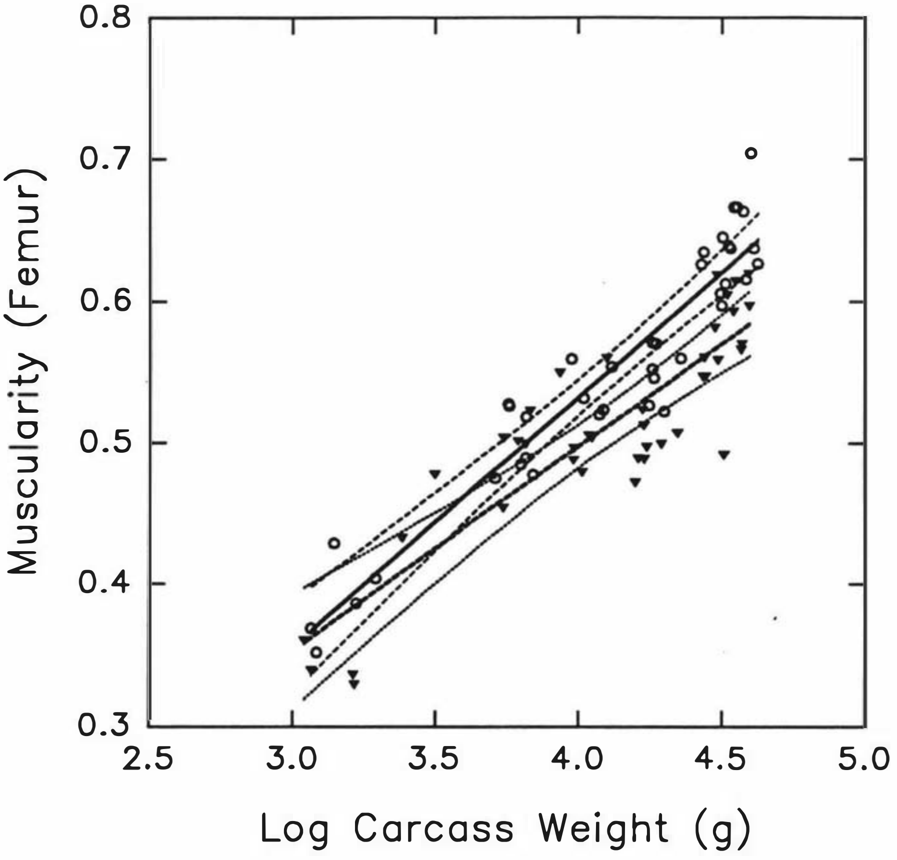


FIGURE 3.2 A scatterplot of muscle:bone ratio (femur) against log carcass weight as an example of a parallel pattern for the two lines. Linear regression lines with 99% confidence limits are shown separately for high (solid line and circles) and low (dashed line and filled triangles) backfat selection lines for Southdown rams.

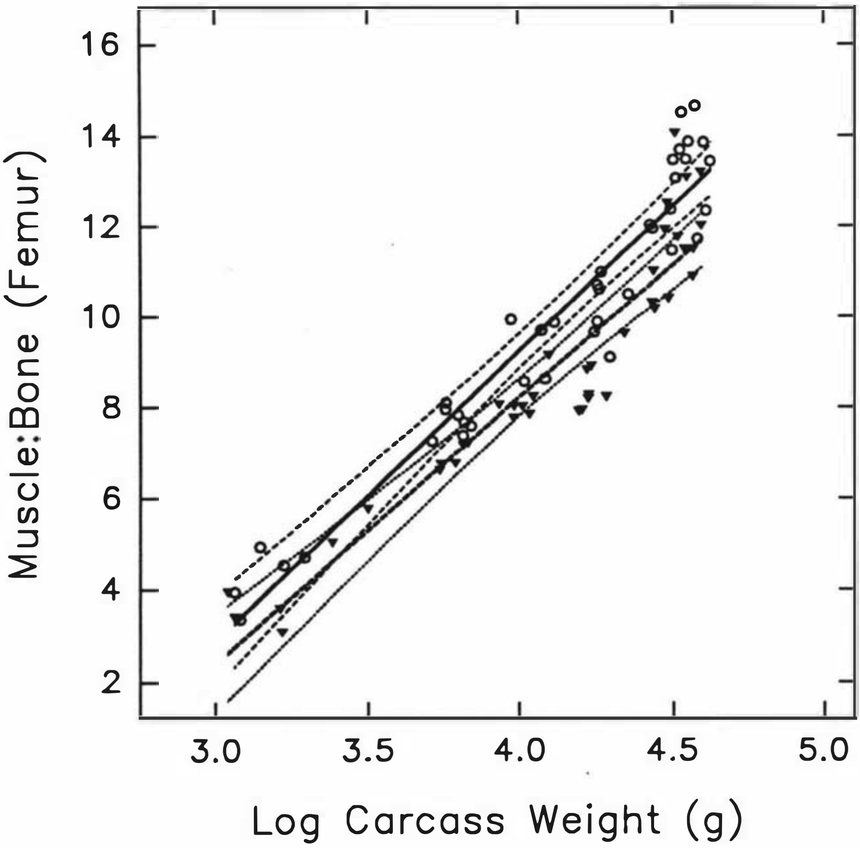
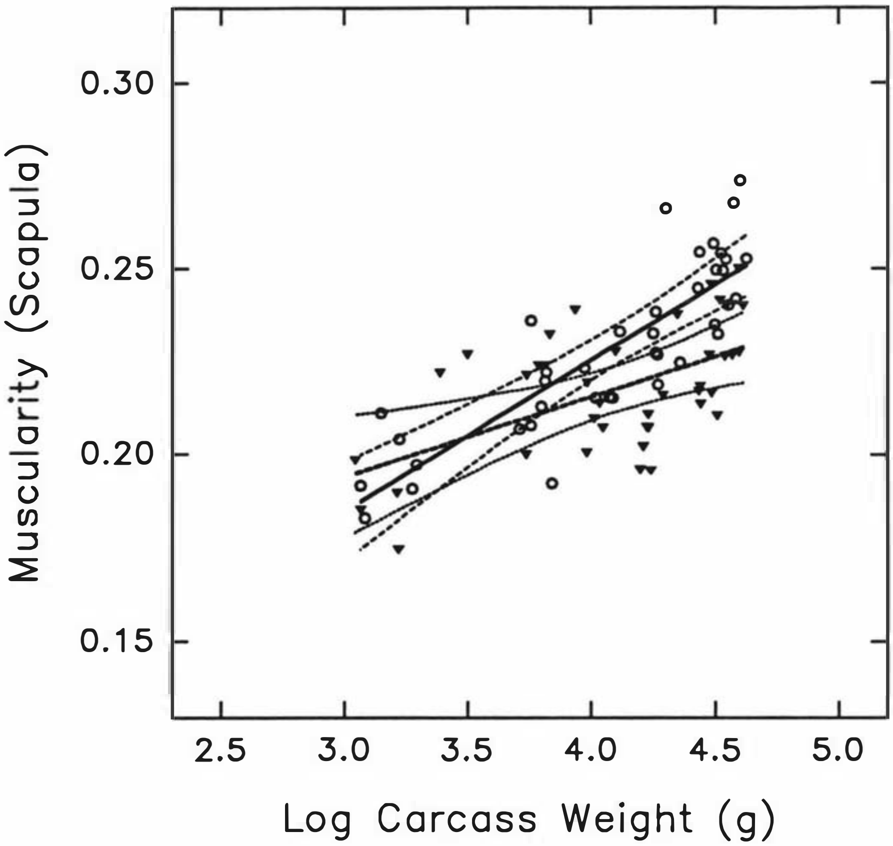


FIGURE 3.3 A scatterplot of muscularity (scapula) against log carcass weight as an example of a pattern where the regression lines crossed over. Linear regression lines with 99% confidence limits are shown separately for high (solid line and circles) and low (dashed line and filled triangles) backfat selection lines for Southdown rams.



Muscle fibre measurements

The first part of Table 3.13 shows the predicted values for the three muscle fibre proportions (red, intermediate and white) from the frozen middle subsample of the left side *M.semitendinosus*. The high-backfat line had a significantly lower intermediate fibre proportion by 2.6%, and a non-significantly higher white fibre proportion by 2.1%.

The three muscle fibre types showed a parallel change in fibre-type percentage for the two lines with increasing carcass weight, but the R^2 values were not high (Table 3.13). The white fibre proportion showed an initial increase followed by a slight decrease with growth, while the red fibres showed a continuous decrease in proportion to around 27 kg carcass weight, and then an increase. This was opposite to the changes shown by intermediate fibre proportion (Figure 3.4).

The three muscle fibre proportions (red, intermediate and white) were plotted against carcass weight rather than muscle weight, and were analysed with carcass weight rather than muscle weight as a covariate because that considered the best measure of the extend of growth. However, the data were analysed with muscle weight and the results were found to be exactly the same.

The second part of Table 3.13 shows data from the middle transverse section of the right side *M.semitendinosus*. There were no significant differences between lines for the patterns of change with carcass weight in total transverse section area, the mean fibre area or the total fibre number.

The results in the second part of Table 3.13 and in Figure 3.5 show a parallel quadratic increase for muscle area, fibre number and fibre area for the two lines with increasing carcass weight. Figure 3.5a demonstrates that there was an increase in the number of fibres postnatally for both lines, with the number reaching a plateau after about 30 kg carcass weight. The number of fibres increased from about <400,000 at birth to 750,000 fibres at about 25kg carcass weight.

To provide further information on this increase in fibre number, the regression of log total transverse area (the transverse area from the fresh muscle (A1)) against log mean fibre area (the mean area of fibres in A1) was calculated. The regression coefficient, which is equivalent to an AGR was 1.21 for the high-backfat line and 1.25 for the low-backfat line with both values being highly significantly different from one ($P<0.001$, $R^2\% = 80$, and $RSD = 0.164$). This test was carried out by the GLM procedure of the SAS computer programme and the significance of the regression coefficient was tested by t-test using the formula of $t_s = (b-1)/S_b$; where b represents the slope of the regression coefficient and S_b equals the standard error of the estimated slope. These results indicate that during growth an increase in mean fibre area of 1% will be associated with about a 1.2% increase in transverse section area, and this must result from an increase in the number of fibres within the muscle in addition to an increase in fibre area. Thus the results of this analysis are consistent with those given in Table 3.13 and Figure 3.5a.

TABLE 3.13 Predicted muscle fibre proportions of the three muscle fibre types (red, intermediate and white) for a frozen middle subsample, and mean fibre area, total number of fibres and muscle area for total middle transverse section from M.semitendinosus at a carcass weight (CW) of 25kg for Southdown rams from high- and low-backfat selection lines ranging in carcass weight from about 1.5kg (birth) to 40kg. Quadratic regression equations were used to calculate predicted values.

	Line effect			Regression coefficient with[b]		Pattern Of Change	R^2%
	High	Low	Effect[a]	CW[c]	CW^2		
For a frozen middle subsample:							
Red fibre %	39.87	39.91	NS	-1.0172	0.0221**	Parallel	15
Intermediate fibre %	31.84	34.40	*	0.6269	-0.0125*	Parallel	20
White fibre %	27.06	24.97	NS	-0.0368	--	Parallel	03
For a total middle transverse section:							
Area (cm^2)	12.10	12.10	NS	0.6129	-0.00600***	Parallel	94
Mean fibre area (um^2)	1798	1763	NS	83.5	-0.898*	Parallel	72
Number of fibres	728893	757419	NS	22891	-359*	Parallel	32

---

[a] See footnotes to table 3.2.

[b] The least-squares equations included either only one covariate (carcass weight), or carcass weight square (CW^2) as a second covariate when it was significant ($P<0.05$).

[c] Carcass weight was highly significant as a covariate for all variables ($P<0.001$).
NS=$P>0.10$; *=$P<0.05$; **=$P<0.01$; ***=$P<0.001$.

FIGURE 3.4 A plot of group means for percentages of the three muscle fibre types in *M.semitendinosus* (red, intermediate, and white) against carcass weight. Data for both lines are combined as there were no significant line effects.

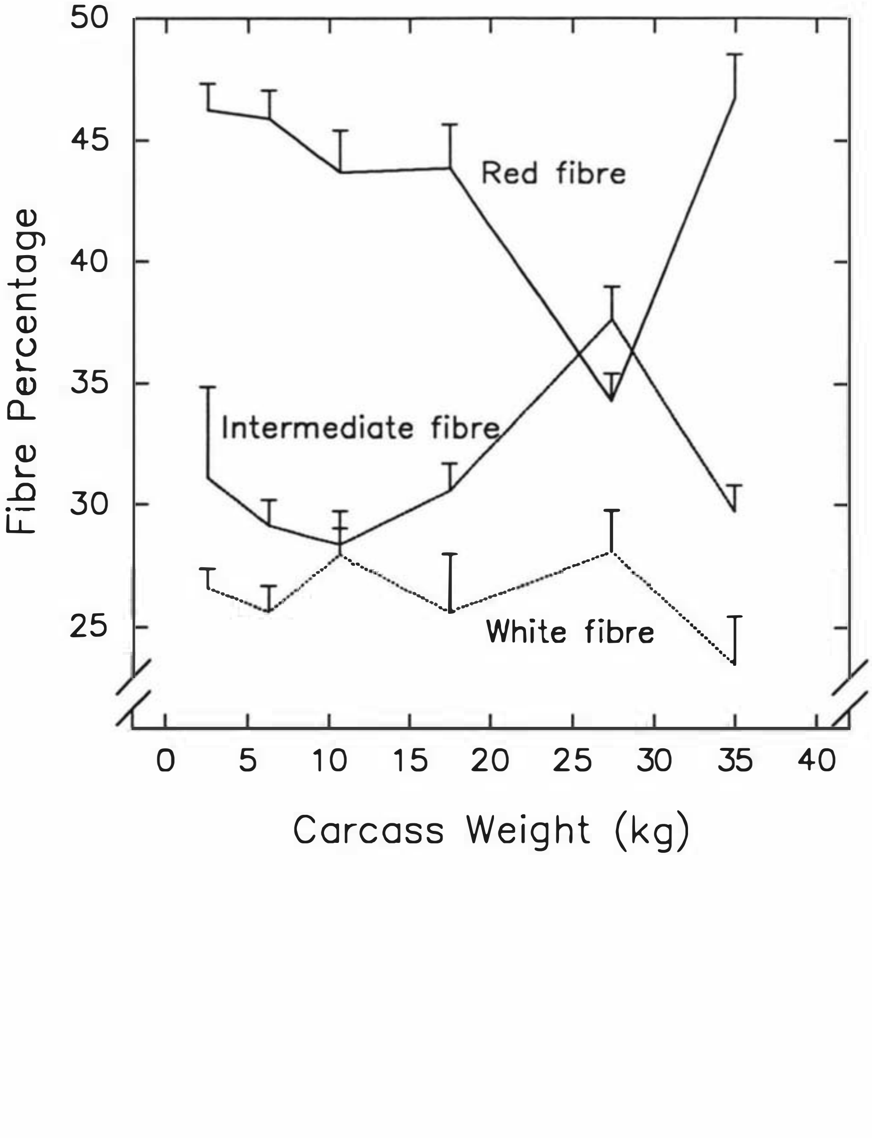
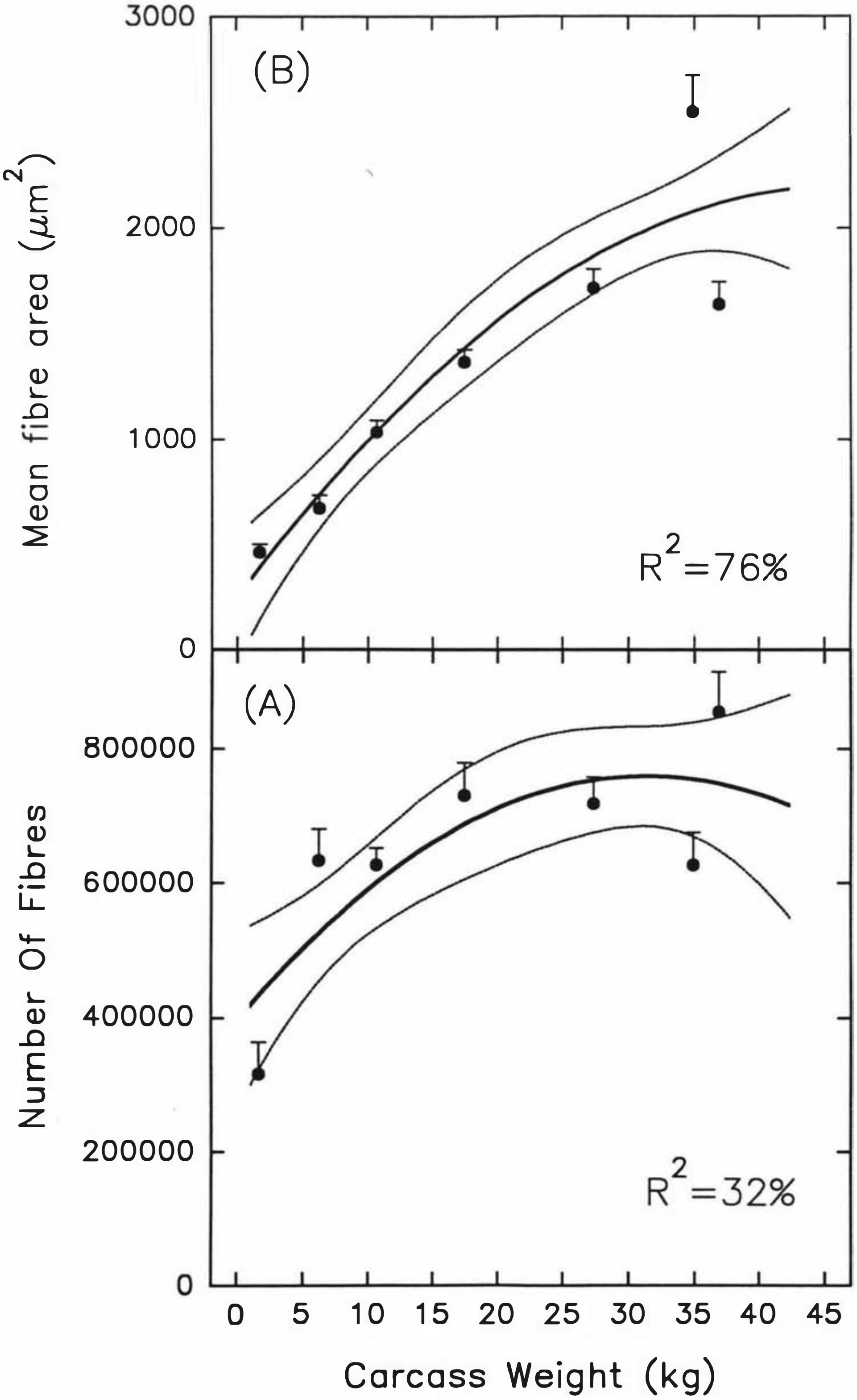


FIGURE 3.5 Quadratic regression lines with 99% confidence limits showing the increase in mean number of fibres per cross section of *M.semitendinosus* (A) and mean muscle fibre area (B) with increasing carcass weight. Group means (± SE bars) are shown within weight groups for both fibre number and area. Data for both lines are combined as there were no significant line effects.



Fat, water and dressing-out percentages

Results of the chemical analysis for fat and water percentage of *M.longissimus* of the high- and the low-backfat lines of Southdown rams showed no line effects (Table 3.14). A similar result was found for the dressing-out percentage with no line effect on the intercept, but the slope was higher for the high-backfat line so that the high-backfat line had a higher mean dressing-out percentage by 2.28% at a carcass weight of 25kg.

As the carcass weight increased after birth, the patterns of change for the fat and water percentages were parallel for both lines, but the fat percentage increased and the water percentage decreased. The dressing-out percentage showed a diverging increase after a carcass weight of 12 kg, with the high-backfat line having a higher slope than the low-backfat line.

Quadratic components were not significant for the variables shown in Table 3.14.

TABLE 3.14 Predicted fat and water percentage from M.longissimus and predicted dressing-out percentage at a carcass weight (CW) of 25kg for Southdown rams from high- and low-backfat selection lines ranging in carcass weight from about 1.5kg (birth) to 40kg. Linear regression equations were used to calculate predicted values.

	Line effect			Regression coefficient with[b]	Pattern Of	
	High	Low	Effect[a]	CW (High/Low)[c]	Change	R^2%
Predicted values at a carcass weight of 25kg:						
Fat percentage (%)	5.10	5.12	NS	0.1717	Parallel	75
Water percentage (%)	72.66	72.95	NS	-0.1362	Parallel	75
Dressing-out percentage (%)	51.50	49.22	NS	0.377/0.233*	Div(12)[d]	57

[a,d] See footnotes to table 3.2.
[c] See footnotes to table 3.12.
[b] The least-squares equation included only one covariate (carcass weight).
NS=P>0.10; *=P<0.05.

DISCUSSION

This discussion is presented in four sections that correspond to the four objectives set out in the introduction.

Differences between the Southdown backfat selection lines in the way in which muscularity and associated composition characteristics change with growth

Measures of muscularity, based on the assessment of the average depth of muscles surrounding the femur relative to femur length, and also leg M:B ratios in this study were found to be higher in the high-backfat line after adjustment for variations in carcass weight. These results agree with the findings of Purchas *et al.* (1991), but extend the carcass weight beyond the range reported in that study. The lightest carcasses in the results presented by Purchas *et al.* (1991) were c. 9 kg while in the current work these characteristics were assessed in lambs at birth with carcass weights as low as 1.5 kg. The range also extended to heavier weights. For the current study only four sires per line were included, but the results from Purchas *et al.* (1991) were for a further six sires per line, which suggests that these are true line differences rather than the effects of a small number of individual sires.

The association of low-backfat thickness with low muscularity and M:B ratios in these selection lines is in agreement with the findings of Kirton *et al.* (1983) and Bass *et al.* (1984) in showing higher M:B ratios in lamb carcasses selected for good muscling (fatter group) compared with carcasses selected for poor muscling (leaner group), although their groups were not based on genetic selection but on the basis of visual carcass conformation.

In sheep growing postnatally the whole-body muscle/bone ratio increases with increasing carcass weight (Butterfield, 1988). For rams from the Southdown selection lines, the means for both leg muscularity and M:B increased from the lighter to the heavier weight groups (Purchas *et al.*, 1991). Results of Zinn *et al.* (1986) and Davies (1974) as calculated by Purchas *et al.* (1991) showed that M:B and muscularity increased with growth for Holstein heifers and for Pietrain and Large White pigs, respectively.

The results of the current experiment are in agreement with the above reports in demonstrating that both muscularity and M:B ratio increased with increasing carcass weight for both selection lines, although some measures increased at different rates for the two lines (Tables 3.10 and 3.11). Other studies showing an increase in M:B ratio in sheep with increased carcass weight include those of Hammond (1932), Palsson & Verges (1952), Fourie *et al.* (1970), McClelland *et al.* (1976), Sents *et al.* (1982), and Thorgeirsson & Thorsteinsson (1989). More details on these relationships were provided in Table 2.2 in Chapter 2 (section 2.2.3). No previous study has reported changes in muscularity with growth of sheep.

Berg & Butterfield (1966) reported that good muscularity or conformation of normal animals implies a higher muscle/bone ratio even when the values are adjusted to a common level of total muscle, total fat, total muscle plus bone or carcass weight. Due to their close positive relationships, patterns of change in M:B are likely to reflect changes in muscularity, and this was shown in the current study by the high correlations in Table 3.12.

The area and dimensions of a cross-section of *M.longissimus* and various ratios of carcass weight in relation to carcass length have been proposed and used as an indices of muscularity in the carcass (Yeates, 1952; Kempster *et al.,* 1976; Kempster *et al.* 1981; Kempster *et al.* 1986; Eldridge, 1989). More details on studies in this area were provided in sections 2.3.2.2.1, 2.3.2.2.3 and 2.3.3.4.

The observation in the current study that animals from the high-backfat line had higher cross-sectional areas of *M.longissimus*, but deeper (B) and narrower (A) muscles (Table 3.3), supports previous findings (Abdullah, 1989; Kadim *et al.*, 1989) for the same selection lines of Southdown sheep, although line differences observed in the present study for the depth (B) and width (A) were less significant than in previous studies. These results are in general agreement with those of other studies showing that fatter carcasses tend to have deeper (B) and narrower (A) *M.longissimus* cross sections, including those of Kemp & Barton (1966), in which fatter and leaner grades of sheep were compared at the same weight, Buhlinger *et al.* (1978), with obese and lean pigs, Wood *et al.* (1983b) and Kirton (1982) with fatter sheep.

In this study, carcasses of the high-backfat line, in addition to having higher muscularity and M:B ratio, also had higher B:A ratios and carcass weight adjusted for carcass length (CWT:L^3), but similar EMA ratios. The ratio of B:A has been proposed as an objective measure of muscle thickness, and the ratio of carcass weight to length as an objective measure of carcass blockiness. However, these ratios, along with the ratio of EMA, do not appear to have been evaluated as measure of carcass muscularity or composition. Thus, there are no previous studies with which to compare the present results. With increasing carcass weight, these ratios were generally larger in the high-backfat line indicating that, especially for the B:A and CWT:L^3 ratios, they were associated with fatter, better muscled, and shorter carcasses.

The higher dressing-out percentage for the high-backfat line (2.28% higher at 25kg carcass weight) was similar in magnitude to that reported by Kadim *et al.* (1989). Both studies are also consistent in showing that animals of the high-backfat line had, at the same carcass weight, lighter weights of several internal organs (liver, spleen, lung & trachea, empty foregut, empty intestine, and kidneys). This observation is similar to the findings of Kauffman *et al.* (1976) for beef and Kirton & Pickering (1967) for lambs which differed in muscularity (conformation). Tess *et al.* (1986) also showed that non-carcass components were heavier in pigs selected for low levels of backfat.

Results of the current experiment showed line differences for most measures of fatness that were consistent with the results of Kadim *et al.* (1989). They support the general finding that selection for changes in backfat thickness will result in changes in fat depths at the selection site and also in most other measures of fatness of sheep (Bennett *et al.*, 1988; McEwan *et al.*, 1989) and pigs (Henderson *et al.*, 1981).

The allometric growth coefficients for the growth of muscle, fat and bone tissue including all individual muscle, and fat depots relative to total muscle plus bone in each cut in this study were shown to be comparable with those reported in Table 2.1 and with other studies including those of Jury *et al.* (1977), Butterfield *et al.* (1984), and Davies *et al.* (1984). In the present study, however, three cuts were dissected rather than a whole side. Therefore total side muscle or bone weight was not available to compare individual muscle and bone weights against, as has been done in most other studies of muscle and bone distribution.

The consistency of line differences in measures of muscularity and other composition characteristics in different anatomical regions.

All calculated muscularity and M:B ratios from the different regions were consistent in showing higher values in the high-backfat line than the low-backfat line (Tables 3.10 and 3.11), but for some of them the relative differences did not reach statistical significance. For example, line differences in muscularity for muscles around the tibia, the total leg, the radius & ulna, and the humerus showed less than a

3% difference between the lines. This contrasted with line differences in muscularity based on muscles around the femur, the pelvic bone, and the scapula which showed differences ranging from 6.3% to 8.7% between the lines. However, the muscularity based on the pelvic bone and the scapula had lower $R^2\%$ values for the statistical model than muscularity based on the muscle around the femur suggesting that muscularity calculated from the femur region was more useful in predicting the muscularity differences between the lines. Three reasons why the femur region of the hind leg may be more suitable for assessing muscularity are as follows:

(1) The five leg muscles used totally surround the femur bone and are probably more closely associated with that bone than for the other regions considered. It was pointed out by Purchas (1993) that when muscles do not totally surround a bone it will be possible to get increases in muscularity as calculated here from increases in muscle width as well as increases in depth. When muscles surround the bone, as is the case for the femur, higher weights at the same length must reflect greater depths.

(2) The individual muscles around the femur were probably more accurately dissected and weighed than total leg muscles because they were relatively large and easily dissectible anatomical entities.

(3) The measurement of the femur bone length can be made more accurately than the measurement of leg length, as the total leg is made up of several bones joined together. The measurements of pelvic length, and scapula length are likely to be less precise due to the shape of these bones.

The pattern of line differences in M:B ratios were similar to the line differences in muscularity in direction but not in level. M:B ratios for muscles around the whole leg and the tibia showed greater line differences than the corresponding muscularity values, probably because weight measurements are more accurate than length measurements.

Comparisons of the usefulness of calculating muscularity indexes for different anatomical regions were not found in the literature, but the results from anatomical studies with sheep have shown that muscle weight distribution is a constant characteristic at a set weight (Jury *et al.*, 1977; Wolf, 1982; Butterfield *et al.*, 1983). It is likely that this was the reason for the consistency of line differences in muscularity indexes and the M:B ratios for different regions in the present study.

Relationships between muscularity differences between the lines and differences in carcass linear measurements and in the size and shape of bones.

Linear measurements made in this experiment agreed well with the results of Kadim *et al.* (1989), Abdullah (1989) and Purchas *et al.* (1982) in showing that the low-backfat line rams had significantly longer bodies (LB), and legs at the same carcass weight and longer individual bones at the same muscle plus bone weight than those selected for high-backfat. The association between low-backfat thickness with larger frame sizes and longer bones has been reported previously in sheep by Kemp & Barton (1966), Wood *et al.* (1980), Bennett *et al.* 1982/1983 and Thorsteinsson & Bjornsson (1982). Levels of fatness have also been shown to be reduced when pigs have been selected for increased carcass length (Duckworth & Holmes, 1968) and when sheep have been selected for long cannon bones (Purser, 1980).

Measures of carcass width (WF, WTh and G) in the present study were higher for the high-backfat line which is in agreement with the study by Kadim *et al.* (1989) for rams with a mean carcass weight of 29.5 kg, but similar differences were not found by Abdullah (1989) for rams with a mean carcass weight of 14.0 kg probably because of lower levels of fatness at this weight. The larger widths, especially for the width behind the shoulder (WTh), for the high-backfat line are consistent with the positive phenotypic and genetic correlations between the WTh width and backfat thickness reported by Mohamed (1976) and Kemp & Barton (1966). The tendency for fat to accumulate in this area is the reason for this association.

The observation that the better carcass muscularity of the high-backfat line was associated with shorter carcasses and shorter bones is similar to the findings of Kirton & Pickering (1967); Jackson & Mansour (1974); Colomer-Rocher *et al.* (1980); Lindsay *et al.* (1978) and is also consistent with previous results from these lines (Kadim *et al.*, 1989; Abdullah, 1989).

Studying the bone shape and weight by allometric analysis indicated that for most bones, the high-backfat line had higher bone weights and circumferences than the low-backfat line at the same bone length. This means that the animals of the high-backfat line had in general thicker bones that were heavier per unit length. However, because bones were shorter for the high-backfat line, the bone weight at a constant muscle plus bone weight was less (Tables 3.4 and 3.6).

Allometric analyses of relationships between bone weight and circumference in relation to length showed considerable variation between bones. By considering significant deviations of weight AGR's from 3 (Table 3.8), there were five bones in which weight increased proportionately more slowly than length (metacarpal, radius & ulna, pelvis, tibia, femur), and two where weight increased proportionately faster (scapula, humerus). This suggests that, except for the scapula and humerus, the bones became more slender with growth. The exception was for the femur where the AGR for weight was less than 3, but for circumference was more than 1. This suggests that the weights of parts other than the shaft were growing proportionately more slowly.

The high AGR values for the circumference of femur and humerus bones, but not for the tibia bone are consistent with reports of Palsson & Verges (1952) and Perry *et al.* (1992) in sheep and by McMeekan (1940) in pigs. These authors reported that the bone diameter or thickness increased more rapidly than length so that, as bone weight increased, bones became relatively thicker per unit length. The differences between the results of the present study for the tibia and those of Perry *et al.* (1992) could be due to the fact that they studied the bone shape in mature animals only (animals slaughtered at approx. 84, 95 and 102 weeks of age) and Palsson & Verges (1952) studied animals from birth to 41 weeks and not from birth to maturity as in this study. Richmond & Berg (1972) studied the growth of bones (femur, humerus, tibia, radius & ulna and scapula) in swine as they grew from 23 kg to 114 kg liveweight and reported a slight decrease in the length-circumference ratio between 23 and 68 kg with little further change above 68 kg.

The analysis of changes in bone dimensions relative to bone length indicated that the log/log relationships were frequently significantly curvilinear (Table 3.7) with the AGR usually decreasing with growth except in the case of circumferences.

Although a number of line differences existed in bone shape parameters they were not consistent from one bone to another and were not helpful in explaining muscularity differences.

Relationships between muscularity differences between the lines and differences in muscle fibre type, size and number.

Kadim *et al.* (1993) found that the *M.semitendinosus* of high-backfat line rams contained significantly higher ($P<0.05$) proportions of red muscle fibres and non-significantly lower proportions of intermediate and white fibres. Mean fibre diameters within fibre types did not differ significantly between lines. The results reported by Abdullah (1989), using younger and lighter Southdown rams from the same lines, together with the results of the present study did not show any significant differences between the lines in the proportion of red fibres in *M.semitendinosus*. This could have been due to the different sires involved in the later two studies or to the fact that a different person was making the evaluation of the muscle fibre types. The allocation of fibres to one of the three classes involves a degree of subjectivity, and this is probably also the reason for the higher values for proportion of red fibre types in this study compared to that of Kadim *et al.* (1993).

The high-backfat line animals of the present study had a significantly lower percentage of intermediate fibres (by 2.6%) which is consistent with the results reported by Nostvold (1979) in comparing a line of pigs selected for high rate of gain and low fat thickness with a line selected in the opposite direction, using *M.longissimus* stained with succinate dehydrogenase. Lower levels of intermediate fibres in better-muscled cattle were reported by Hendricks *et al.* (1973) with double-muscled and normal cattle, and by Tatum *et al.* (1990) in comparing cattle of high and low muscularity. More details of these studies are given in section 2.4.2.1 in chapter 2.

Ashmore *et al.* (1972) suggested that muscle growth can be attributed to both the enlargement of all muscle fibres and also to the conversion of small red fibres to large white fibres. Table 3.13 and Figure 3.5b demonstrate that in the present study, fibre area within *M.semitendinosus* increased with increasing carcass weight. However, there was no indication of a shift in the relative proportion of the different fibre types with increased weight and age. This finding does not agree with that of Moody *et al.* (1980) who showed that for *M.longissimus* in lambs ranging in weight from 31 to 50 kg the number of red fibres decreased while the number of intermediate and white fibres increased. However, the staining methods differed from those used in the current study.

It is generally believed that the number of total muscle fibres is set at birth or soon after and does not change during the postnatal life of sheep (Ashmore & Addis, 1972; Sivachelvan & Davies, 1986) and pigs (Stickland *et al.*, 1975 and Swatland, 1976). Thus postnatal growth in muscle mass has been reported to be due mainly to fibre hypertrophy rather than fibre hyperplasia (for more details see section 2.4.1 in Chapter 2). However, Ashmore & Addis (1972) reviewed data on growth of muscle in lambs mainly in prenatal stage and concluded that the number of total muscle fibres is set at birth. Sivachelvan & Davies (1986) studied the development of skeletal muscle in both antenatal and postnatal stages of growth using the *M.semitendinosus* of 18 fetuses from 60 days gestation to birth and 15 sheep from birth to adulthood. Their results showed that the number of fibres within fascicles appeared constant both antenatally and postnatally, but the fascicles increased in number antenatally and remained relatively constant postnatally. They concluded that postnatally, the growth range is too small to establish a definite pattern of changes in fibre number. Joubert (1956) did not measure the number of fibres per muscle but on the basis of a consistent decline in the coefficient of variation of muscle fibre size, suggested that postnatal muscle growth involved no increase in fibre number. The results of the present experiment, however, showed that the increase in muscle mass after birth was due to both an increase in muscle fibre area as well as number. The number of fibres reached a plateau at about 30 kg carcass weight, having almost doubled in numbers from birth to maturity. The largest increase, however, was from birth to a liveweight of about 10 kg (Table A3.4 and Figure 3.5a).

Wegner (1979) noted on the basis of limited data that muscle could grow according to two theories. The first involved hypertrophy of existing muscle fibres or the transformation of fibre types on the assumption that the number of muscle fibres is already fixed at birth, and the second involved increasing the number of muscle fibres after birth due to division of existing muscle fibres and also the degeneration of individual large muscle fibres at the periphery of the primary bundle. The latter theory may explain why the muscle fibre number increased with increasing muscle growth during the postnatal stage in the current study.

The absence of any significant line effects on the size, number or type of muscle fibres in this study may have been partly due to the fact that the muscle on which these measurements were made did not differ between the lines in mean cross-sectional area (Table 3.13) or weight (Table 3.4).

SUMMARY AND CONCLUSIONS

1. Muscularity and carcass composition of 80 Southdown rams from lines selected for high- or low-backfat depths were studied at birth, 10, 20, 40, 60, and 80 kg liveweight, and at near maturity (28 months). A standard muscularity was calculated objectively from the weights of 5 muscles around the femur and femur length, and measurements were also made of various composition characteristics together with some other shape indexes.

2. For all shape indexes, the pattern of changes with increasing carcass weight were described by regressing them on log carcass weight. These equations gave a better fit than alternatives and the regression coefficients provided an estimate of the change in the index per unit proportional change in carcass weight. The results thus showed that with increasing carcass weight, muscularity based on the 5 muscles around the femur, for example, increased, but at a decreasing rate for each kilogram.

3. The pattern of increase in MUSC(FL) was similar for both lines, but the high-backfat line had higher values at all weights and the difference between the two lines increased with increasing weight.

4. The M:B ratio based on weights of the same 5 muscles and femur weight was also linearly related to log carcass weight, but for this ratio and most of other M:B ratios from different regions there was a parallel increase for the high and low-backfat selection lines.

5. Although muscularity calculated from dissection data in several anatomical regions all showed higher values for the high-backfat lines rams, the difference was clearest in the region of the femur.

6. Allometric relationships between individual muscle and bone weights and muscle plus bone weights of several anatomical regions indicated that the overall higher bone weight and lower muscle weight for the low-backfat line was not uniform for all muscles and bones.

7. The shape of several bones was assessed on the basis of weights and a range of linear measurements in order to investigate possible explanations for the genetic line differences in muscularity. Allometric relationships between these measurements and bone length failed to reveal consistent line differences in bone shape, although a number of line effects were shown for some measurements on some bones. Therefore bones of rams of the low-backfat line appear to be larger and longer relative to muscle weight with relatively minor differences in shape.

8. Quadratic regression models were used to investigate line effects on the pattern of change for muscle fibre type, size and number in *M.semitendinosus* with increasing carcass weight. Proportions of muscle fibre types in the *M.semitendinosus* were similar for the two selection lines except that the proportion of intermediate fibres (based on SDH staining) was slightly lower (2.6%) in the low-backfat line ($P<0.05$). There were no significant differences between lines for the patterns of change in total muscle transverse area, the mean fibre area, or the total fibre number. The absence of line effects may have been because the *M.semitendinosus* was one leg muscle that was not significantly heavier in the high backfat line at the same muscle+bone weight. Therefore conclusions regarding relationships between fibre characteristics and muscularity can not be drawn.

9. The results contrasted with those of other studies in showing that the increase in mass of *M.semitendinosus* after birth was due to both an increase in muscle fibre area as well as number. The number of fibres reached a plateau at about 30 kg carcass weight, having almost doubled in numbers from birth to maturity, but the largest increase was from birth to a liveweight of about 10 kg.

10. Lower muscularity and fatness of the low-backfat line rams were associated with heavier internal organs, slightly lower dressing-out percentages, and longer carcasses than rams of the same weight from the high-backfat line.

CHAPTER FOUR

DIFFERENCES IN MUSCULARITY BETWEEN BREED AND SEX GROUPS

INTRODUCTION

Many comparisons have been made between sheep breeds for carcass composition (McClelland *et al.*, 1976; Wolf *et al.*, 1980; Cameron & Drury, 1985; Kempster *et al.*, 1987; Webster *et al.*, 1990), but little is known about the comparative muscularity of the many breeds available. However, in many breed comparisons indirect measurements of muscularity have been made, including subjective assessments of conformation, M:B ratios or eye muscle area measurements.

The results reported by Anous (1989) showed that several pure breeds including the Southdown and the Texel breeds were distinguished by a specific muscle/bone ratio and this varied from three units for breeds with poor conformation (but comparable fatness) to about six units for breeds with good conformation. Kempster *et al.* (1981) showed that breeds with better conformation do not necessarily have higher muscle/bone ratios when compared at equal fatness and at equal subcutaneous fat proportion in the carcass. By adjusting for variation in fatness, conformation becomes essentially the same as muscularity (De Boer *et al.*, 1974). Texel crosses, for example, had a high M:B ratio but did not have sufficiently high conformation scores to identify that advantage when compared with Suffolk crosses, which had relatively low M:B ratios in relation to their conformation score. Fourie *et al.* (1970) showed that the blockier carcasses of the Southdown breed and the Southdown X Romney cross had higher M:B ratios than leggier carcasses of the Romney breed.

The study reported here investigated differences in muscularity and related characteristics between different breeds and sexes of sheep and also differences between groups in the pattern of change in muscularity with increasing carcass weight.

MATERIALS AND METHODS

Animal and experimental design

Data for this study came from sheep within four trials (Table 4.1).

Trial 1 included the 80 Southdown rams from high- and low-backfat selection lines as described in Chapter 3. Animals were slaughtered in 7 weight groups ranging in age from birth to approximately 27 months. This provided a basic pattern of change against which other groups were compared.

Trial 2 compared Romney and Texel-cross rams which were part of an experiment to study the value of ultrasound in assessing the leg muscling of lambs in 89 ram lambs, comprising 3 sire breed crosses and described further by Ward *et al.* (1992). The purebred Romneys were from a Manawatu stud farm, and the Texel X Coopworth were from a second stud farm. The lambs were slaughtered within 48 hours of scanning and the hot carcass weight taken. After chilling the carcasses several measurements were taken and the right hindlegs were dissected into lean, fat, bone and scrap.

Trial 3 involved 48 twin-born Coopworth lambs with an equal number of rams and ewes. They were used in a study of the effects of recombinant ovine placental lactogen or bovine somatotropin on carcass components. The animals were allocated to three groups balanced for age and sex. After a three week treatment, half of the animals were slaughtered, while the remaining lambs received no further treatments and were slaughtered at a mean age of 9 months.

In Trial 4, 38 Dorset Horn X Coopworth cryptorchids were used to study the effect of a melatonin-protein conjugate on growth and carcass composition of grazing lambs (the trial was run by AgResearch, Grasslands, Palmerston North). The animals were allocated at random to 5 groups with one group of 10 animals being slaughtered just prior to the beginning of the study to obtain baseline composition data. The remaining four groups of 7 each were run together and one was used as a control group and the other three treatment groups were injected with 0.25, 1 and 4 mg, respectively, of the melatonin protein conjugate. All sheep were grazed as one mob for 30 weeks.

TABLE 4.1 An outline of the experimental designs for the four trials.

Trial No.	Breed or cross and sex	No. of animals	Age at[a] slaughter (days)	Carcass wt.(kg)	
				Mean	SD
1	Southdown rams				
	(High-backfat)	40	1-838	19.0	13.6
	(Low-backfat)	40	3-838	17.9	12.5
2	Romney rams	19	270-470	23.2	7.9
	Texel-cross rams	27	180-470	21.9	9.2
3	Coopworth rams and ewes				
	Ram	24	24-270	14.1	9.2
	Ewes	23	24-270	15.0	9.5
4	Dorset Horn X Coopworth cryptorchids				
		38	1-210	19.1	3.8

[a] Means are given for those trials where the age range was low (less than 60 days), and approximate ranges are given for those trials where there was a wide variation.

Slaughter procedure and carcass measurements

Animals from all trials were slaughtered and dressed after a fasting period (c. 10.0-17.0 hours) following normal commercial procedures. Carcasses were weighed after being chilled overnight at 1-3^{o}C. The body length (LB) was measured (Moxham & Brownlie, 1976) and the carcasses were then sawn down the backbone and divided into four cuts (Appendix 1: Figure A1.2). A cut between the last and second-to-last lumber vertebrae was made to separate the leg, and the shoulder cut was removed by a cut along the caudal edge of rib 7. The rack and the loin cuts were separated by a cut between ribs 12 and 13.

Several measurements were then taken on the surface of the cut, between ribs 12 and 13, including *M.longissimus* area, muscle width (A), muscle depth (B), and fat depth C (Palsson, 1939) (Appendix 1: Table A1.1 and Figure A1.3). Leg length was measured from the distal edge of the tarsals to the cranial end of the cut pelvic bone.

The right hind leg was frozen for later dissection.

Dissection procedures and measurements

Dissection commenced after thawing the legs for c. 12 hours at room temperature. The right hindquarter was weighed and dissected first into individual cuts, and then into individual muscles, bone, fat and scrap following the procedures of Brown & Williams (1979). Individual muscles weighed were the *M.semimembranosus, M.semitendinosus, M.biceps femoris, M.quadriceps femoris* and *M.adductor*. The femur and tibia bone were weighed and their maximum length recorded (Appendix 1: Figure A1.4).

Calculation of derived indexes

Index of muscularity and muscle to bone ratio was calculated from the weight of five leg muscles (*M.semimembranosus, M.semitendinosus, M.biceps femoris, M.quadriceps femoris* and *M.adductor*) to femur length or weight (MUSC(FL); M:B(FW)).

Muscularity was calculated as the ratio of an index of muscle depth (the square root of the weight of muscle per unit length of an adjacent bone or bones) to the length of the bone or bones (Purchas *et al.*, 1991).

Other indexes of shape calculated (Appendix 2: table A2.1) included:

(1) the ratio of carcass weight (kg) to carcass length cubed (m) (CWT/L^3).
(2) the ratio of eye-muscle depth (B) to width (A) (B:A ratio).
(3) the ratio of eye-muscle area (EMA, cm^2) raised to the power of 1.5 to carcass weight (EMA ratio).

Statistical methods

The four trials were analysed by general-least-squares procedures within the SAS computer programme (SAS Institute Inc. 1987). The significance of differences between breeds, or lines within breeds, or sexes within breed in each trial was assessed by fitting these effects after carcass weight as a covariate and testing for all first-order interactions. Comparisons between least-squares means were made using the "PDIFF" option within the "LSmean" statement in the "GLM" procedure of the SAS programme (SAS Institute Inc., 1987).

RESULTS

Although results for all trials are presented together in Figures 4.1 to 4.6, the comparisons between trials should be made with caution because all animals had not been run together. For this reason the statistical significance of differences between groups in different trials were not estimated except in the case of the males in Trials 3 and 4, which were run under similar conditions.

Treatment effects on the variables of interest in Trials 3 and 4 were found to be non-significant ($P>0.10$) and will not be considered further.

The results of line effects within Trial 1 will not be discussed here as they were discussed in detail in Chapter 3.

Table 4.2 shows basic information for animals of the four trials. The group of Coopworth males from Trial 3 are shown twice in Table 4.2 in order to compare them with both Coopworth females and also Dorset Horn-cross males. Carcass weights were similar for the animals of Trials 1, 2, and 3, but significantly higher for Dorset Horn crosses when compared with Coopworth males. Similar results were found for the leg weight when compared at similar carcass weight, but the Dorset Horn-cross had higher slope than the Coopworth group, which means that the leg percentage values for the Dorset Horn-cross was higher than the Coopworth group and increased with increasing carcass weight.

The fat depth C and the leg fat percentage were significantly higher for the high-backfat line than the low-backfat line in Trial 1, for the Romney breed than the Texel crosses in Trial 2, and for the Coopworth breed than the Dorset Horn crosses, but the female of the Coopworth breed did not differ significantly from the male in Trial 3 when comparisons were made at similar carcass weights. Fat depth C of the high-backfat line and the Coopworth males increased more rapidly with increasing carcass weight than the low-backfat line and the Dorset Horn crosses, respectively.

TABLE 4.2 Least-squares means for carcass weight, leg weight, fat depth C, and leg fat percentage for animals of Trials 1, 2, 3, and 3 + 4, after correction to a constant carcass weight[a], except in the case of carcass weight.

Trial	n	Car. Wt.	Leg Wt.	Fat[b] depth C	Leg[c] fat %
Trial 1					
High-backfat	40	19.1	3012	6.7	24.9
Low-backfat	40	17.9	3008	3.7	22.5
Effect		NS	NS	***	**
Effect on slope		--	NS	***	NS
R^2%		0.1	99	79	66
Trial 2					
Romney	19	23.2	3555	4.1	21.2
Texel-X	27	21.9	3712	2.7	16.6
Effect		NS	NS	*	***
Effect on slope		--	NS	NS	NS
R^2%		0.5	83	34	64
Trial 3					
Female	23	15.0	2233	4.1	--
Male	24	14.1	2256	4.9	--
Effect		NS	NS	NS	--
R^2%		0.2	99	66	--
Trials 3 and 4 (males)					
Coopworth	24	14.1	2611	5.7	--
Dorset Horn-X	34	19.1	2893	1.8	--
Effect		**	***	***	--
Effect on slope		--	**	*	—
R^2%		13	99	70	--

[a] The carcass weight effect was highly significant for all variables.

[b] The number of animals involved was 34 for each of the Southdown lines, 13 for the Romney breed, 19 for the Texel breed, and 38 for the Dorset Horn-X.

[c] The number of animals involved was 7 for the Romney breed, and 10 for the Texel breed.

-- Indicates no data available.

NS=P>0.10; *=P<0.05; **=P<0.01; ***=P<0.001.

Muscularity indexes and M:B ratios

Results in Table 4.3 and in Figures 4.1 and 4.2 show that the Texel-crosses had significantly higher muscularity and M:B ratios than the Romney, and that these differences were associated with higher 5-leg muscle weight, femur weight and femur weight to length ratio for the Texel-cross at the same carcass weight. This represented an increase by 5.2% and 7.0%, respectively, for MUSC(FL) and M:B(FW) in the Texel-crosses. Of these variables, the 5-muscle weight was the only one to show a significantly higher slope for the Texel-X group than the Romney group (Table 4.3). Muscularity and M:B ratios of the Texel-crosses were generally lower than the Southdown groups in Trial 1, but at the same time these ratios were higher in the Texel-crosses than the Coopworth, Romney and Dorset Horn-crosses and increased with increasing carcass weight for all animals in Trials 1, 2, 3 and 4 (Figures 4.1 and 4.2).

In Trial 3 the female Coopworths had slightly higher muscularity indexes by 2.6% ($P<0.10$) and M:B ratios by 6.0% than males, but similar 5-muscle weights and femur weights (Table 4.3). The higher femur weight/length ratio for males ($P<0.10$) explains why the sex effect was greater for M:B than muscularity.

At the same carcass weight, the Coopworth males had higher muscularity values ($P<0.10$) by 1.7%, but lower M:B ratio values by 8.8% ($P<0.001$) than Dorset Horn X Coopworth crosses (Table 4.3, Figures 4.1 and 4.2). In addition the Coopworths had lower 5-leg muscle weights and femur weight than Dorset Horn X Coopworth crosses, while the latter had a lower rate of increase of muscularity and femur weight/length ratio with increasing carcass weight than the Coopworths (Table 4.3).

Table 4.4 presents the regression relationships between muscularity and M:B ratios for all groups of animals studied. Single equations are shown for Trials 1, 2 and 3 because there were no treatment effects on the relationships within these trials. This table together with Figure 4.3 shows that the relationship did differ between Coopworth and Dorset Horn X Coopworth males for both slope ($P<0.001$) and intercept ($P<0.001$), such that at the same muscularity, the Dorset Horn crosses had a higher M:B ratio than the Coopworths.

TABLE 4.3 Least-squares means for muscularity indexes, M:B ratios and associated carcass characteristics for animals of Trials 1, 2, 3, and 3 + 4, after correction to a constant carcass weight[a].

Trial		n	MUSC (FL)	M:B (FW)	5-muscle Wt. (g)	Femur Wt. (g)	Femur (Wt/L)
Trial 1							
	High-backfat	40	0.548	9.8	968	85.8	0.592
	Low-backfat	40	0.514	8.9	996	99.0	0.646
	Effect		***	***	NS	***	**
	Effect on slope		NS	NS	+	+	NS
	R^2%		76	87	98	88	83
Trial 2							
	Romney	19	0.477	8.4	1259	149	0.839
	Texel-X	27	0.503	9.0	1469	160	0.890
	Effect		***	**	***	**	**
	Effect on slope		NS	NS	**	NS	NS
	R^2%		54	68	97	89	85
Trial 3							
	Female	23	0.475	7.0	824	109	0.700
	Male	24	0.463	6.6	823	112	0.725
	Effect		+	*	NS	NS	+
	R^2%		56	91	98	97	95
Trials 3 and 4 (males)							
	Coopworth	24	0.471	7.11	963	125	0.773
	Dorset Horn-X	34	0.463	7.80	1071	136	0.797
	Effect		+	***	***	***	NS
	Effect on slope		+	NS	NS	NS	**
	R^2%		43	90	97	93	88

[a] The carcass weight effect was highly significant for all variables.
NS=P>0.10; +=P<0.10; *=P<0.05; **=P<0.01; ***=P<0.001.

FIGURE 4.1 Patterns of change in muscularity with increasing carcass weight for animals from Trials 1, 2, 3, and 4. Group means (± SE bars) are shown within weight groups.

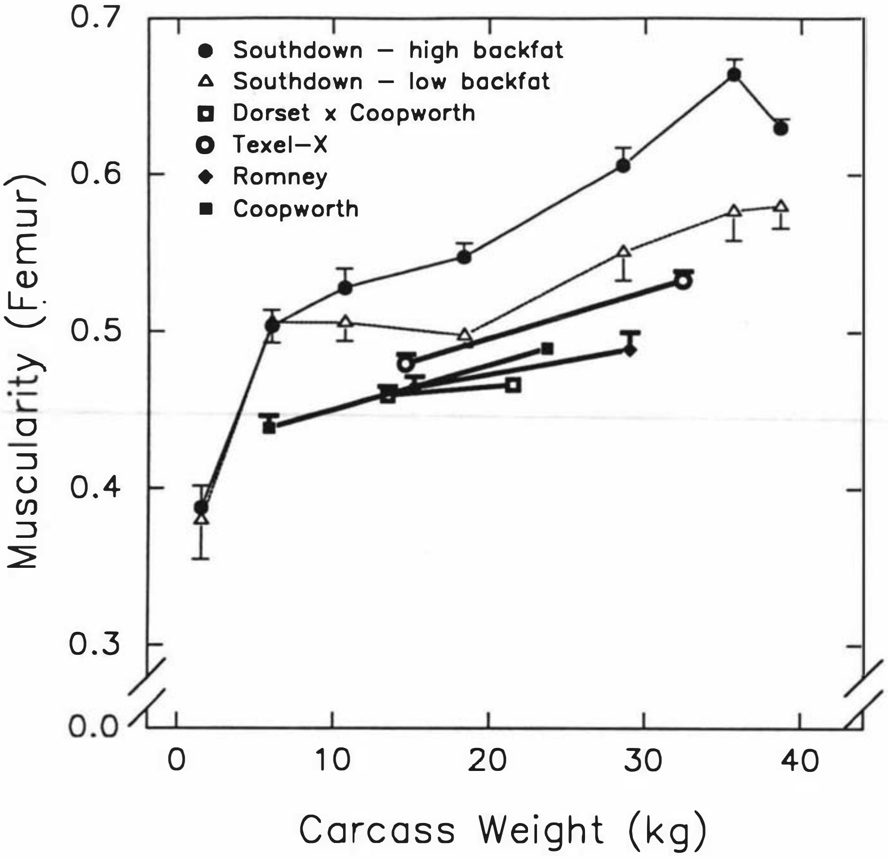


FIGURE 4.2 Patterns of change in M:B ratio with increasing carcass weight for animals from Trials 1, 2, 3, and 4. Group means (± SE bars) are shown within weight groups.

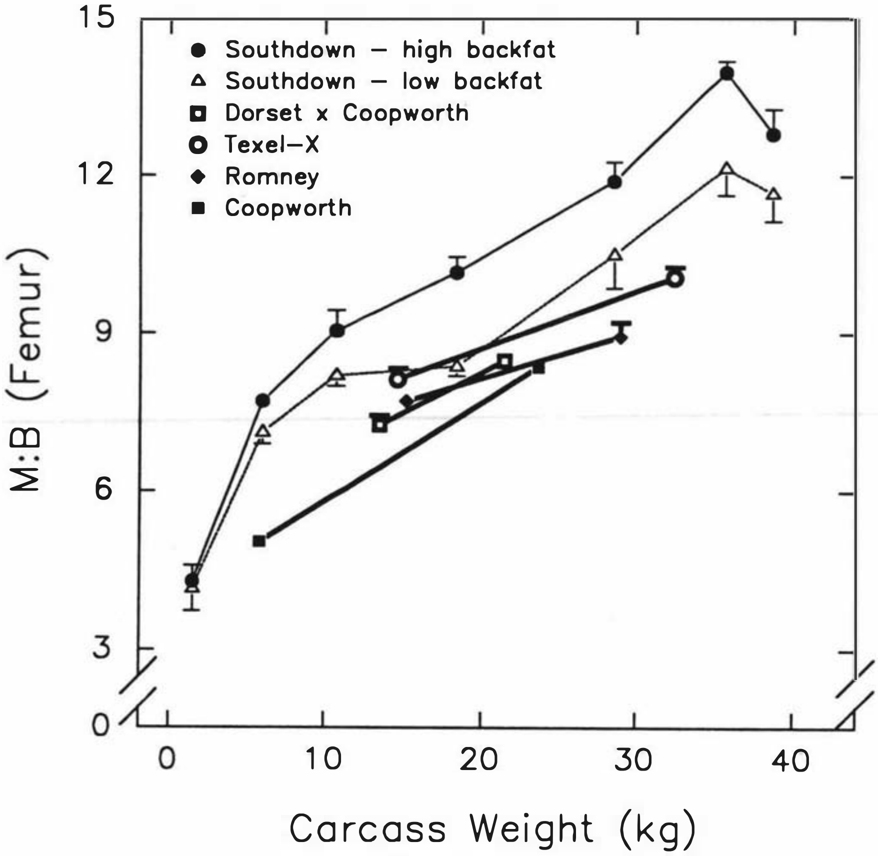
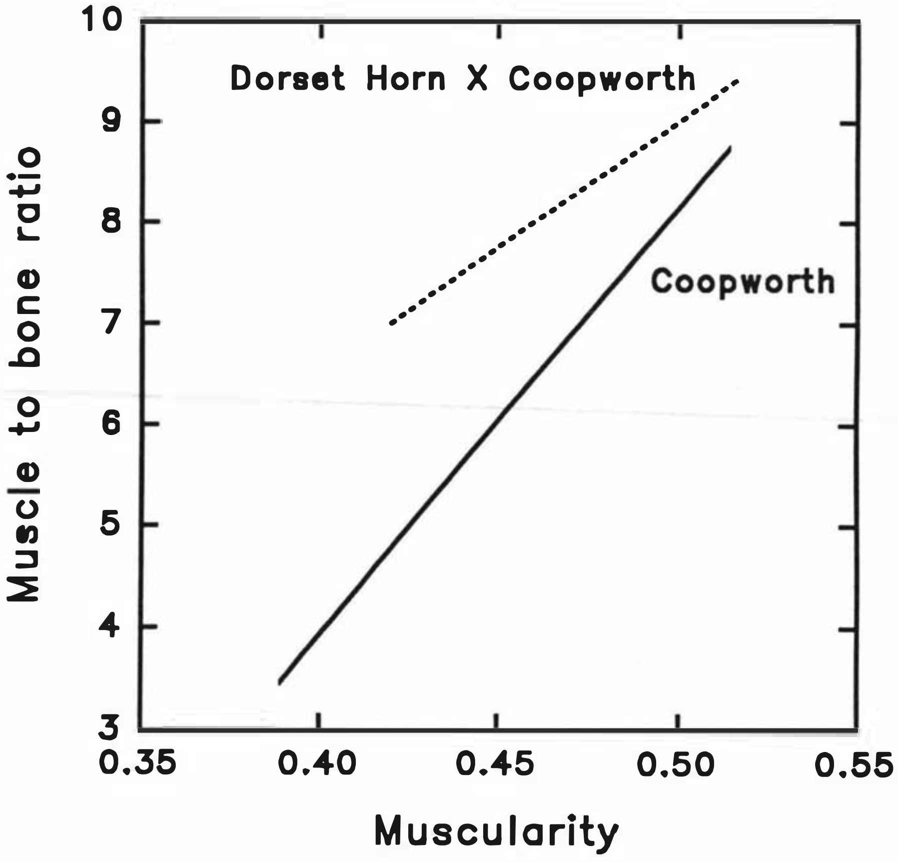


TABLE 4.4 Regression equations relating M:B and muscularity in the femur area for the 4 trials. Group differences within trials were not significant.

Trial	Model	R^2%	RSD
Trial 1	M:B = -8.598 + 33.785(MUSC)	88	1.030
Trial 2	M:B = -4.872 + 27.613(MUSC)	72	0.608
Trial 3	M:B = -13.941 + 44.233(MUSC)	65	0.944
Trial 3 and 4 males[a]		71	0.811
Coopworth	M:B = -12.911 + 42.127(MUSC)		
Dorset Horn-X	M:B = -3.505 + 25.022(MUSC)		

[a] The slope and the intercepts were significantly different (P<0.001) between breeds.

FIGURE 4.3 Linear regression lines relating M:B ratio and muscularity for the Coopworth and Dorset Horn X Coopworth male lambs in Trials 3 and 4, respectively. Measurements were based on the weight of 5-muscles around the femur and femur weight or length.



Eye muscle dimensions and ratios

Data in Table 4.5 shows that the Texel-cross group at the same carcass weight had significantly larger and wider *longissimus* muscles than the Romney breed, but that the muscle depth (B) was similar. The results in Table 4.5 and in Figures 4.4 and 4.5 also show that the Texel-crosses had a significantly higher mean EMA ratio (by 18%), but a similar B:A ratio.

At similar carcass weight the female from the Coopworth breed had higher EMA ratio ($P<0.10$) and similar B:A ratio and *longissimus* muscle dimensions than the male Coopworth breed.

Relative to the male Coopworth, the Dorset Horn X Coopworths showed significantly larger and wider *longissimus* muscles, but a similar mean EMA ratio and a significantly lower B:A ratio.

The ratio of B:A (Figure 4.4) for all groups increased with increasing carcass weight, but the rate of increase differed somewhat between trials. To describe the pattern of this increase, the Southdown lines were the best example to follow as they cover a wide weight and age range. Thus, B:A ratio for both lines increased at an early age and decreased later at around 8 to 20 kg carcass weight and then increased gradually with increasing carcass weight. It should be noted that the B and A measurements were difficult to measure accurately at carcass weights below about 10 kg, which may affect this pattern at early ages. However, Figure 4.4 shows that the high-backfat line from the Southdown breed had the higher ratio followed by the Coopworth breed, the Dorset Horn X Coopworth, the Romney, and finally the Texel-cross.

The EMA ratio decreased with increasing carcass weight for the two lines of the Southdowns, for the Coopworth and for the Dorset Horn X Coopworth breeds, but tended to increase for the Texel and the Romney breeds (Figure 4.5). In the case of Trial 2, which included the Texel crosses and Romneys the effect of carcass weight as a covariate was not significant ($P>0.10$) for EMA ratio. At lower carcass weights the two Southdown lines and the Coopworth group all had higher EMA ratios than the Texel-cross, and the Texel-cross group was the only group to show a higher EMA ratio than the two Southdown lines at heavier carcass weights.

TABLE 4.5 Least-squares means for eye-muscle dimensions and ratios of the *M.longissimus* animals of Trials 1, 2, 3, and 4 after correction to a constant carcass weight[a].

Trial		n	B:A ratio	EMA[b] ratio	EMA[b] (cm^2)	Width (A) (mm)	Depth (B) (mm)
Trial 1							
	High-backfat	40	0.553	3.16	15.1	51.4	29.0
	Low-backfat	40	0.505	2.96	14.7	53.9	27.6
	Effect		***	*	NS	NS	+
	Effect on slope		NS	NS	NS	NS	NS
	R^2%		50	61	90	76	87
Trial 2							
	Romney	13	0.516	2.23	14.8	60.7	31.4
	Texel-X	19	0.491	2.73	16.8	64.7	32.1
	Effect		NS	***	**	**	NS
	Effect on slope		NS	NS	NS	NS	NS
	R^2%		48	34	87	82	79
Trial 3							
	Female	23	0.562	2.46	9.8	48.4	27.3
	Male	24	0.589	2.32	9.6	48.8	26.9
	Effect		NS	+	NS	NS	NS
	R^2%		26	59	94	90	90
Trials 3 and 4 (males)							
	Coopworth	24	0.555	2.25	10.5	50.7	28.3
	Dorset Horn-X	38	0.510	2.22	11.0	55.2	28.1
	Effect		***	NS	*	***	NS
	Effect on slope		NS	NS	NS	NS	NS
	R^2%		29	28	89	89	83

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[a] The carcass weight effect was highly significant for all variables except the EMA ratio from Trial 2.

[b] The number of animals involved was 34 for each line within Trial 1 as measurements were not made at birth.

NS=P>0.10; +=P<0.10; *=P<0.05; **=P<0.01; ***=P<0.001.

FIGURE 4.4 Patterns of change in B:A ratio with increasing carcass weight for animals from Trials 1, 2, 3, and 4. Group means (± SE bars) are shown within weight groups.

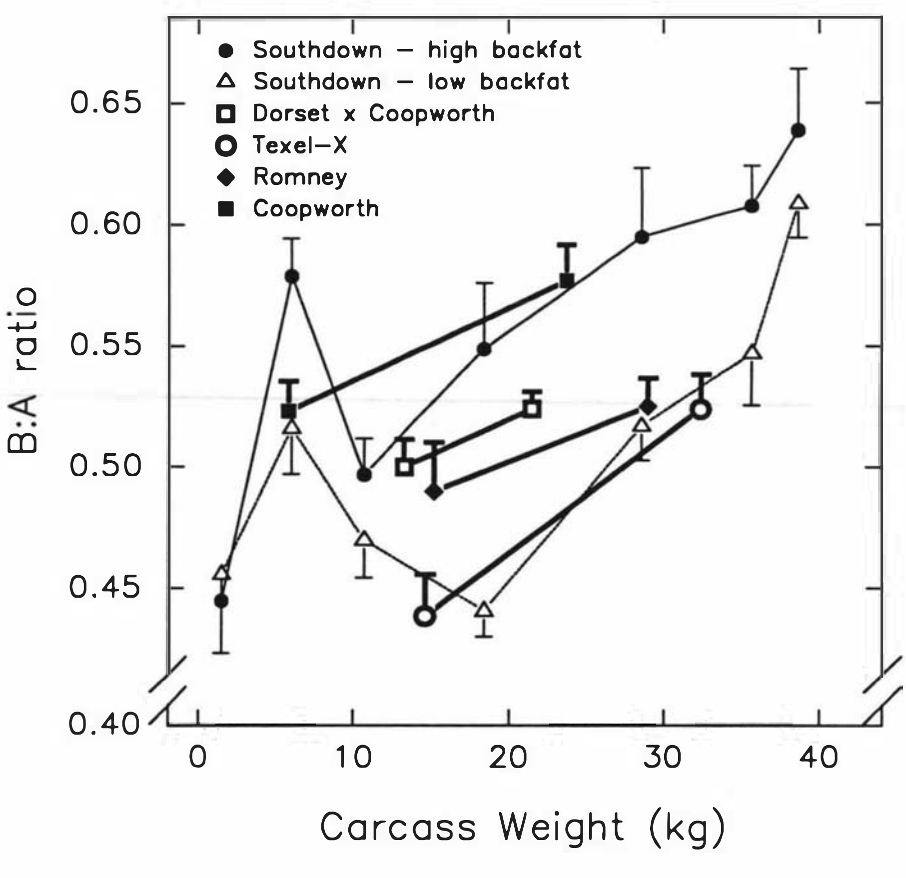
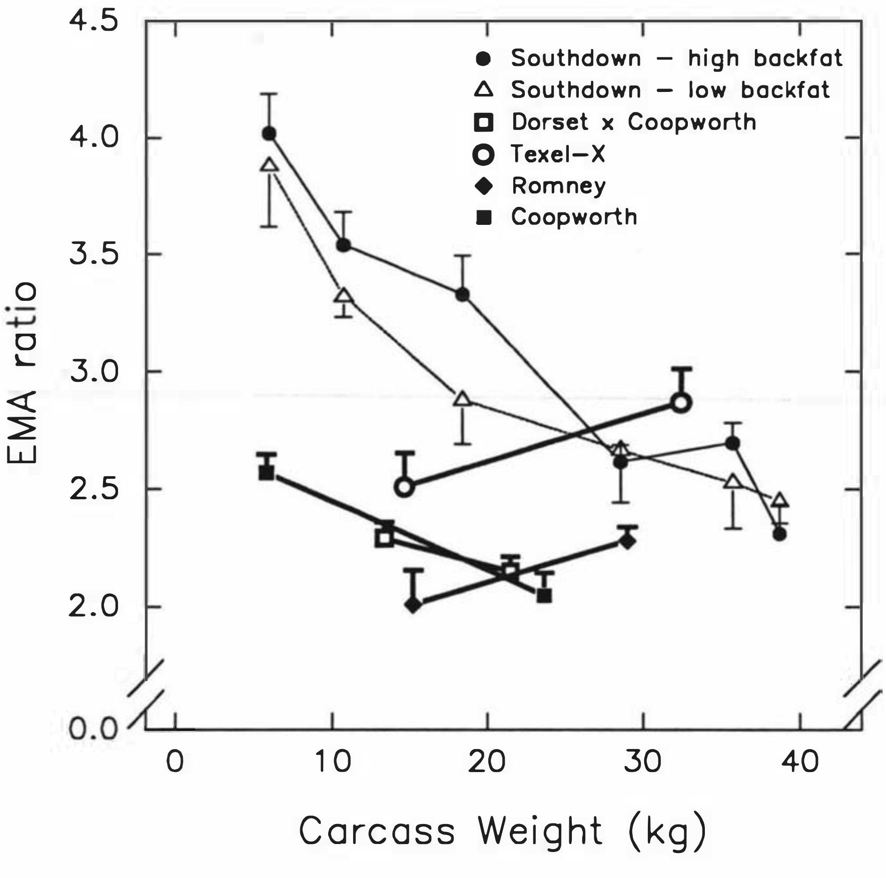


FIGURE 4.5 Patterns of change in EMA ratio ($EMA^{1.5}$/Carcass weight) with increasing carcass weight for animals from Trials 1, 2, 3, and 4. Group means (± SE bars) are shown within weight groups.



Carcass linear dimensions measurements and ratios

Texel-cross group had a similar weight-adjusted femur length to that of the Romney breed (Table 4.6), but data for carcass length and therefore CWT:L^3 were not available for this trial.

At similar carcass weights the Coopworth females had similar CWT:L^3 and similar carcass, leg and femur lengths to the Coopworth males. However, CWT:L^3 increased with increasing carcass weight at a greater rate for the male than the female (Table 4.6).

Coopworth males had significantly shorter femurs and carcasses, but significantly higher values for the CWT:L^3 ratio than Dorset Horn X Coopworth males (Table 4.6 and Figure 4.6). In addition CWT:L^3 increased with increasing carcass weight at a greater rate for the former group (Table 4.6 and Figure 4.6).

The CWT:L^3 ratio generally increased with increasing carcass weight for all groups except the Dorset Horn crosses (Figure 4.6) with Coopworth values between those for the two Southdown lines and the values for the Dorset Horn crosses being lower than for the Coopworth and similar to the low-backfat Southdowns.

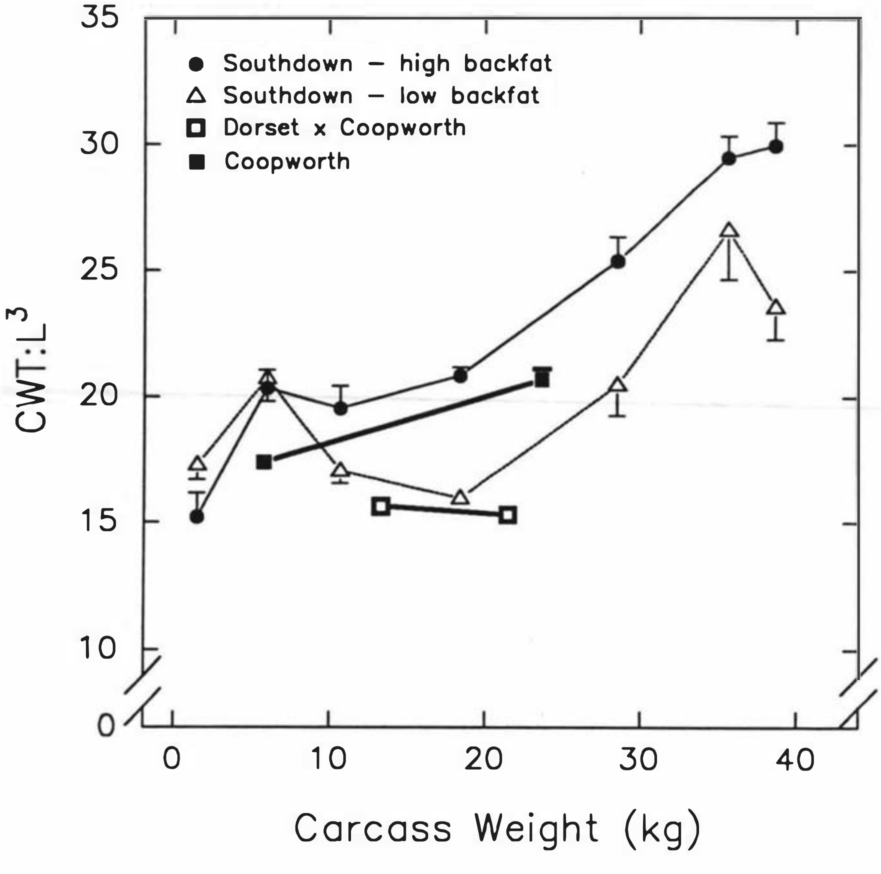
For both Southdown groups the CWT:L^3 ratio was higher in the second weight group at a carcass weight of about 6 kg than for the groups that preceded or followed it. This was similar to the pattern shown for B:A ratio in Figure 4.4.

TABLE 4.6 Least-squares means for carcass linear dimensions and ratios for animals of Trials 1, 2, 3, and 4 after correction to a constant carcass weight[a].

Trial	n	CWT/L^{3}[b]	Carcass[b] length (mm)	Leg length (mm)	Femur length (mm)
Trial 1					
High-backfat	40	22.4	852	297	135
Low-backfat	40	20.2	902	308	144
Effect		***	*	NS	**
Effect on slope		*	NS	NS	NS
R^2%		72	83	71	79
Trial 2					
Romney	19	--	--	--	175
Texel-X	27	--	--	--	177
Effect		--	--	--	NS
Effect on slope		--	--	--	NS
R^2%		--	--	--	85
Trial 3					
Female	23	19.2	862	318	146
Male	24	19.0	867	325	148
Effect		NS	NS	NS	NS
Effect on slope		*	NS	NS	NS
R^2%		63	98	96	97
Trials 3 and 4 (males)					
Coopworth	24	19.5	909	--	156
Dorset Horn-X	34	15.5	1023	--	170
Effect		***	***	--	***
Effect on slope		***	NS	--	+
R^2%		73	97	--	96

[a] The carcass weight effect was highly significant for all variables.
[b] The number of animals involved was 38 for the Dorset Horn-X group in Trial 4.
-- Indicates no data available.
NS=$P>0.10$; *=$P<0.05$; **=$P<0.01$; ***=$P<0.001$.

FIGURE 4.6 Patterns of change in the CWT:L^3 ratio with increasing carcass weight for animals from Trials 1, 2, 3, and 4. Group means (± SE bars) are shown within weight groups.



DISCUSSION

Data from the high- and low-backfat lines of Southdowns have been included in this chapter as a basic pattern against which the other groups could be compared. The line effects and patterns of change for those groups have been discussed in Chapter 3 and will not considered again.

Results concerning muscularity and M:B ratios are discussed first and then other potential indices of muscularity including eye-muscle area and dimensions, and length-adjusted weight are considered. Within each section, the discussion of breed effects is followed by a consideration of patterns of change with growth, and finally differences between sexes are discussed.

In choosing ratios, care was taken to ensure that dimensions of the numerator and denominator were comparable (Young & Sykes, 1987). Thus, in adjusting EMA for weight, the measurement of area was raised to the power of 1.5 to convert it from an area measurement to the equivalent of weight, thereby making the ratio of this to carcass weight dimensionless. Similarly, in relating carcass weight to length, the length was cubed (CWT:L^3).

Breed and sex differences in muscularity and M:B ratios.

The higher muscularity values and M:B ratios based on muscles around the femur, heavier muscles, and lower total leg fat percentage for the Texel-cross over the Romney breed shown in Tables 4.2 and 4.3 are consistent with the previous results of Ward *et al.* (1992) and with the results of several other studies showing the Texel to excel in these characteristics (More O'Ferrall & Timon, 1977; Wolf *et al.*, 1980; Butler-Hogg & Whelehan, 1984; Kempster *et al.*, 1987; Clarke & Kirton, 1990; Holloway *et al.*, 1994), although these studies have not all involved comparisons between the Texel and Romney breeds. Ward *et al.* (1992) showed that Texel-cross rams had at the same carcass weight significantly higher leg muscularity and M:B ratios than Oxford-cross rams. Holloway *et al.* (1994) reported that Awassi-cross lambs had longer carcasses, longer legs, longer and heavier leg bones, lower leg muscle to bone ratios (3.49 vs 3.88), and lower leg muscularity values based on five muscles around the femur (0.440 vs 0.481) than Texel-cross lambs at a constant carcass weight. More O'Ferrall & Timon (1977) found that Texel-cross lambs had a higher carcass lean to bone ratio than the Suffolk, Dorset Horn, Hampshire, Oxford Down, Lincoln, Ile-de-France, and Dorset Down cross lambs at 36 and 45 kg liveweight.

The trend towards an increased M:B ratio of the carcasses from Southdown breed rams compared with those of the other four breeds are therefore consistent with the findings of other studies that have compared the Southdown breed with breeds both similar and different to those used in the present study. The Southdown breed was shown by Fourie *et al.* (1970) to have higher M:B ratios than the Romney or Southdown X Romney cross at comparable carcass weights. Fahmy *et al.* (1972) reported that lambs born to crossbred ewes by Southdown or Suffolk rams had higher M:B ratios than the Suffolk crosses at similar carcass weights. Similar findings were reported by Kempster *et al.* (1976) for 424 lambs comprising seven breed-type groups (Welsh Mountain, Blackface, Longwool, Suffolk crosses, Intermediate, Southdown crosses and Longwool crosses). McClelland *et al.* (1976) compared a range of contrasting breed types (Soay, Finnish Landrace, Southdown and Oxford) which were serially slaughtered at 40%, 50%, 60% and 70% of their estimated mature weight and found that the Southdown breed had higher M:B ratios than the Soay, Finnish Landrace, and Oxford breed at the same degree of maturity (3.85 vs 2.54, 3.29 and 3.09, respectively).

The results from the MLC's Ram Breed Evaluation Project reported by Kempster *et al.* (1983), which compared 10 sires breeds (Border Leicester, Dorset Down, Hampshire Down, Ile-de-France, North Country Cheviot, Oxford Down, Southdown, Suffolk, Texel and Wensleydale) showed Texel crosses to have higher carcass M:B ratios than other sire breed crosses including the Southdown in both early- and late-maturing flocks. Oxford Down crosses had a lower M:B ratio than all other meat breeds in both types of flock, although they did not differ significantly from some of the other breeds in this respect. However, the Southdown breed was ranked second after the Texel breed and each of the Dorset Down and Suffolk breeds were ranked third and fourth respectively. Similar findings were reported by Kempster *et al.* (1987) and by Croston *et al.* (1987). More O'Ferrall & Timon (1977) also demonstrated that the Texel breed had higher M:B ratios than all other breeds including the Dorset Horn breed when compared at a similar liveweight.

The higher M:B ratio of male Dorset Horn-cross lambs relative to Coopworth lambs (Table 4.3) is in keeping with other studies showing that Dorset Horn or Poll Dorset crosses had higher M:B ratios than non-meat breeds (More O'Ferral & Timon, 1977; Geenty *et al.*, 1979; and Holloway *et al.*, 1994). More O'Ferrall & Timon (1977) compared the M:B ratio of eight sire breeds and demonstrated that Dorset Horns were similar to Texels and Dorset Downs and better than all other sire breeds. In the present study the muscularity was slightly lower for the Dorset Horn-cross, in contrast to the higher M:B for that group. This appears to be because the femur length and weight were lower for the Coopworth group at the same carcass weight, but the length difference was proportionately greater. This provides further evidence that these characteristics should be treated separately because the muscularity is based on linear dimensions, while M:B is a ratio of weights (Purchas *et al.*, 1991). Holloway *et al.* (1994) reported a similar pattern with lambs from Poll Dorset dams having a higher leg M:B ratio, but similar muscularity values to lambs from Romney dams. They attributed this difference to the fact that the femur bones were heavier but of similar length for the latter breed.

In comparing the results of Trial 3 and 4, care was taken to insure similarity in the measurements. However, the results should be treated with caution because the two groups of lambs were run separately and differed significantly in fatness which may indicate that they were at a different level of maturity. In addition the Coopworths were rams while the Dorset Horn crosses were cryptorchids, but published studies on this topic have shown that measures of fatness, M:B ratio and *M.longissimus* area do not usually differ significantly between the two groups (Wilson *et al.* 1970, Corbett *et al.* 1973, Probert & Davies, 1986, Hopkins *et al.* 1991). Thus the differences shown are most likely to be due to breed. Although the effects of breed and of ram vs cryptorchid are confounded in the fourth comparison this is not particularly important here as the value of the comparison for the present study is that it demonstrates how the relationship between M:B and muscularity of the leg can differ significantly between groups.

Purchas *et al.* (1991) provided evidence of a breed effect on the relationship between muscularity and M:B ratio in sheep when they showed from the data of Wood *et al.* (1980) that the Hampshire breed had a slightly lower M:B ratio but a higher muscularity than the Suffolk.

The difference between Dorset Horn cross cryptorchids and Coopworth rams in the relationship between M:B and muscularity was further illustrated by the significantly different regression lines between these characteristics. At the same muscularity, the Dorset Horn crosses had higher M:B ratios than the Coopworths. Further evidence of variability in the relationship between muscularity and M:B ratio has been reviewed in Chapter 2, Section 2.3.3.2.

Consistent increases in muscle to bone ratio and muscularity with increasing liveweight for all groups in this study are consistent with the results of Campion *et al.* (1976), Sents *et al.* (1982), and Purchas *et al.* (1991) and with other work that has been reviewed in Chapter 2 (Table 2.2). Butler-Hogg & Whelehan (1984) found that the M:B ratio at constant subcutaneous fat percentage increased with age, and was greater in both older rams and in the Texel than the Scottish Blackface rams (M:B ratio was 3.1 and 3.0 for the Texel and Scottish Blackface respectively at 6 months old and 4.8 and 3.8 at 30 months old).

Reports in the literature generally indicate that the M:B ratio is highest for ewes, lowest for wethers and intermediate for rams (Fourie *et al.*, 1970; Ahmad & Davies, 1986). The higher leg M:B ratio and muscularity values for the ewe lambs relative to the ram lambs in Trial 3 supports evidence in the literature involving total carcass M:B for a number of breeds and carcasses (Wood *et al.*, 1980; Theriez *et al.*, 1982; Butler-Hogg *et al.*, 1984; Thorgeirsson & Thorsteinsson, 1989; and Purchas *et al.*, 1991). However, the similar results in fatness between the male and the female in Trial 3 differs from most results in the literature (Section 2.3.4.2), which usually shows that rams contained on average less fat than wethers or ewes of similar liveweight or carcass weight.

Fourie *et al.* (1970) showed that the female of Southdown, Romney, and Southdown X Romney groups had higher carcass M:B ratios at 5, 10, 20, and 30 kg carcass weight by 1.05, 0.33, 0.57, and 0.66, respectively than males. Similarly female Icelandic lambs at birth, 20 to 24 weeks, and 74 weeks of age showed increases of -0.2, 0.1, and 0.5 for carcass muscle/bone ratios relative to male lambs (Thorgeirsson & Thorsteinsson, 1989), although this difference was significant only at 74 weeks. Wood *et al.* (1980) showed that females of four breeds had significantly higher carcass lean/bone ratios (4.56 vs 4.47) than male lambs. Purchas *et al.* (1991) calculated the M:B ratio and muscularity from the sheep data of Wood *et al.* (1980) using the weight of muscle in the prime cuts and the femur bone weight and length and showed that the female lambs had higher M:B ratio (47.68 vs 45.95) and muscularity (1.145 vs 1.139) than the male lambs, but that the proportionate difference was greater for M:B than muscularity as was the case in the current study (Table 4.3).

Breed and sex differences in eye muscle and carcass linear dimensions and ratios

The cross-section area and dimensions of *M.longissimus* and various combination of ratios from these measurements have been widely used as indicators of muscularity (reviewed in Chapter 2).

The greater area and dimensions of *M.longissimus* for carcasses from Texel-crosses than Romneys at a similar carcass weight are consistent with the results of other studies comparing the Texel with Romney and Texel with other breeds (More O'Ferral & Timon, 1977; Wolf *et al.*, 1980; Butler-Hogg & Whelehan, 1984; Kempster *et al.*, 1987; Clarke *et al.*, 1988; Ward *et al.*, 1992; and Holloway *et al.*, 1994). Ward *et al.* (1992) reported that the Texel-cross lambs had larger area and depth (B) than the Oxford-cross lambs when measured directly from the carcass, and by ultrasonic measurements and compared at similar carcass weight. At the same estimated carcass subcutaneous fat proportion, Kempster *et al.* (1987) reported that Texel-cross lambs had a higher *M.longissimus* width (A) and depth (B) than nine other sire crosses (Border Leicester, Dorset Down, Hampshire Down, Ile-de-France, North Country Cheviot, Oxford Down, Southdown, Suffolk, and Wensleydale). Clarke *et al.* (1988) found significant breed differences in eye muscle dimensions (A, B, and AxB) with the Texel highest, the Oxford and Suffolk crosses intermediate and the Finn and Border crosses lowest.

The Texel-cross animals when compared with Romneys at similar carcass weight had a higher EMA ratio, but a lower B:A ratio ($P>0.10$). This indicates that the superior muscularity of the Texel-cross was associated with a proportionately greater increase in A than B. Thus higher B:A values do not necessarily indicate better muscularity.

Kempster *et al.* (1987) compared 10 sire breeds (Border Leicester, Dorset Down, Hampshire Down, Ile-de-France, North Country Cheviot, Oxford Down, Southdown, Suffolk, Texel and Wensleydale) and showed that the Texel breed had wider and deeper (A and B) *M.longissimus* than the Southdown and Suffolk breed, but the B:A ratio was lower than the Southdown breed and higher than the Suffolk breed. The calculated values for the B:A ratio were 0.488, 0.470, and 0.466 for the Southdown, Texel, and Suffolk breeds, respectively. Similar results for the Texel breed were found by Clarke *et al.* (1988) when compared the Texel breed with four other breeds at constant carcass weight. Also, the calculated values for the B:A ratio were 0.513, 0.493, 0.488, 0.478 and 0.464 for the Border Leicester, Suffolk, Oxford Down, Texel and Finn, respectively.

The finding that Dorset Horn crosses had larger *M.longissimus* areas and wider muscles (A) than the Coopworth lambs at a similar carcass weight supports previous findings (More O'Ferrall & Timon, 1977; Geenty *et al.*, 1979; Kirton *et al.*, 1982; and Holloway *et al.*, 1994) in showing the Dorset Horn or Poll Dorset breeds to be superior meat breeds. Kirton *et al.* (1982) examined the carcass composition of wether lambs and hoggets of different breeds and crosses including Romney, Merino X Romney, Drysdale X Romney, Drysdale, Cheviot, Coopworth, Perendale, and Poll Dorset X Romney and found that the Coopworth breed had the smallest eye-muscle area measurements when compared at the same carcass weight within a season. The Romney and Drysdale breeds had slightly larger areas and the Cheviot, Merino X Romney and Dorset X Romney wethers had the largest. Similar results were found by Geenty *et al.* (1979) with eye-muscle area, depth (B) and width (A) significantly higher for the Poll Dorset breed than for Romneys or Corriedales.

The B:A ratio, the EMA ratio, and the ratio of carcass weight to length cubed (CWT:L^3) were tested in the present study as an indicators of muscle thickness, carcass blockiness and carcass muscularity. These were evaluated in Chapter 3 within the Southdown breed and gave an indication that these ratios were associated with fatter, better muscled, and shorter carcasses. This conclusion was generally in keeping with results obtained in the present study, with higher muscularity, EMA ratios, and CWT:L^3 for the high-backfat line in Trial 1, the Texel-crosses in Trial 2 and the Coopworth males relative to the Dorset Horn-cross males being associated with shorter carcasses, greater fat depths, and higher muscularity measurements. The difference in B:A was not so clear cut as the superior muscularity of the high-backfat line in Trial 1 and the Coopworth males relative to the Dorset Horn-cross were associated with significantly higher B:A ratio, but the Texel-cross, when compared with the Romney group in Trial 2, had lower B:A ratio ($P<0.10$), although it also had higher muscularity. Coop & Clark (1957) reported that Southdown lambs had at a similar age deeper, more round cross-sections of muscle, and superior conformation compared with Dorset Down and Suffolk lambs which both had similar conformation. The B:A ratio calculated from their results showed higher values for the Southdown lambs (0.586) followed by the Suffolk lambs (0.523) and the Dorset Down lambs (0.516). Wood & Macfie (1980) showed a significant breed difference in *M.longissimus* A and B measurements, with the ranking of breeds (from higher to lower) for A measurements being Suffolk, Colbred, Hampshire, and Clun, for B measurements being Hampshire, Suffolk, Clun, and Colbred. The conformation of these breeds which was reflected in the shape of the eye-muscle was shown to be higher in the ram breeds (Hampshires and Suffolks) than the ewe breed (Colbreds and Cluns) in term of the eye-muscle depth (B) and eye-muscle area (defined as A X B at the mean carcass weight of 18 kg). However, the calculated B:A ratios for the Hampshire, Clun, Suffolk, and Colbred which were 0.537, 0.508, 0.504, and 0.478, respectively, is another example showing that the B:A ratios do not show consistent results.

The pattern of growth for both B:A ratios and carcass weight to length (CWT:L^3) (Figures 4.4 and 4.6) were similar, with both increasing with increasing carcass weight. Also, the fatter breeds or lines were shown to have higher values at all carcass weights. Thus, Figure 4.6 confirms the previous finding that the ratio of carcass weight per unit length can be affected by fat weight in the carcass.

Butler-Hogg & Whelehan (1984) showed that the dimensions of *M.longissimus* (A and B) and the calculated B:A ratio increased significantly with increasing age for both Texel and Scottish Blackface rams when compared at constant subcutaneous fat percentage. The calculated B:A ratio was 0.383 and 0.460 for the Texel and Scottish Blackfaced rams at 6 months and 0.520 and 0.619 at 30 months. The M:B ratio also increased with age, but was higher within both age for the Texel breed than the Scottish Blackface. Similar results were reported by Palsson (1939) for the differences between different Scottish breeds and crosses in meat quality. The measurements of depth (B) and width (A) of the *M.longissimus* increased with increasing carcass weight, but the depth (B) increased at a faster rate than A. The B:A ratio also increased in lambs with increasing weight, but at a similar carcass weight this ratio was highest in the Southdown crosses, the Cheviot and the Blackface X Blackface (0.53, 0.54, 0.52, respectively), and lowest in the Uruguay, Oxford X Blackface-Cheviot, Blackface X Cheviot and Iceland breeds (0.41, 0.44, 0.44, and 0.44, respectively).

A possible explanation for the contrasting patterns of change in EMA ratio with increasing carcass weight (Figure 4.5), with increases for Texel crosses and Romneys and decreases for the other groups, is that breeds differ in the fat component of carcass weight. Thus while for the Southdown, EMA ratio declines with increasing carcass weight, fat does not affect the relationships to the same extent for the Texel.

Leymaster & Jenkins (1993) studied differences in carcass composition between Texels and Suffolks at slaughter ages of 63, 105, 147, and 189 days. The area of *M.longissimus* increased with increasing age, but the effect of sire breed on muscle area was not significant at constant age or constant carcass weight. Young (1990) found from a growth study on data of 48 female sheep slaughtered in groups (n=6) from 10 kg to 45 kg, that muscularity increased with growth. This was indicated by the growth of *M.longissimus* depth relative to width which had an allometric growth coefficient (b) equal to 1.55.

Few reports of differences between male and female sheep or lambs in eye-muscle area and dimensions were found in the literature, and the results from the present study did not show any significant differences. These results agree with those of Barton & Purchas (1974); More O'Ferrall & Timon (1977) and Purchas (1978) in showing that the eye-muscle depth (B) and area did not differ between sexes.

SUMMARY AND CONCLUSIONS

1. Carcasses from 3 trials were evaluated and the results compared with those from the Southdown growth trial (Chapter 3). This study investigated differences between breed and sex groups of sheep in the pattern of change in muscularity with increasing carcass weight. An index of muscularity was calculated from the weight of five leg muscles and femur length (MUSC(FL)).

2. For all groups MUSC(FL) increased with increasing carcass weight, and the rate of increase was similar between groups at carcass weights above 10 kg.

3. Texel-cross ram carcasses had significantly higher muscularity than Romney ram carcasses at similar carcass weights ($P<0.001$), but mean MUSC(FL) values for both groups were lower than for either Southdown line.

4. Within the Coopworth breed there was an advantage of females over males for muscularity at a similar carcass weight ($P<0.10$), but values for both sexes were lower than for the Southdown lines or the Texel crosses.

5. At the same carcass weight, Coopworth rams had slightly higher muscularity values (+1.7%; $P<0.10$) than Dorset Horn-cross cryptorchids. Differences in M:B in the femur region generally paralleled differences in MUSC(FL) except that Coopworth rams had values that were 8.8% less than Dorset Horn-cross cryptorchids ($P<0.001$). Also the superiority of female Coopworths over males was larger for M:B (5.7% vs 2.5% for MUSC(FL)). These results provide further confirmation that these two characteristics may change independently.

6. Other indirect measures of muscularity based on carcass length and measurements on a ***M.longissimus*** cross section did not consistently reflect differences in MUSC(FL), suggesting that their value may be limited.

CHAPTER FIVE

RELATIONSHIPS BETWEEN OBJECTIVE AND SUBJECTIVE MEASUREMENTS OF CARCASS MUSCULARITY

INTRODUCTION

Carcass muscularity was defined by DeBoer *et al.* (1974) as the thickness of muscle relative to skeletal dimensions, and conformation as the thickness of muscle and fat relative to skeletal dimensions. However, despite the existence of such clear definitions, objective measurements of muscularity have not been widely reported because of difficulties in measuring average muscle depth. Most information in this area is in terms of subjective scores (Colomer-Rocher *et al.,* 1980; Kempster *et al.,* 1981; Kirton *et al.,* 1983).

In previous studies, subjective muscularity and conformation scores have been evaluated on the basis of their relationships with various objective carcass measurements. Some workers have reported that cattle carcasses with better conformation have higher meat yields and greater muscle content (Martin *et al.,* 1966; Kempster & Harrington, 1980; Colomer-Rocher *et al.,* 1980) particularly when differences in fatness have been small or have been adjusted for statistically. Also, at the same carcass weight and fatness, carcasses with better conformation have been reported to have higher muscle to bone ratios (Cuthbertson *et al.,* 1972; Kempster, 1978), shorter hindquarters (Colomer-Rocher *et al.,* 1980) and greater *M.longissimus* depths (Kempster *et al.,* 1981, Kirton *et al.,* 1983).

Anous (1989) stated that muscle to bone ratio (M:B) offered an index of carcass muscling, but it may be unreliable because, although a high M:B is often associated with superior muscularity (Young & Sykes, 1987; Dumont & Pouliquen, 1988), this will not necessarily be the case. Theoretically, a higher M:B ratio can be due to a lower bone weight per unit length rather than heavier muscles so that measures of muscularity as defined above may not differ even when quite large differences in M:B exist. Fisher & Bayntun (1981), for example, found that the ranking of four sheep breeds was different for conformation score (weight of lean per unit bone length) than M:B. They concluded that differences in bone shape rather than bone density were responsible, with some breeds having thinner bones than others. Young (1989) also showed in sheep that differences in bone weight per unit length were due to differences in bone shape rather than density.

In order to facilitate the study of muscularity, Purchas *et al.* (1991) proposed an objective muscularity index based on a measure of muscle depth relative to a skeletal dimension. In this study relationships between subjective scores of conformation or muscularity and objective indexes were investigated.

MATERIAL AND METHODS

Animals and carcass measurements

Data for this study came from two AgResearch-Ruakura experiments with lambs (data sets 1 and 2), and an experiment with bulls from Massey University (data set 3).

Data set 1 included information on the 26 carcasses described by Kirton *et al.* (1983). Carcasses of unknown origin were selected by supervising graders of the New Zealand Meat Producers Board to represent three levels of muscling (well muscled, average muscled, and poorly muscled). Later, the authors assessed the carcasses for conformation on a 6-point British Meat and Livestock Commission (MLC) conformation scale (E, Av+, Av, Av-, C, and Z, where E is blockiest and Z is leggiest; Cuthbertson & Harrington, 1976). Carcass evaluation procedures in terms of linear measurements and physical dissection were described by Kirton *et al.* (1983) except that additional muscle weights and bone weights and lengths were taken.

Data set 2 included information on carcasses of 69 1981-born lambs that were processed at the Ruakura abattoir in January and April 1982 according to standard Ruakura procedures (Kirton & Pickering, 1967). The four breed and breed crosses involved were Perendale, Romney, Coopworth and Southdown X Romney. Assessments of MLC conformation on a 6-point scale were conducted as for data set 1. Linear measurements and all other carcass evaluation procedures including physical dissection were carried out according to standard Ruakura procedures (Kirton & Pickering, 1967; Kirton *et al.*, 1983) with some additional bone and muscle measurements being taken.

Data set 3 contained information from 90 bull carcasses including the weight and length of one femur bone and the weights of the three main commercial cuts from around the femur (knuckle, inside, and outside)(NZMPB, 1991) from both sides (Purchas *et al.*, 1992). The bulls included 30 each of Friesian, Piedmontese X Friesian, and Belgian Blue X Friesian. Carcass conformation was assessed using the 5-point MLC scale (Kempster *et al.*, 1982) by a supervising grader of the New Zealand Meat Producers Board.

Calculation of derived indexes

Indexes chosen as potential objective measures of muscularity were those that measured differential growth and that would not change if growth involved no changes in the proportions of body parts (i.e., isometric growth).

Muscularity as described by Purchas *et al.* 1991 was calculated as the ratio of an index of muscle depth (the square root of the weight of muscle per unit length of an adjacent bone or bones) to the length of bone or bones. This ratio and muscle to bone ratio (Appendix 2: Table A2.1), respectively, were calculated from either:

(1) the weight of four leg muscles *(semimembranosus, semitendinosus, biceps femoris, and quadriceps femoris)* to femur length or weight (MUSC(FL); M:B(FW)).

(2) the total muscle weight in the side to carcass length (in lamb as defined by Moxham & Brownlie, 1976) or total bone weight (MUSC(LB); M:B(TBWT)).

(3) the weight of three leg cuts (inside, knuckle, and outside) to femur length or weight (MUSC(CFL); M:B(CFW)).

Other indexes of shape calculated (Appendix 2: Table A2.1) included:

(1) the ratio of eye muscle depth (B) to width (A) (B:A ratio) as an index of muscle depth,
(2) the ratio of eye-muscle area (EMA, cm^2) raised to the power of 1.5 and carcass weight (EMA ratio),
(3) the ratio of carcass weight (kg) to carcass length (in lamb as defined by Moxham & Brownlie, 1976; in beef as defined by Purchas *et al.,* 1992) cubed (m) (CWT/L^3).

Statistical methods

The three data sets were analysed by general-least-squares procedures within the SAS computer programme (SAS Institute Inc., 1987). General-least-squares models were used with conformation class as a discrete design variable and objective measures as dependent variables. Covariates were not included for the indexes described above but side weight was included as a covariate for some other variables as indicated below. Multiple comparisons between means were made using the "PDIFF" option within the "LSmean" statement in the "GLM" procedure of the SAS programme (SAS Institute Inc., 1987).

RESULTS

Results for data sets 1 and 2 (Tables 5.1,5.2, and 5.3) are presented as two parts within each table. The first part of each table include mainly ratios that are measures of differential growth, while the second part of each table includes characteristics that will change with both absolute and differential growth. The measures of absolute growth have been adjusted to a constant weight, but the measures of differential growth have not been because this may have removed some of the variation associated with differences in the subjective conformation or muscularity scores. The same procedures have been used for data set 3 (Table 5.4), but no measures of absolute growth are shown except for carcass weight.

Characteristics indicating differential growth.

Results in Tables 5.1 to 5.4 and Figures 5.2 and 5.3 show that for data sets 1,2, and 3 the better muscling and conformation classes had significantly higher mean muscularity indexes, M:B ratios, EMA ratios, B:A ratios, and CWT:L^3 ratios.

For data set 1 (Table 5.1) muscling class accounted for variation ranging from a high of 75% for MUSC(FL) to 40% for EMA ratio. Thus, the ranking of the variables as predictors of muscling class based on R^2 values was: MUSC(FL)> CWT:L^3 ratio> MUSC(LB)> M:B(TBWT)> B:A ratio> EMA ratio. Similar patterns were found when the carcasses were assessed according to the five MLC conformation classes (Table 5.2). In this case the ranking from best to worst predictor was MUSC(FL)> CWT:L^3> MUSC(LB)> M:B(TBWT)> EMA ratio> B:A ratio.

Relationships between subjective scores and objective muscling indexes for data set 2 (Table 5.3 and Figure 5.2) showed that MLC conformation class generally explained less variation than for data set 1 (Tables 5.1 and 5.2). R^2(%) values for MUSC(FL) and M:B(FW) were 69% and 62% respectively, so that the ranking of predictors in terms of R^2 was similar with MUSC(FL)> M:B(FW)> MUSC(LB)> CWT:L^3 ratio> M:B(TBWT)> EMA ratio> B:A ratio.

Results for bull carcasses (Table 5.4) showed that a move from the best conformation [E] class to the poorest conformation [O] class was accompanied by decreases in means for carcass weight, six-cut yield, dressing-out percentage and in CWT:L^3 ratio. Relationships of subjective scores with indexes of muscling were generally lower than those for lamb carcasses. R^2(%) values for MUSC(CFL) and M:B(CFW) were 56% and 52% respectively, so that the ranking of indexes was similar in terms of R^2% values with MUSC(CFL)> M:B(CFW)> CWT:L^3 ratio.

For the results in Tables 5.1 to 5.4, the muscling or conformation classes were fitted as independent variables because they comprised a small number (3 to 5) of discrete classes. However, the objective of this study was to evaluate the accuracy with which objective measurements predicted the subjective scores of muscling/conformation. Table 5.5 shows coefficients of determination (R^2%) when the subjective muscling or conformation classes were fitted as dependent variables (y) in linear regression analyses with the objective measures of differential growth as independent variable (x). The results in Table 5.5 are very similar to those in Tables 5.1 to 5.4 in terms of both the closeness of the relationships as well as the ranking of the objectively measured predictors.

Relationships amongst measures of muscularity, M:B ratios, B:A ratios, EMA ratios and CWT:L^3 ratios for data sets 1,2, and 3 are shown in terms of R^2% values in Table 5.6. Relationships were closest between the M:B ratios and muscularity indexes and the poorest relationships were with B:A ratio. Relationships between MUSC and M:B were not significantly different between conformation or muscularity classes for any of the data sets

TABLE 5.1 Means for measures of muscularity, M:B and associated characteristics of lamb carcasses, which were subjectively placed into three muscling classes (data set 1).

	Muscling Class[d]				Side weight effect
Item	1	2	3	R^2%	
n[e]	7	7	12		
Variables not adjusted for weight:					
Side weight.(kg)	6.8	6.6	5.9	11	
MUSC(LB)	0.072^{a}	0.069^{b}	0.064^{c}	64	
M:B(TBWT)	3.57^{a}	3.19^{b}	2.93^{b}	52	
EMA ratio	2.437^{a}	2.182^{a}	1.846^{b}	40	
B:A ratio	0.508^{a}	0.529^{a}	0.450^{b}	42	
CWT:L3	19.8^{a}	17.9^{b}	14.8^{c}	70	
MUSC(FL)	0.475^{a}	0.418^{b}	0.391^{b}	75	
Variables adjusted for weight:					
Femur length(mm)	142.5^{a}	150.3^{b}	159.1^{c}	66	NS
Eye muscle area(cm^2)	9.8^{a}	9.0^{ab}	8.2^{b}	76	***
Muscle width A(mm)	51.6	49.8	51.1	44	***
Muscle depth B(mm)	25.9^{a}	26.1^{a}	23.4^{b}	76	***
Carcass length(mm)	860.0^{a}	888.0^{b}	942.0^{c}	85	***
Side muscle %	54.9	55.0	58.0	18	NS
Side fat %	29.6^{a}	27.6^{a}	22.1^{b}	36	NS

[a,b,c] Mean values in the same row with superscripts that do not contain a common letter differ significantly (P<.05)

[d] 1=good, 2=average and 3=poor.

[e] n=The number of animals for the different muscling classes applied to all variables except that for MUSC(FL) and femur length the numbers were 4,5 and 9 for muscling classes 1,2 and 3, respectively.

NS=P>0.10; *=P<0.05; **=P<0.01; ***=P<0.001.

TABLE 5.2 Means for measures of muscularity, M:B and associated characteristics of lamb carcasses which were subjectively placed into four conformation classes (data set 1).

Item	MLC Conformation Class^d				R^2%	Side weight effect
	5	4	3	2		
n^e	7	6	7	6		
Variables not adjusted for weight:						
Side weight.(kg)	6.8	6.4	6.1	5.9	7	
MUSC(LB)	0.072^a	0.069^b	0.065^{bc}	0.064^c	59	
M:B(TBWT)	3.57^a	3.21^b	3.05^{bc}	2.82^c	57	
EMA ratio	2.437^a	2.220^{ab}	1.918^{bc}	1.780^c	42	
B:A ratio	0.508^{ab}	0.531^a	0.459^{bc}	0.450^c	37	
CWT:L^3 ratio	19.8^a	18.0^b	15.6^c	14.2^c	72	
MUSC(FL)	0.475^a	0.418^b	0.402^{bc}	0.377^c	80	
Variables adjusted for weight:						
Femur length(mm)	141.9^a	150.2^b	156.0^b	163.8^c	76	NS
Eye muscle area(cm^2)	9.8^a	9.2^{ab}	8.4^{bc}	8.0^c	78	***
Muscle width A(mm)	51.6	50.0	51.4	50.3	44	***
Muscle depth B(mm)	25.8^a	26.4^a	23.8^b	23.1^b	78	***
Carcass length(mm)	861.3^a	885.5^a	927.3^b	951.1^b	86	***
Side muscle %	55.0	54.2	57.2	59.3	29	NS
Side fat %	29.5^a	28.7^{ab}	24.0^{bc}	19.6^c	50	NS

[a,b,c] Mean values in the same row with superscripts that do not contain a common letter differ significantly (P<.05).

[d] 5 represents the best conformation.

[e] n=The number of animals for the different conformation classes applied to all variables except that for MUSC(FL) and femur length the numbers were 4,5,5 and 4 for conformation classes 5,4,3 and 2, respectively.

NS=P>0.10; *=P<0.05; **=P<0.01; ***=P<0.001.

TABLE 5.3 Means for measures of muscularity, M:B and associated characteristics of lamb carcasses, which were subjectively placed into five conformation classes (data set 2).

Item	MLC Conformation Class^{e}						Carcass weight effect
	5	4	3	2	1	R^2%	
n	13	18	26	6	6		
Variables not adjusted for weight:							
MUSC(FL)	0.497^{a}	0.443^{b}	0.409^{c}	0.406^{c}	0.366^{d}	69	
MUSC(LB)	0.074^{a}	0.070^{b}	0.066^{c}	0.064^{c}	0.061^{d}	58	
M:B(FW)	7.86^{a}	6.60^{b}	5.77^{c}	5.70^{c}	4.85^{d}	62	
M:B(TBWT)	3.84^{a}	3.43^{b}	3.12^{c}	3.04^{c}	2.65^{d}	53	
EMA ratio	2.478^{a}	1.977^{b}	1.702^{bc}	1.681^{bc}	1.474^{c}	52	
B:A ratio	0.589^{a}	0.521^{b}	0.514^{b}	0.497^{b}	0.473^{b}	31	
CWT:L^3	21.6^{a}	19.3^{b}	17.1^{c}	17.1^{cd}	15.0^{d}	55	
Variables adjusted for weight:							
Eye muscle area(cm^2)	10.9^{a}	9.3^{b}	8.3^{c}	8.3^{c}	7.6^{c}	79	***
Muscle width A(mm)	52.6^{a}	51.6^{a}	49.3^{b}	49.9^{ab}	48.2^{b}	29	***
Muscle depth B(mm)	29.1^{a}	26.8^{b}	25.2^{c}	25.2^{c}	23.9^{c}	82	***
Femur weight(g)	95.9^{a}	104.9^{b}	114.8^{c}	118.4^{c}	124.1^{c}	46	***
Femur length(mm)	144.5^{a}	152.0^{b}	157.9^{c}	159.8^{cd}	164.4^{d}	56	***
Carcass length(mm)	886.5^{a}	903.2^{b}	927.7^{c}	945.3^{cd}	959.5^{d}	72	***
Side muscle %	57.6^{a}	57.8^{a}	56.5^{a}	55.2^{ab}	52.4^{b}	53	***
Side fat %	26.3	25.1	25.5	26.5	27.8	61	***

a,b,c,d See footnotes to Table 5.1.
e 5 represents the best conformation.
NS=P>0.10; *=P<0.05; **=P<0.01; ***=P<0.001.

TABLE 5.4 Means for measures of muscularity, M:B and associated carcass characteristics of bull carcasses, which were subjectively placed into four conformation classes (data set 3).

	MLC Conformation Class[e]					
Item	E	U	R	O	P	R^2%
n	2	28	50	10	0	
Variables not adjusted for weight:						
Carcass weight(kg)	297.8^{ab}	315.0^{b}	291.1^{ab}	264.5^{a}	-	17
MUSC(CFL)	0.683^{a}	0.600^{b}	0.572^{c}	0.522^{d}	-	56
M:B(CFW)	12.10^{a}	9.88^{b}	8.85^{c}	7.73^{d}	-	52
CWT/L^3	35.69^{a}	34.04^{a}	30.44^{b}	26.88^{c}	-	45
Yield of 6 cuts(%)[f]	26.2^{a}	24.0^{b}	23.3^{bc}	22.5^{c}	-	31
Dressing-out %	61.1^{a}	57.8^{b}	55.2^{c}	52.0^{d}	-	45

[a,b,c,d] Mean values in the same row with superscripts that do not contain a common letter differ significantly ($P<.05$).

[e] E represents the best conformation.

[f] knuckle+inside+outside+tenderloin+striploin+D-rump.

TABLE 5.5 Relationships between subjective muscling or conformation score (y) and measures of muscularity, M:B, B:A, EMA ratios, and CWT:L^3 ratio (x) (data sets 1,2, and 3) in term of coefficients of determination (R^2%).

	DS1[a]		DS2[a]	DS3[a]
Item	MSCC[b]	MLCC[c]	MLCC[c]	MLCC[c]
MUSC(FL)	72	74	63	
MUSC(LB)	64	58	56	
M:B(FW)	-	-	56	
M:B(TBWT)	51	55	51	
EMA ratio	39	42	44	
B:A ratio	26	25	23	
CWT:L^3 ratio	69	71	51	49
MUSC(CFL)				52
M:B(CFW)				50

[a] DS1=data set 1; DS2=data set 2; DS3=data set 3.

[b] MSCC = Muscling class.

[c] MLCC = MLC conformation class.

TABLE 5.6 Relationships between selected measurements made on carcasses (data sets 1,2, and 3) in terms of coefficients of determination (R^2%).

	DS1		DS2		DS3	
Item	M:B(TBWT)	MUSC(FL)	M:B(FW)	MUSC(FL)	M:B(CFW)	MUSC(CFL)
MUSC(FL)	53	-	85	-		
MUSC(LB)	53	79	79	76		
M:B(TBWT)	-	53	88	76		
EMA ratio	66	45	52	55		
B:A ratio	15	3	49	37		
CWT:L^3	50	67	74	71	52	46
MUSC(CFL)					64	-

FIGURE 5.1 Mean (± SE) carcass weights and carcass muscle and fat percentages for 5 MLC lamb conformation classes (data set 2). The significance of differences between adjacent means are shown (NS=P>0.10; *=P<0.05; **=P<0.01).

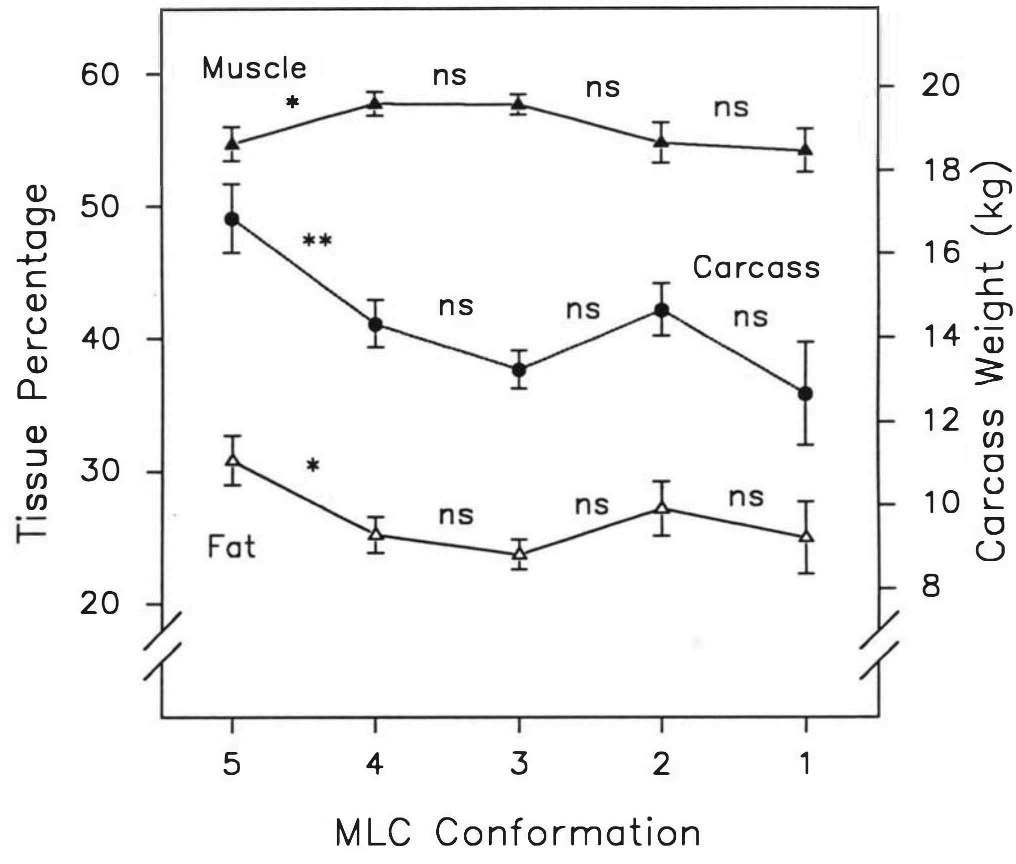


FIGURE 5.2 Mean (± SE) leg muscularity indexes (MUSC(FL)) and muscle to bone ratios (M:B(FW)) for 5 MLC lamb conformation classes (data set 2). The significance of differences between adjacent means are shown (NS=P>0.10; *=P<0.05; ***=P<0.001).

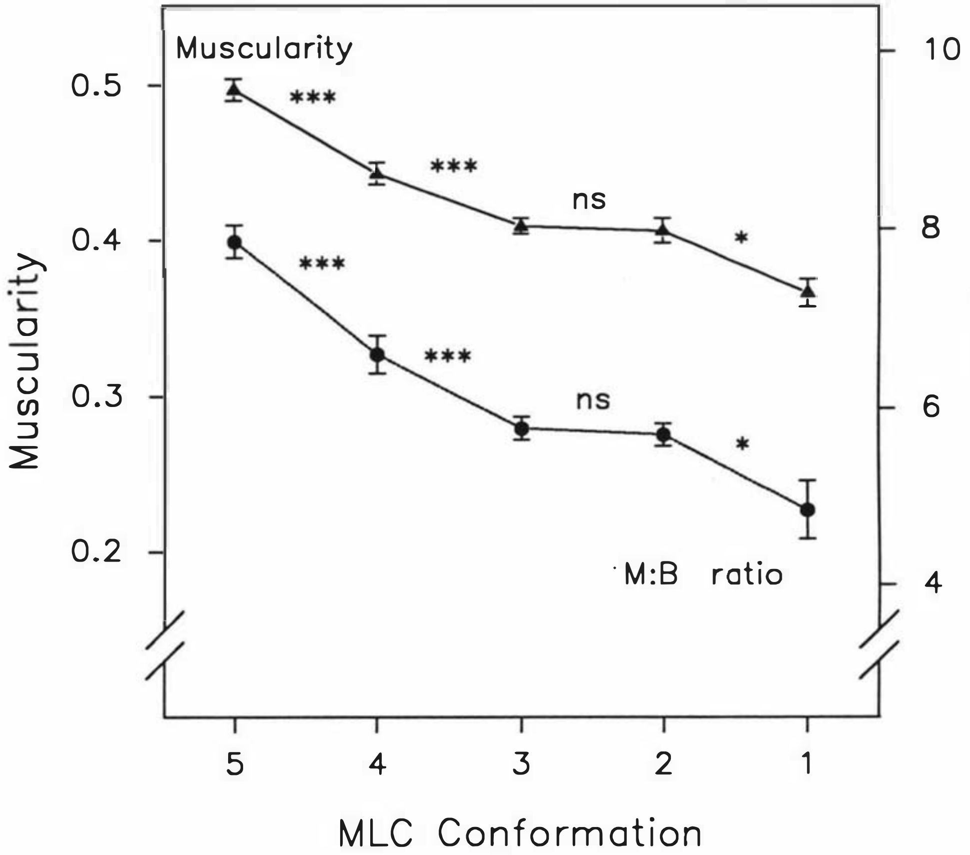
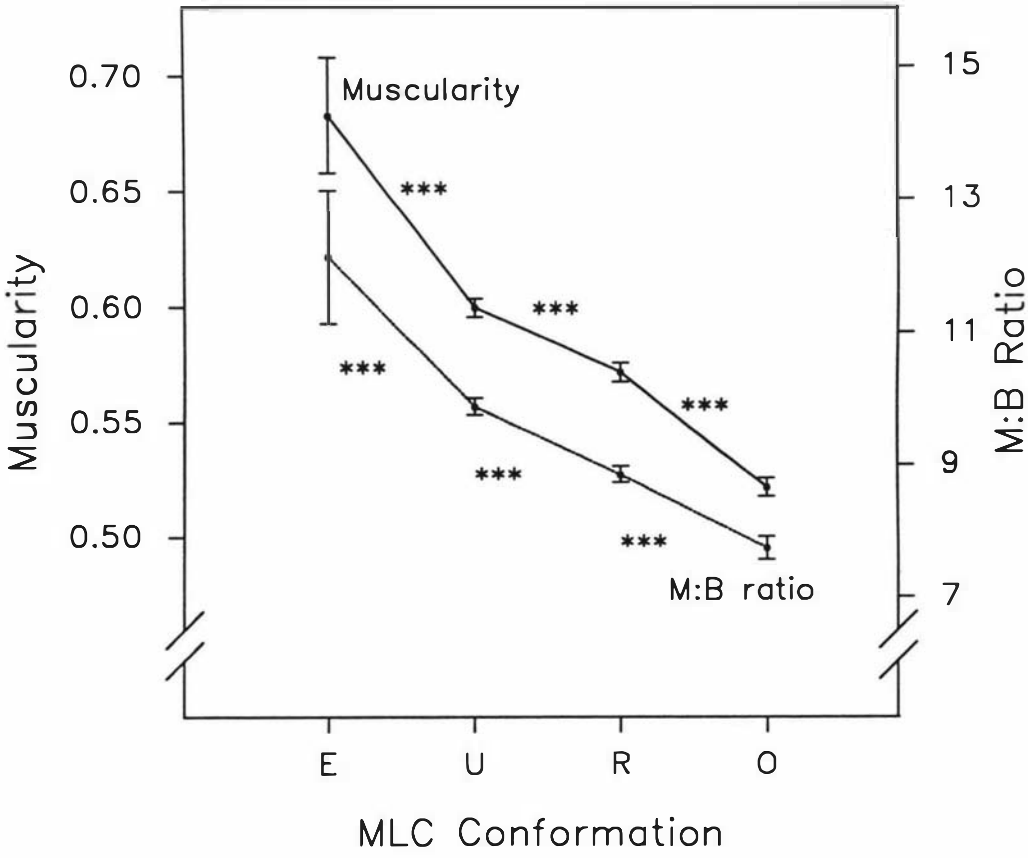


FIGURE 5.3 Mean (± SE) leg muscularity indexes (MUSC(CFL)) and muscle to bone ratios (M:B(CFW)) for 5 MLC beef conformation classes (data set 3). The significance of differences between adjacent means are shown (***=P<0.001).



Characteristics indicating absolute growth.

For data set 1 (Table 5.1 and 5.2), better-muscled classes had significantly larger eye muscle areas, deeper muscle depths (B), and lower length measurements (femur and carcass length). Side muscle percentage did not differ between the muscling classes, but side fat percent increased from worst to best muscling class.

Results for data sets 1 and 2 (Table 5.3) were similar except that better conformation was associated with wider eye muscles (A), and higher weight-adjusted side muscle percent in data set 2 only, apparently because better conformation was accompanied by higher side fat percent in data set 1 to a greater extent than for data set 2 (Table 5.1 and Figure 5.1).

For the two lamb data sets most of the variation in carcass muscle percent was accounted for by variation in carcass fat percent ($R^2\% = 86$ and 85 for data sets 1 and 2, respectively), but when MUSC(FL) was fitted after fat percent in multiple regression equations significant positive relationships were found ($P<0.001$, $R^2\% = 96$ and 95 for data sets 1 and 2, respectively). For data set 3 all carcasses were very lean and a moderately close positive relationship between MUSC(CFL) and 6-cut yield percent was found ($R^2\% = 38$). For all three data sets measures of M:B accounted for a similar proportion of variation in muscle percent as measures of muscularity.

Interactions between the appropriate covariates and subjective scores were not significant for any of the characteristics analysed.

DISCUSSION

Carcass shape and muscularity or muscle to bone ratio

Subjective scores of muscling or conformation were more closely related to indexes based on ratios of the thickness of muscle relative to skeletal dimensions than any other objective index. The muscularity index calculated from the weight of four leg muscles and femur length MUSC(FL) had the closest relationships with subjective scores, possibly because these four leg muscles are closely associated with the femur bone and because the measurement of the femur bone length can be made more accurately than the measurement of carcass length. Also the individual muscles were probably more accurately weighed than the total side muscle or the 6 commercial cuts because the four muscles chosen were relatively large and were easily dissectible anatomical entities. Finally, the relationships may have been closer because the femur region is one of the main regions assessed when conformation scores are given.

Relationships between muscle to bone ratios (M:B) and subjective scores were not as close as for MUSC indexes indicating that the two variables were not measuring the same characteristic. Studies of Kempster *et al.* (1981) for sheep, and Kempster (1978) for cattle, showed that measures of conformation were not always closely related to M:B ratio, especially when animals from different breeds were being compared. Kempster (1978) suggested that the poor relationships between the breeds of cattle resulted from differences in bone structure and density. However, Purchas *et al.* (1991) noted that the breed differences discussed by Kempster (1978) could have arisen from bones with different diameters. Kempster & Cuthbertson (1977) reported that 7-point carcass conformation scores for lambs were poorly related ($R^2\% = 13$) to lean to bone ratio. Similar results were also observed by Harries *et al.* (1974), Dolezal *et al.* (1982), and Muller *et al.* (1989) (See Chapter 2 for more details on these studies). Relationships between objective indexes of muscularity and M:B reported here (Table 5.6) were moderately close, however.

Carcass shape and eye muscle dimensions

Poor relationships between B:A ratios or EMA ratios and subjective scores may be partially explained by the inaccuracies associated with linear and area measurements taken on the cut surface of ***M.longissimus***, compared with measurements of muscle weights and bone lengths. Kempster & Cuthbertson (1977) found that a 7-point lamb carcass conformation score was poorly related to eye muscle area ($R^2\% = 18$). Similar results for cattle were reported by Apple *et al.* (1991) and Kempster & Harrington (1980).

In this study, lamb carcasses with better conformation or muscling at a set weight had larger eye muscle areas, deeper muscle depths (B), and similar or wider muscle widths (A), which is in general agreement with the results of Martin *et al.* (1966), Kirton & Pickering (1967), Kirton *et al.* (1983), and Williams *et al.* (1989). Also, the association of higher eye muscle areas with shorter carcass lengths agrees with the suggestion of Butterfield (1965) that, at the same weight, shorter carcasses have bigger eye muscle areas.

Carcass shape and carcass length

Carcass weight per unit length was quite closely related to subjective scores in some cases, but this ratio can be affected by fat weight in the carcass, which may be why R^2 values were higher for data set 1 than for the other two data sets. Lindsay *et al.* (1978) studied the relationships between beef side length and a 7-point subjective score, and showed that longer sides within weight groups had a thinner shape. In that study correlations between objective and subjective scores were not reported, but it was concluded that side length may be used as an objective indicator of carcass shape. Kadim *et al.* 1989 also indicated that carcasses from a high-fat selection line, that had higher muscularity values than a low-fat line at a set weight, also had shorter carcasses and femurs.

For all three data sets, the indications that better carcass conformation or muscling at a set weight were associated with shorter carcasses and femurs at the same weight are consistent with results of other studies with sheep (Kirton & Pickering, 1967; Jackson & Mansour, 1974) and cattle (Colomer-Rocher *et al.*, 1980).

Carcass shape and percent meat yield

Carcass meat yield is determined by trimmed fat percent and meat to bone ratio. In order for muscularity to be closely related to meat yield it must be closely related to muscle to bone ratio and variation in trimmed fat percent must account for only a small proportion of the variation in meat yield.

Significant group differences were found in side muscle percentage or yield of 6 cuts in data sets 2 and 3, respectively, but not in data set 1. For all three data sets in this study higher values of MUSC indexes were significantly associated with higher yields of muscle or meat cuts, although for the lamb data this relationship was only apparent after adjusting for differences in fat percent. Differences between conformation classes for muscle percentage have also been reported by Colomer-Rocher *et al.* (1980) in cattle. They found that the concave carcasses had the lowest percentage of meat and the highest percentage of fat at the same carcass weight when the carcasses were classified according to MLC conformation classes.

Garrett *et al.* (1992), in contrast, reported a correlation of only -0.12 between measures of lamb leg conformation and the yield of cuts trimmed to 0.25cm. Kempster *et al.* (1982) in a review of the relationships between conformation and meat yield concluded that 'fat-corrected' conformation is not a valuable predictor of carcass composition in sheep. Apple *et al.* (1991) found that hindquarter muscling score in beef carcasses was significantly but poorly related to percentage of retail product trimmed to 0.76cm of fat ($R^2\%$ = 2). In an experiment with dissected carcasses from beef, Kempster & Harrington (1980) reported that the relationship between a 5-point conformation scale and carcass lean percentage was low ($R^2\%$ = 8), both at equal carcass subcutaneous fat percentage (SF%) and when both SF% and carcass weight were held constant. Similar results were reported in cow carcasses by Harries *et al.* (1974) and Muller *et al.* (1989).

Repeatability of subjective scores

The closeness of relationships between objective and subjective measurements will be limited by the repeatability with which visual appraisals can be made. Repeatability can be improved with training and experience (Harries *et al.*, 1974), and the use of well-designed score cards (Williams, 1972) or photographic standards (DeBoer & Nijeboer, 1973) can help, but the subjective element will mean that objective/subjective relationships will never be perfect (See Chapter 2, section 2.3.2.1 for more details).

SUMMARY AND CONCLUSIONS

1. Data from 95 lamb carcasses (2 data sets) and 90 bull carcasses were used to examine relationships between objective measures of carcass muscling and subjective scores of muscularity or conformation. Objective indexes calculated for lamb carcasses included muscle to bone ratios (M:B), muscularity indexes (MUSC) for both the leg and the whole side, the ratio of eye muscle depth to width (B:A), weight-adjusted eye muscle area and carcass weight per unit length. Similar variables were calculated for beef carcasses except that the weights of three commercial leg cuts were used in place of dissected muscle weights.

2. Leg MUSC (based on the depth of muscles surrounding the femur relative to femur length) had the closest relationships with subjective scores of muscularity or conformation ($R^2\%$ = 69 to 80% for lambs and 56% for bulls), with leg M:B being only slightly inferior ($R^2\%$ = 62% for lambs and 52% for bulls).

3. Side MUSC or M:B were the next best as predictors, but variables based on the eye muscle were poor. Carcass weight per unit length showed close relationships with subjective scores in some cases but its usefulness is limited by the fact that it can be influenced by fatness.

4. The results showed that measures of M:B may not always reflect muscularity scores because they are based on weights rather than depths and lengths.

5. It is concluded that the objective measures of MUSC used here reflect subjective scores satisfactorily, given that subjective scores have limitations with respect to repeatability. It is suggested that the MUSC index, based on the femur and the

muscles or cuts surrounding it, may constitute a useful objective standard for use in training and calibrating carcass graders in the industry. This would be more practical if commercial cuts could be used in place of dissected muscles.

CHAPTER SIX

THE INDIRECT PREDICTION OF LEG MUSCULARITY FOR SHEEP CARCASSES

INTRODUCTION

Information on carcass or leg muscularity can be obtained by using 'direct' or 'indirect' methods. A direct approach was described by Purchas *et al.* (1991) and results from using this approach were presented in Chapters 3, 4, and 5. These studies demonstrated that the muscularity index based on weights of five leg muscles around the femur and femur bone length was a good objective measure of carcass muscularity (especially leg muscularity) and that relationships with subjective measures of muscularity were good. However, the direct approach involves measurements that are time-consuming, costly, and could not be used in a commercial carcass grading or classification system. Thus, an indirect predictor of carcass or leg muscularity would be very useful if it permitted a saving of time and cost of dissection in any research study, or if it enabled fast, easy, nondestructive, and practical measurements to be made in the boning room or on an intact carcass.

This study, therefore, has evaluated relationships between the objective muscularity index based on muscles around the femur and femur length (MUSC(FL)) and indirect predictors that can be measured more easily. Indirect predictors evaluated included weights of individual leg muscles, weights of commercial cuts, and linear measurements made on photographs of the leg or directly on the leg.

MATERIALS AND METHODS

Animals and experimental design

Five trials conducted between 1990 and 1992 provided data for this study (Table 6.1).

Trial 1 was run at Massey University and included Southdown rams from the high (L1) and low (L2) backfat selection lines described by Kadim *et al.* (1989). Details of this trial were given in Chapter 3.

Trial 3 was designed to study the effects of recombinant ovine placental lactogen or bovine somatotropin on lamb carcass components. Forty eight twin-born Coopworth (CPW) lambs of both sexes were allocated to 3 groups balanced for age and sex. After three weeks of treatment, half the animals were slaughtered while the remaining lambs received no further treatments and were slaughtered at a mean age of 9 months.

In Trial 4 the effect of a melatonin-protein conjugate on growth and carcass composition of 38 Dorset horn X Coopworth crossbred rams (DS X CPW) was studied. The animals were divided randomly into five groups with one group of 10 being slaughtered just prior to the beginning of the study to obtain baseline data on carcass composition. The remaining four groups of 7 each were run together. One was used as a control group and the other three treatment groups were injected with 0.25, 1 and 4 mg of a melatonin-protein conjugate. All sheep were grazed as one mob for 30 weeks.

The Romney (ROM) rams in Trial 5 had been reared on pasture as one group from birth and slaughtered at 16 months of age. The objective of this study was to determine the effects of 35 years of single-trait selection for yearling greasy fleece weight on carcass composition in young rams (McCutcheon *et al.*, 1993).

Trial 6 involved a study of the effects of recombinantly-derived IGF-1 (150 ug/kg LW/day; Ciba-Geigy, Summit, N.J) on carcass composition of 31 Border Leicester X Romney wethers (BL X ROM) after treatment for 8 or 12 weeks.

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TABLE 6.1 An outline of the experimental designs for the 6 trials.

Trial No.[a]	Breed or cross and sex	No. of animals	Age at slaughter (days)[b]	Carcass wt.(kg)	
				Mean	SD
1	Southdown rams				
	(High-backfat)	40	1-838	19.0	13.6
	(Low-backfat)	40	3-838	17.9	12.5
3	Coopworth rams and ewes	47	24-270	14.5	9.2
4	Dorset Horn X Coopworth cryptorchids	38	210	19.1	3.8
5	Romney rams	26	488	20.3	4.1
6	Border Leicester X Romney wethers	31	314	19.3	1.5

[a] Trial numbers correspond to those for Chapter 4

[b] Means are given for those trials where the age range was low (less than 60 days), and ranges are given for those trials where there was a wide variation

Slaughter procedures and carcass measurements

After a fasting period (c. 10.0-17.0 hours) animals of Trials 1, 3, 4, and 5 were slaughtered and dressed following normal commercial procedures. Animals of Trial 6 were not fasted prior to slaughter but were weighed off feed. On the day after slaughter, carcass length (LB) was measured (Moxham & Brownlie, 1976), and *M.longissimus* area, width (A) and depth (B) (Palsson, 1939) were measured on the surface of a cut between ribs 12 and 13.

Photographic measurements

On the day after slaughter and before cutting the carcasses, the right leg was photographed from the lateral surface with the carcass hanging vertically by the cannon calcanean (achilles) tendon. The area of interest on the lateral view of the leg was between two horizontal lines, one tangential to the top edge of the gambrel where it passed through the leg (the distal anatomical landmark), and the other passing through the mid point of the dorsal part of the tuber ischii (the proximal anatomical landmark) (Figure 6.1). This point was located by palpation after removing excess fat on the medial side of the hip bone in this area when necessary. It was particularly easy to locate on lean carcasses and was usually slightly dorsal to, and 15 to 25 mm cranial to the most caudal edge of the ischiatic tuberosity (Appendix 1: Figure A1.6). These anatomical landmarks were identified clearly before taking the photo by hanging a frame in front of the lateral view. Rulers at the top and bottom of the frame were adjusted to the these positions. A spirit level was used to ensure that the rulers were horizontal. A black curtain was hung behind the carcass to give a good contrast.

Kodak 35 mm black & white T.Max 100 ASA film was used in an Asahi Pentax camera with 100 mm focal-length lens set at F8, and at a distance of approximately 2 m from the carcass. The 35mm negatives were set in slide frames and were projected on a screen marked from 0 to 100 cm with 41 horizontal lines at 2.5 cm intervals. The area of interest was then adjusted by moving the projector so that the bottom of the upper ruler in the picture was at 0 cm and the top of the lower ruler was at 100 cm. Then the leg widths at fixed proportions of the distance between the distal and proximal anatomical landmarks were measured along the appropriate lines on the screen (Figure 6.2). Twenty one widths were measured corresponding to distances from 35% to 85% of the distance from the top line to the lower line, with intervals between widths of 2.5% (Figure 6.2). Widths above and below these were not measured because the upper area (the distal part of the leg) had less muscle to measure and the lower area (the proximal leg) had more fat covering the muscles. Widths measured from the screen in this way have been adjusted to a constant distance between the distal and proximal landmarks, and are therefore measures of width to length ratios. They will henceforth be referred to as (W/L)1 to (W/L)21. From these W/L several bands were also calculated as the mean of 10 adjacent W/L values.

In order to assess the sensitivity of W/L values and band values to errors in the location of the proximal anatomical landmark, W/L values were remeasured for 12 Southdown ram carcasses (carcass weight range from 19.4 to 32.4 kg) with the distance between the two landmarks adjusted to 96, 98, 102 and 104% of the measured distance on the screen in addition to the usual 100%. This was done by projecting the slides at five different magnifications rather than by taking extra slides. This procedure gave 5 measurements for each W/L value and for each calculated band for each animal.

FIGURE 6.1 A lateral view of a carcass showing the positions of the distal (top of hook (gambrel)) and proximal (dorsal part of tuber ischii) anatomical landmarks used to determine where to make leg width measurements either on photographs or on the intact side.

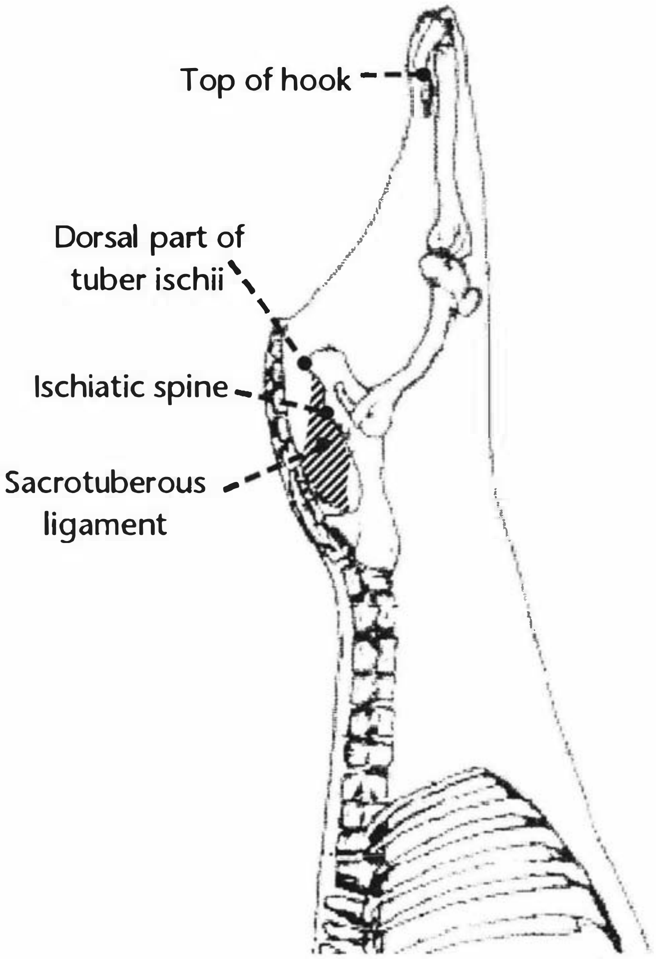
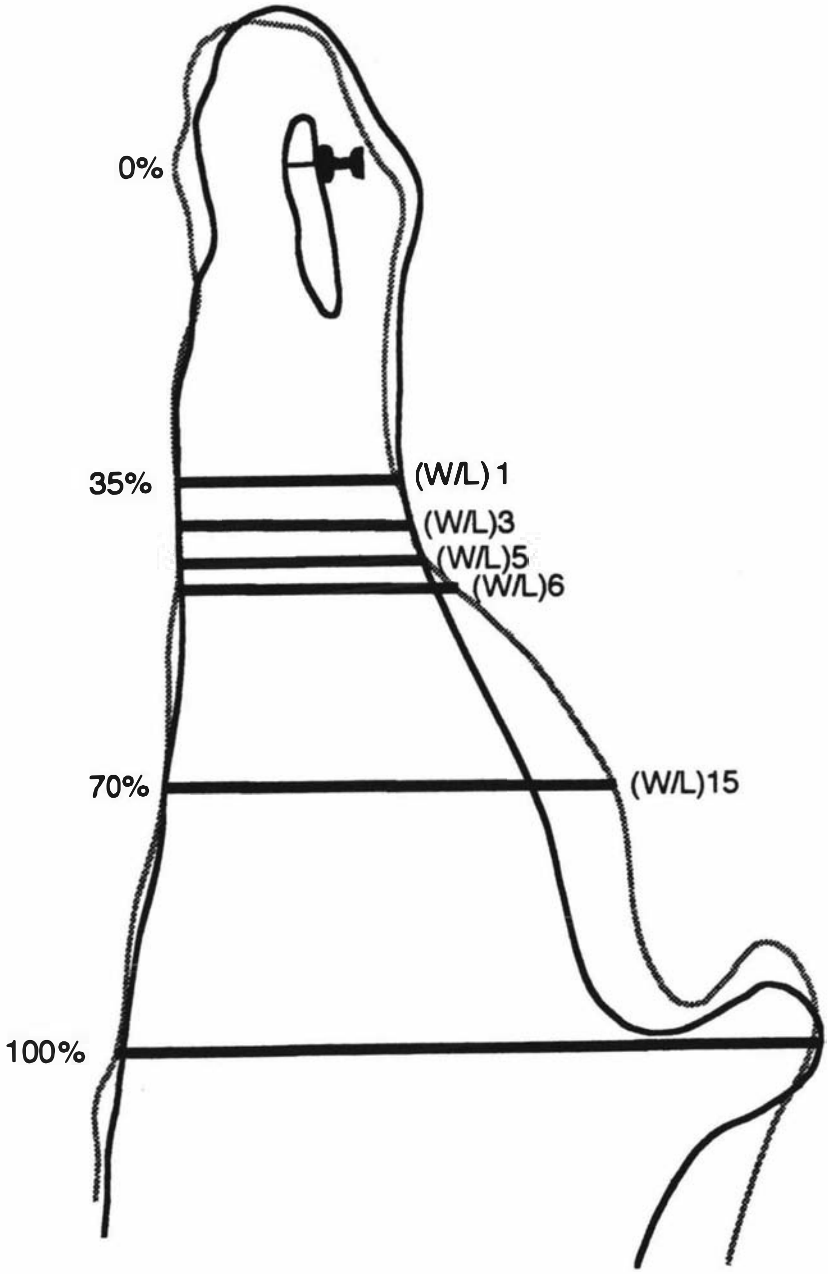


FIGURE 6.2 A diagram showing the outline of two legs of contrasting muscularity that have been adjusted proportionately to a constant distance between the distal and proximal anatomical landmarks. The locations of selected widths are shown on the legs.



A calipers-holding device (CHD)

A device to measure leg width at a constant proportion of leg length from the lateral view of a hanging carcass was designed and tested (Figure 6.3). The upper and lower anatomical landmarks used to position the CHD were the same as those described above for use in photographic assessments.

Figure 6.4 is a diagrammatic outline of the device. Two perspex triangles (ABC and ADE) were bolted together at point A so that the angle between the triangles (BAD) could be changed. A vertical rod (FG) was attached at F and G in such a way that points F and G could slide along AB and AD, respectively. A hook was attached to the rod at F and a pointer at G so that these points could be aligned with the distal and proximal anatomical landmarks, respectively. Thus for any particular carcass the rod was adjusted to the left or right until the distance FG was correct for that carcass. Triangle (ADE) had lines at right angles to AE drawn on it at 10mm intervals to help ensure that the rod FG was set at right angles to AE. A ledge (AEIH) was built out from edge AE of triangle ADE to hold calipers for measuring leg width. With this design the proportion that FJ made up of the total distance FG was constant for a set value of angle BAD regardless of how far the rod was along the line AE, provided FG was kept at right angles to AE. The value of this proportion could be increased by increasing angle BAD. The two proportions, chosen in this work to measure a part of the leg with relatively thick muscles, were with FJ at 63.9% and 68.7% of FG, to give widths 1 and 2, respectively.

Leg widths measured in this way were divided by carcass length (LB) to give width-to-length ratios written as CHD(W/L)1 and CHD(W/L)2, respectively.

FIGURE 6.3 A photograph showing the calipers-holding device (CHD) being used to measure leg width at a set proportion of leg length.

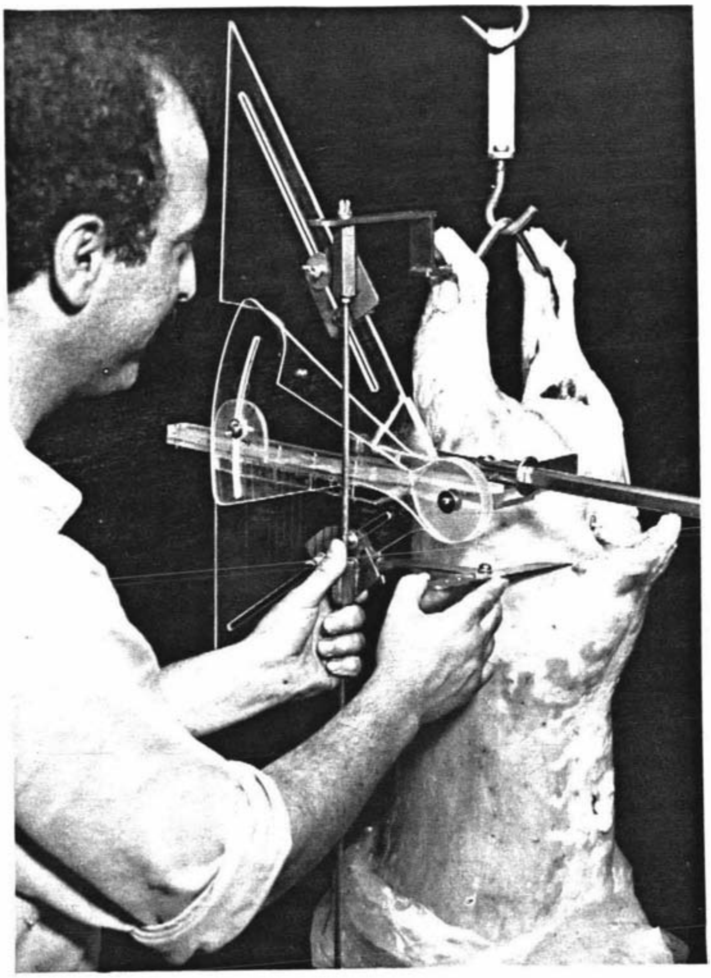
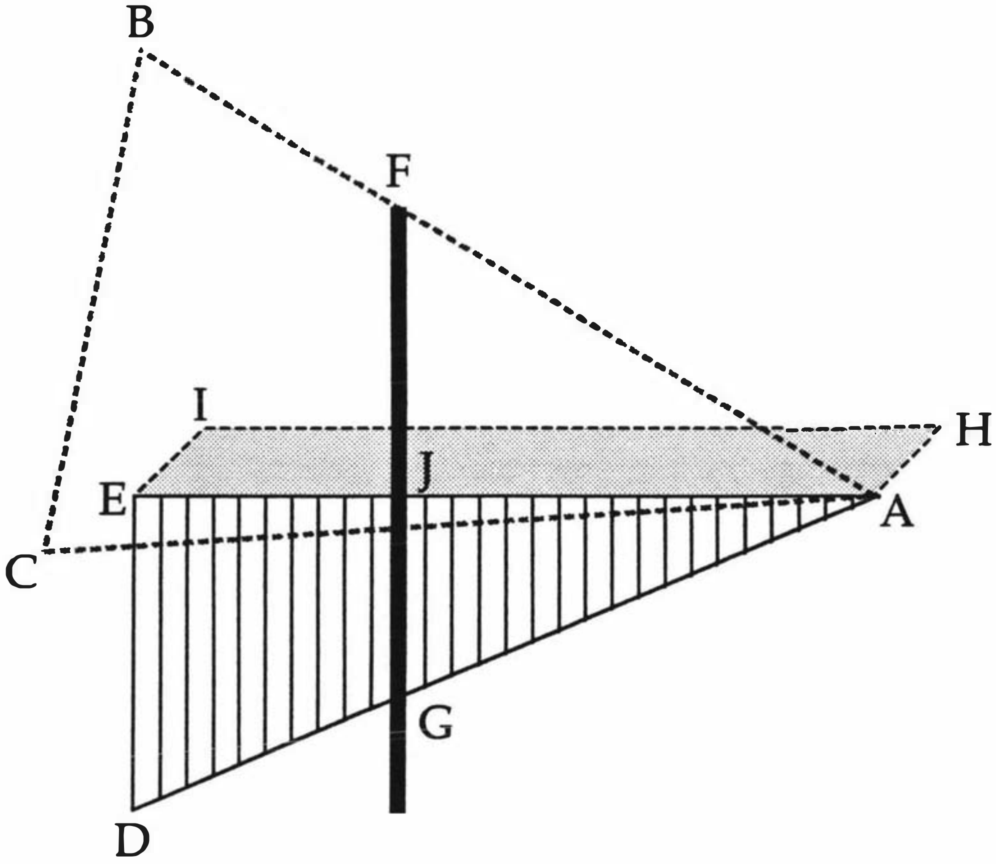


FIGURE 6.4 A diagrammatic outline of the calipers-holding device (CHD). Key components include the two triangles (ABC and AED) connected at A, the vertical rod FG that could be moved left or right, and the platform AEIH on which the calipers were placed.



Dissection procedures and cut preparation

Carcasses were sawn down the middle of the backbone and divided into several cuts (Appendix 1: Figure A1.2). The leg was separated by making a cut between the last and second-to-last lumbar vertebrae at right angles to the dorsal surface and frozen for subsequent dissection.

After thawing for c. 12 hours at room temperature, legs were dissected first into individual trimmed boneless leg cuts, and then into individual muscles, bone, fat and scrap following the procedures of Brown & Williams (1979). Individual muscles weighed were the *M.semimembranosus* (SM), *M.semitendinosus* (ST), *M.biceps femoris* (BF), *M.quadriceps femoris* (QF) and *M.adductor* (AD). The femur bone was cleaned, weighed and the maximum length recorded (Appendix 1: Figure A1.4).

The procedures followed to prepare four boneless leg cuts are set out in Appendix 4. Individual leg cuts prepared and weighed were the rump, knuckle, topside, and outside (silverside).

Calculation of derived indexes

Indexes of shape derived from the linear measurements are outlined in Appendix 2: Table A2.1. These include:

(1) the ratio of eye-muscle depth (B) to width (A) (B:A ratio).

(2) the ratio of eye-muscle area (EMA, cm^2) raised to the power of 1.5 and carcass weight (EMA ratio).

(3) the ratio of carcass weight (kg) to carcass length cubed (m) (CWT/L^3).

All indexes of leg muscularity derived in the present study were calculated, as proposed by Purchas *et al.* (1991), as the ratio of an index of muscle depth (the square root of the total weight of some muscle or muscles per unit length of the femur) to the length of the femur (Appendix 2: Table A2.1).

Indexes of muscularity, were calculated from either:

(1) The weight of five leg muscles (SM, ST, BF, QF and AD) and femur length (MUSC(FL)).

(2) The weight of four leg muscles (SM, ST, BF, and AD) and femur length (MUSC(FL4)).

(3) The weight of a set of three leg muscles (Set 1: SM, ST, and BF) and femur length (MUSC(FL3,1)).

(4) The weight of a second set of three leg muscles (Set 2: SM, ST, and AD) and femur length (MUSC(FL3,2)).

(5) the weight of two leg muscles (SM and AD) and femur length (MUSC(FL2)).

(6) The weight of each individual muscle, except AD, and femur length: (MUSC(FLSM)), (MUSC(FLST)), (MUSC(FLBF)), and (MUSC(FLQF)).

(7) The weight of of three leg cuts (knuckle, topside and outside) and femur length (MUSC(FLTC)).

(8) The weight of each individual cut and femur length for: the knuckle (MUSC(FLKNL)), the topside (MUSC(FLTOP)), and the outside cut (MUSC(FLOUT)).

Statistical methods

Statistical analysis of the data of the present study was carried out using the SAS computer programme (SAS 1987) using several procedures as following:

(1) Differences between groups within trials was carried out using general-least-squares procedures.

(2) Relationships between the standard muscularity and potential predictors were evaluated on the basis of simple correlation coefficients using the correlation procedure within the SAS programme.

(3) The SAS REG procedure was used to produce simple regression equations to predict standard muscularity using some potential predictors as the independent variables and to find the precision of different potential predictors of muscularity.

(3) In the case of the 21 measurements from the leg photographs, the value of individual width to length ratios (W/L) and bands calculated as the mean of several adjacent W/L values were evaluated as predictors of the standard muscularity using simple correlation coefficients. The value of combinations of widths was assessed by multiple regression using the SAS REG procedure. The

choice of which W/L values to include in the prediction equations was made on the basis of high R^2 values, but equations for which the Mallow's Cp values were greater than the number of independent variables were not considered (Mallows, 1975).

(4) The data obtained in evaluating the sensitivity of W/L values to errors in the location of the anatomical landmarks were analysed using a randomized block model with the 12 animals as blocks and 5 positions within each animal. Comparisons between the 5 position means were tested by Duncan's Multiple Range Test within the SAS ANOVA procedure.

RESULTS

Differences between treatment groups or genetic groups within trials were not significant except for differences between the Southdown selection lines (see Chapter 3). Therefore, results are presented either as overall trial values or in some cases with the two Southdown lines analysed separately.

Prediction from individual muscles and commercial cuts

The overall means, standard deviations and coefficients of variation for the standard muscularity MUSC(FL) and selected predictors are presented in Table 6.2 for all trials. The coefficients of variation for most variables were higher for Trial 1 than all other trials due to the wider range of carcass weights.

Table 6.3 shows simple correlations between the standard muscularity (MUSC(FL)) calculated from the weight of five muscles and several predictors based on either fewer muscles, commercial cut weights, or other measurements. For all trials close relationships were shown between muscularity based on the weights of individual muscles and cuts and standard muscularity.

The highest correlations were obtained when the weight of four muscles (all except *M.adductor*; MUSC(FL4)) or the weight of three muscles (Set 1: SM, ST, and BF; MUSC(FL3,1)) were used, but these were only slightly higher than when only the

Set 2 of the three muscles (SM, ST, and AD; MUSC(FL3,2)) or the weight of two leg muscles (SM and AD; MUSC(FL2)) were used. Correlations obtained from using the weights of the individual muscles, BF (MUSC(FLBF)) and SM (MUSC(FLSM)), were similar to the previous two combinations of muscles, and higher than when the weights of either QF or ST were used.

TABLE 6.2 Means, standard deviations, and coefficients of variation for the standard muscularity (MUSC(FL)) and potential predictors of muscularity based on dissected muscle, commercial boneless cuts, or linear and area measurements for the 5 trials.

	Trial number[a]														
	1			3			4			5			6		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Standard muscularity															
MUSC(FL)	0.531	0.083	15.6	0.469	0.029	6.2	0.465	0.020	4.2	0.479	0.017	3.5	0.473	0.022	4.6
Muscularity predictors based on muscles & cuts															
MUSC(FL4)	0.435	0.074	15.0	0.383	0.024	6.2	0.376	0.017	4.5	0.386	0.015	4.0	0.376	0.019	5.1
MUSC(FL3,1)	0.401	0.070	17.4	0.351	0.021	6.0	0.346	0.016	4.8	0.353	0.016	4.4	0.343	0.018	5.2
MUSC(FL3,2)	0.351	0.060	17.0	0.307	0.019	6.1	0.302	0.014	4.7	0.309	0.012	3.8	0.302	0.015	5.0
MUSC(FL2)	0.309	0.053	17.1	0.275	0.017	6.2	0.269	0.013	4.8	0.273	0.010	3.8	0.270	0.014	5.1
MUSC(FLQF)	0.304	0.044	14.5	0.271	0.018	6.8	0.273	0.011	4.2	0.284	0.010	3.5	0.287	0.013	4.4
MUSC(FLSM)	0.261	0.045	17.5	0.229	0.013	5.9	0.224	0.012	5.5	0.225	0.011	4.8	0.223	0.012	5.3
MUSC(FLBF)	0.255	0.045	17.7	0.228	0.015	6.7	0.224	0.011	4.8	0.232	0.011	4.9	0.223	0.013	5.7
MUSC(FLST)	0.164	0.031	18.7	0.137	0.009	6.9	0.137	0.007	5.2	0.142	0.007	5.1	0.135	0.008	6.0
MUSC(FLTC)	0.561	0.087	15.5	--	--	--	0.486	0.020	4.1	--	--	--	--	--	--
MUSC(FLKNL)	0.316	0.044	14.0	--	--	--	0.279	0.012	4.2	--	--	--	--	--	--
MUSC(FLTOP)	0.353	0.057	16.2	--	--	--	0.303	0.014	4.5	--	--	--	--	--	--
MUSC(FLOUT)	0.298	0.052	17.4	--	--	--	0.257	0.012	4.5	--	--	--	--	--	--
Other muscularity predictors															
B:A ratio	0.529	0.076	14.4	0.555	0.048	8.6	0.515	0.039	7.6	0.505	0.053	10.5	0.519	0.049	9.5
EMA ratio	3.058	0.662	21.6	2.386	0.420	17.6	2.175	0.276	12.7	--	--	--	1.636	0.262	16.0
CWT:L^3	21.36	5.006	23.4	19.10	1.855	9.7	15.39	1.317	8.6	16.50	2.38	14.4	17.55	1.509	8.6

[a] Trial numbers 1, 3, 4, 5, and 6 involved Southdown, Coopworth, Dorset Horn X Coopworth, Romney, and Border Leicester X Romney sheep, respectively.

-- indicates no data available.

TABLE 6.3 Simple correlation coefficients (r x 100) between standard muscularity (MUSC(FL)) and potential predictors of muscularity for the 5 trials.

	Trial number[a]				
Predictor	1	3	4	5	6
n	80	47	38	26	31
MUSC(FL4)	99	99	98	97	97
MUSC(FL3,1)	99	98	98	95	96
MUSC(FL3,2)	98	97	93	92	96
MUSC(FL2)	97	95	93	94	94
MUSC(FLQF)	91	95	91	83	89
MUSC(FLSM)	99	93	91	89	93
MUSC(FLBF)	99	95	94	93	90
MUSC(FLST)	98	88	77	59	78
MUSC(FLTC)	99	--	99	--	--
MUSC(FLKNL)	99	--	91	--	--
MUSC(FLTOP)	99	--	91	--	--
MUSC(FLOUT)	99	--	95	--	--
B:A ratio	73	52	5	43	26
EMA ratio	-51	-39	12	--	15
CWT:L^3	84	80	36	45	57

[a] Trial numbers 1, 3, 4, 5, and 6 involved Southdown, Coopworth, Dorset Horn X Coopworth, Romney, and Border Leicester X Romney sheep, respectively.

-- indicates no data available.

In Trial 1 correlations between muscularity calculated from total cuts or from any individual cut and standard muscularity were similar to those obtained using 4 muscles (MUSC(FL4)) (Table 6.3). In Trial 4 correlations between muscularity based on total cuts (MUSC(FLTC)) and standard muscularity was higher than for muscularity based on individual cuts.

Regression lines for the groups from the different trials for muscularity based on the weight of SM (Figure 6.5 and Table 6.4) and BF (Figure 6.6 and Table 6.4) corresponded closely. Differences between trials in regression slope and intercept were not tested statistically, but there were no significant differences in these parameters between the two Southdown lines.

The value of potential predictors of muscularity in the prediction of standard muscularity were evaluated further by assessing their value as predictors after adjusting for carcass weight effects (Table 6.5). An indication of the value of the predictors over and above carcass weight alone is provided by the extent to which the R^2 value increased, and the residual standard deviation decreased, when each predictor was added as a second independent variable in the prediction equations. Carcass weight alone was moderately good as a predictor for Trials 1 and 2 where the range of weights was large, but poor as a predictor for the other trials. Across the trials, all predictors involving weights of individual muscles and commercial cuts were found to explain a high proportion of additional variation in standard muscularity, but the predictors based on the weight of four muscles (SM, ST, BF, QF; MUSC(FL4)), or three muscles (Set 1: SM, ST, and BF; MUSC(FL3,1)), and the weight of total cuts (topside, outside, and the knuckle; MUSC(FLTC)) were the highest across all trials. Of the individual muscles and cuts, muscularity based on weights of SM, BF, inside and outside were the most effective predictors in terms of correlation coefficients.

TABLE 6.4 Simple regression equations relating standard muscularity (MUSC(FL) = Y = dependent variable) and some potential predictors of muscularity for the 5 trials.

Independent variable (X)	Y = a ± bX	R^2%	RSD
MUSC(FLSM) (X):			
Trial 1 (L1)[a]	Y = 0.0529 + 1.8332X	98	0.012
(L2)	Y = 0.0516 + 1.8298X	99	0.007
Trial 3 (CPW)	Y = 0.0069 + 2.0155X	87	0.011
Trial 4 (DS X CPW)	Y = 0.1414 + 1.4411X	83	0.008
Trial 5 (ROM)	Y = 0.1628 + 1.4054X	80	0.008
Trial 6 (BL X ROM)	Y = 0.0946 + 1.6925X	87	0.008
MUSC(FLBF) (X):			
Trial 1 (L1)	Y = 0.0664 + 1.8093X	98	0.012
(L2)	Y = 0.0388 + 1.9381X	99	0.008
Trial 3 (CPW)	Y = 0.0540 + 1.8176X	90	0.009
Trial 4 (DS X CPW)	Y = 0.0860 + 1.6918X	88	0.007
Trial 5 (ROM)	Y = 0.1562 + 1.3907X	87	0.006
Trial 6 (BL X ROM)	Y = 0.1326 + 1.5268X	81	0.009
BAND 4 (X):			
Trial 1 (L1)	Y = 0.1346 + 0.0011X	89	0.021
(L2)	Y = 0.1391 + 0.0010X	75	0.024
Trial 3 (CPW)	Y = 0.2785 + 0.0006X	21	0.026
Trial 4 (DS X CPW)	Y = 0.2524 + 0.0007X	40	0.016
Trial 5 (ROM)	Y = 0.4326 + 0.0002X	3	0.017
Trial 6 (BL X CPW)	Y = 0.3238 + 0.0005X	25	0.019

[a] Trial numbers 1, 3, 4, 5, and 6 involved Southdown, Coopworth, Dorset Horn X Coopworth, Romney, and Border Leicester X Romney sheep, respectively.

FIGURE 6.5 Linear regressions relating the standard muscularity index (based on the weight of five leg muscles and femur length) to an index of muscularity based on the weight of *M.semimembranosus* and femur length for the high- (L1) and low- (L2) backfat Southdown selection lines (Trial 1), the Coopworth (CPW, Trial 3), the Dorset Horn X Coopworth (DSXCPW, Trial 4), the Romney (ROM, Trial 5), and the Border Leicester X Romney (BLXROM, Trial 6) groups.

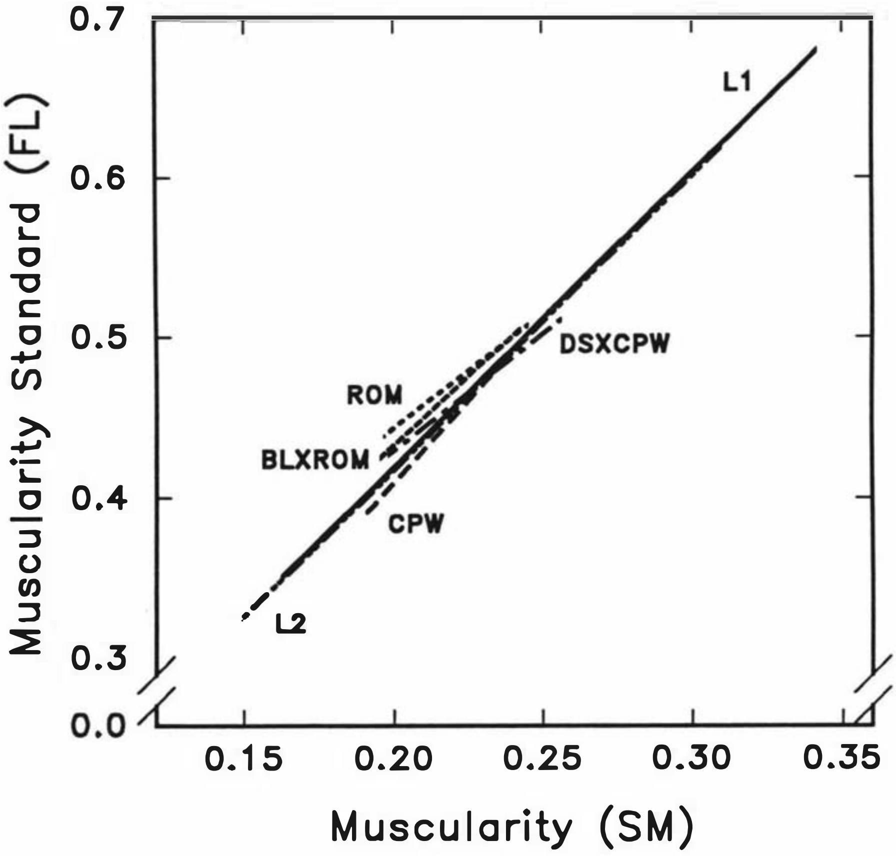


FIGURE 6.6 Linear regressions relating the standard muscularity index (based on the weight of five leg muscles and femur length) to an index of muscularity based on the weight of *M.biceps femoris* and femur length for the high- (L1) and low- (L2) backfat Southdown selection lines (Trial 1), the Coopworth (CPW, Trial 3), the Dorset Horn X Coopworth (DSXCPW, Trial 4), the Romney (ROM, Trial 5), and the Border Leicester X Romney (BLXROM, Trial 6) groups.

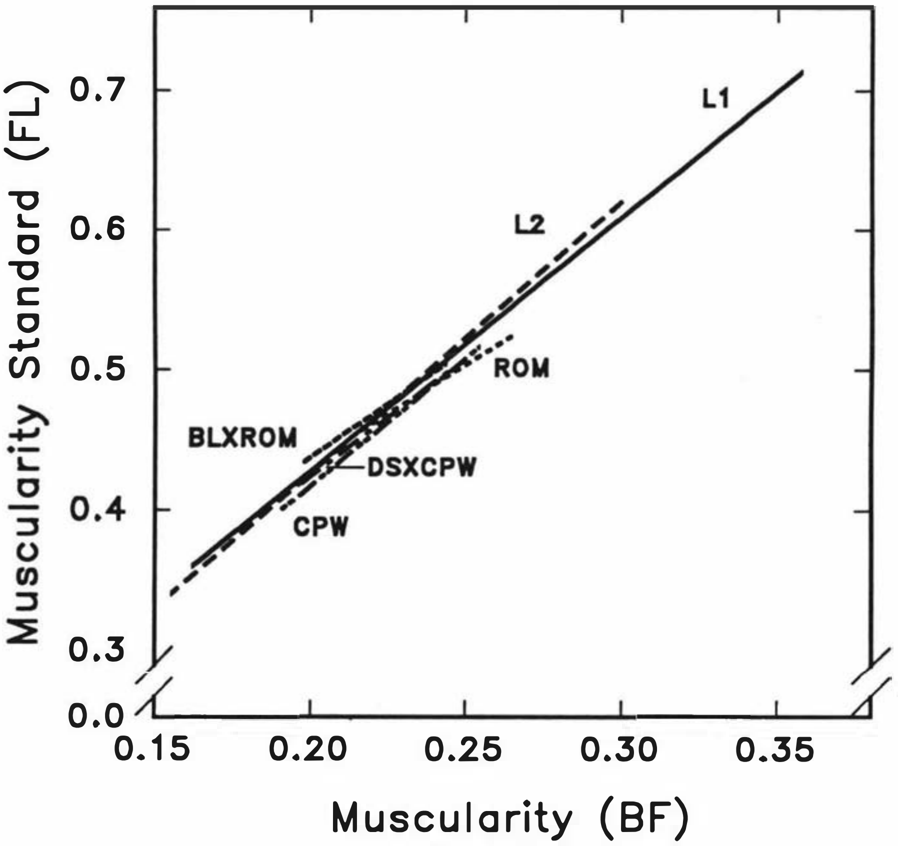


TABLE 6.5 The accuracy of potential predictors of standard muscularity (MUSC(FL) when included along with carcass weight (CWT) in multiple regression equations. Measures of accuracy given are the coefficient of determination (R^2%) and the residual standard deviation (RSD) for the 5 trials.

	Trial number[a]														
	1			3			4			5			6		
Predictor(s)	Sig[b]	R^2%	RSD	Sig	R2%	RSD	Sig	R2%	RSD	Sig	R2%	RSD	Sig	R2%	RSD
Carcass weight alone															
CWT	***	71	0.045	***	52	0.020	NS	4	0.019	NS	8	0.017	NS	7	0.021
Carcass weight + muscularity based on muscles and cuts															
MUSC(FL4)+CWT	***	98	0.010	***	97	0.005	***	96	0.004	***	95	0.004	***	95	0.005
MUSC(FL3,1)+CWT	***	99	0.005	***	97	0.005	***	96	0.004	***	90	0.005	***	93	0.006
MUSC(FL3,2)+CWT	***	96	0.016	***	95	0.007	***	87	0.007	***	85	0.007	***	93	0.006
MUSC(FL2)+CWT	***	95	0.019	***	92	0.009	***	86	0.007	***	89	0.006	***	89	0.007
MUSC(FLQF)+CWT	***	90	0.027	***	90	0.009	***	85	0.008	***	79	0.008	***	81	0.010
MUSC(FLSM)+CWT	***	99	0.009	***	90	0.010	***	83	0.008	***	80	0.008	***	87	0.008
MUSC(FLBF)+CWT	***	98	0.010	***	93	0.008	***	89	0.007	***	87	0.006	***	82	0.010
MUSC(FLST)+CWT	***	95	0.018	***	81	0.013	***	61	0.013	**	35	0.014	***	61	0.014
MUSC(FLTC)+CWT	***	99	0.005	--	--	--	***	98	0.003	--	--	--	--	--	--
MUSC(FLKNL)+CWT	***	97	0.014	--	--	--	***	85	0.008	--	--	--	--	--	--
MUSC(FLTOP)+CWT	***	99	0.009	--	--	--	***	86	0.008	--	--	--	--	--	--
MUSC(FLOUT)+CWT	***	98	0.011	--	--	--	***	90	0.006	--	--	--	--	--	--

[a] Trial numbers 1, 3, 4, 5, and 6 involved Southdown, Coopworth, Dorset Horn X Coopworth, Romney, and Border Leicester X Romney sheep, respectively.

[b] The significant levels refer to carcass weight for the first row and for the independent variable other than carcass weight for all other rows.

NS=P>0.10; **=P<0.01; ***=P<0.001.

-- indicates no data available.

Prediction from carcass linear and eye muscle dimensions

The means, standard deviations and coefficients of variation of eye-muscle depth to width ratio (B:A ratio), the ratio of eye-muscle area raised to the power of 1.5 and carcass weight (EMA ratio), and the ratio of carcass weight to carcass length cubed (CWT:L^3 ratio) are presented in Table 6.2. More variation was found within the animals of Trial 1 for these predictors than all other trials due to the wider range in carcass weights. There was more variation in the ratio of EMA than in the B:A or CWT:L^3 ratios, especially for Trials 3, 4, and 6.

Table 6.3 shows that simple correlations between these three predictors and standard muscularity were lower than for other potential predictors in Table 6.3, although they varied considerably between trials. The negative correlations between EMA ratio and standard muscularity for Trials 1 and 3 may be explained by negative correlations between these characteristics and carcass weight ($r = -0.76$ and -0.75 for Trials 1 and 3, respectively). Because of the low correlations these three ratios were not evaluated further as predictors of muscularity.

Prediction from a calipers-holding device and measurements on photographs

Table 6.6 shows the means, standard deviations and coefficients of variation of W/L values and bands based on measurements using the calipers-holding device (CHD) or measurements from photographs. The (W/L) values and band values represent a range of those measured rather than including all those that were measured. Most variation was again found within Trial 1, but in general W/L values and band values had similar levels of variation between Trials.

Correlation coefficients between the two W/L values obtained using the CHD and standard muscularity (MUSC(FL)) (Table 6.7) were low to medium in Trials 3, 4 and 6, but slightly higher in Trial 1. For most trials these were appreciably lower than for the comparable measurements made from photographs, so CHD measurements were not evaluated further as predictors.

The mean width to length ratios (W/L) from the photographic method are shown in Table 6.6 and Figure 6.7 to increase with increasing percentage distance from the distal anatomical landmark for the high- and the low-backfat lines. The high-backfat line had higher mean W/L values than the low-backfat line (Figure 6.7).

The results in Table 6.7 shows that the simple correlations of all W/L values with standard muscularity (MUSC(FL)) were higher in Trial 1 than all other trials. The highest correlation coefficients between individual W/L values and standard muscularity (MUSC(FL)) were 0.91, 0.54, 0.69, 0.24 and 0.52 for Trials 1, 3, 4, 5 and 6, respectively. The highest correlations between W/L values and standard muscularity were generally those between (W/L)5 and (W/L)17.

The potential for predicting muscularity from a profile area rather than from single widths was investigated by calculating several bands, as the mean of 10 adjacent widths. Because the distance between widths measured on the projected image was kept constant at 25 mm, the mean of 10 W/L values will be directly proportional to the area of the leg profile that they span. Table 6.7 shows similar correlations for all bands within any trial. Table 6.7 shows that the highest correlation values were obtained for Trial 1 and the lowest correlations were for Trial 5.

Band four (B4) was chosen for further analysis, because it was one of the bands most closely related to the standard muscularity and it contains most of the middle widths (W/L)6-15 which are believed to represent the area with thickest muscling. Table 6.4 and Figure 6.8 shows regression relationships between the standard muscularity and B4 for all breeds and lines. The slopes and the intercepts of the regression lines differed widely. For example, for the two lines of Southdowns at the same B4 value the high-fat line had a significantly higher standard muscularity ($P<0.001$) than the low-fat line. Statistical analyses across trials were not made because the trials were conducted at different geographical regions and at different times. However, the regression relationships between the standard muscularity (MUSC(FL)) and B4 were not similar for all groups. The R^2(%) values match the correlations in Table 6.7.

Table 6.8 shows the predictive ability of the best combinations for each trial of the ten individual W/L values that were used to calculate B4. The best combination within a multiple regression equation was that with the highest R^2 value but with a Mallow's Cp value not less than the number of independent variables in the model. The results show that the data of the Southdown breed (Trial 1) gave the highest R^2 values. This table also shows that R^2 values for combinations of individual W/L values were higher than those when B4 was used for each trial, despite the fact that all 10 W/L values were not used in the multiple regression equations. When more than the number of variables shown were included, the Cp values were lower than the constraint permitted.

The value of different predictors after adjusting for carcass weight effects (Table 6.9) showed that W/L values and B4 for Trial 1 explained a significant proportion of additional variation in standard muscularity. However, in Trials 3, 4, and 6 much less of the variation of standard muscularity was explained after adjusting for carcass weight, and in Trial 5 the predictors did not account for any variation over that accounted for by carcass weight.

Results from the test of the sensitivity of W/L and band values to errors in the location of the two anatomical landmarks are given in Table 6.10 for a selection of W/L values and B4. Position effects were not significant for W/L values 5, 7, 9, 11 and 13, but in the more proximal part of the leg there were significant position effects. B4 values were unaffected by changes in position of the size shown. Table 6.11 shows correlations between the five different positions for the same measurements. These correlations were consistently high in spite of the simulated errors in the location of the anatomical landmarks.

Figure 6.9 shows that differences in the value of B4 when deviations in the distance between the distal and proximal landmarks ranged from -4 to +4% of the correct value, were small compared with differences between the two Southdown selection lines.

The 12 carcasses used in the sensitivity analysis had a mean weight of 27.4 kg (standard deviation = 4.1 kg).

TABLE 6.6 Means, standard deviations, and coefficients of variation for some potential predictors of muscularity based on leg weight to length (W/L) ratios for the 5 trials.

	Trial number[a]														
	1			3			4			5			6		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Predictors based on measurements from the Calipers-holding Device (CHD) (mm/m)															
CHD(W/L)1	1.190	0.129	10.9	1.077	0.067	6.3	0.933	0.050	5.4	--	--	--	0.968	0.065	6.7
CHD(W/L)2	1.086	0.132	12.1	0.968	0.070	7.3	--	--	--	--	--	--	0.883	0.055	6.2
Predictors based on measurements from Photographs (mm/m)															
(W/L)2	267.6	20.99	7.8	221.0	14.08	6.4	216.8	11.64	5.4	226.8	13.28	5.9	215.1	12.68	5.9
(W/L)4	290.4	25.57	8.8	231.3	15.44	6.7	226.8	14.42	6.4	238.7	13.99	5.9	227.4	15.04	6.6
(W/L)6	326.1	37.65	11.5	249.3	16.81	6.7	243.3	14.80	6.1	255.6	15.22	6.0	244.6	16.03	6.6
(W/L)8	367.2	47.24	12.9	280.8	19.85	7.1	262.2	14.96	5.7	276.3	17.46	6.3	269.0	21.4	8.0
(W/L)10	402.0	53.02	13.1	319.1	20.90	6.6	293.2	17.79	6.1	302.6	18.75	6.2	297.2	24.74	8.3
(W/L)12	437.2	56.62	13.0	346.7	24.50	7.1	322.7	18.12	5.6	324.3	31.85	9.8	324.8	22.96	7.1
(W/L)14	473.9	54.4	11.5	373.5	29.77	8.0	349.9	20.70	5.9	348.8	27.39	7.9	349.4	27.13	7.8
(W/L)16	506.7	49.5	9.8	410.2	38.26	9.3	390.3	27.67	7.1	383.8	35.88	9.4	385.2	33.75	8.8
(W/L)18	531.1	44.3	8.3	448.0	42.03	9.4	435.0	32.42	7.5	428.0	38.83	9.1	429.2	37.09	8.6
(W/L)20	545.7	42.5	7.8	465.5	42.60	9.2	458.0	29.64	6.5	465.3	38.80	8.5	456.2	33.98	7.5
Prediction based on band measurements from Photographs[b]															
B2 ((W/L)4-13)	373.8	44.8	12.0	292.4	19.29	6.6	275.3	15.90	5.8	285.4	17.64	6.2	278.9	19.46	7.0
B4 ((W/L)6-15)	410.6	49.7	12.1	321.8	22.50	7.0	301.1	17.64	5.9	307.9	20.47	6.7	304.2	22.14	7.3
B6 ((W/L)8-17)	445.9	51.2	11.5	354.9	26.88	7.6	332.1	19.8	6.0	335.0	24.79	7.4	333.5	27.79	7.7
B8 ((W/L)10-19)	477.7	50.2	10.5	387.3	31.21	8.1	366.4	18.1	4.9	365.7	29.09	8.0	365.6	28.81	7.9

[a] Trial numbers 1, 3, 4, 5, and 6 involved Southdown, Coopworth, Dorset Hom X Coopworth, Romney, and Border Leicester X Romney sheep, respectively.

[b] Bands represent the means of 10 adjacent W/L values as indicated.

-- indicates no data available.

TABLE 6.7 Simple correlation coefficients (r x 100) between a standard muscularity (MUSC(FL)) derived from the five muscles around the femur and measures of muscle depth to length ratio, using a calipers holding device (CHD) or from lateral photographs.

	Trial number[a]				
Predictor	1	3	4	5	6
n	80	47	38	26	31
Measurements from the Calipers-holding Device (CHD)					
CHD(W/L)1	78	27	30	--	41
CHD(W/L)2	80	17	--	--	53
Measurements from photographs					
(W/L)1	84	11	52	15	41
(W/L)2	84	18	53	12	40
(W/L)3	86	31	50	11	41
(W/L)4	89	40	48	12	41
(W/L)5	90	47	50	7	42
(W/L)6	91	52	52	18	46
(W/L)7	91	54	32	22	47
(W/L)8	90	52	64	15	47
(W/L)9	90	43	69	20	51
(W/L)10	91	35	65	20	52
(W/L)11	90	35	65	21	50
(W/L)12	89	39	64	-3	50
(W/L)13	87	41	61	22	48
(W/L)14	85	45	59	22	48
(W/L)15	85	46	61	20	47
(W/L)16	83	48	57	24	49
(W/L)17	82	49	56	23	49
(W/L)18	81	49	-1	18	46
(W/L)19	80	48	3	15	44
(W/L)20	80	43	8	13	42
(W/L)21	80	42	8	12	43
Band measurements from photographs[b]					
B1 (W/L)3-12	92	45	61	14	49
B2 (W/L)4-13	92	46	62	16	50
B3 (W/L)5-14	91	46	63	17	50
B4 (W/L)6-15	91	46	63	18	50
B5 (W/L)7-16	90	46	63	19	50
B6 (W/L)8-17	89	46	65	20	51
B7 (W'L)9-18	88	46	64	20	50
B8 (W/L)10-19	87	47	61	19	49
B9 (W/L)11-20	86	47	57	18	48

[a] Trial numbers 1, 3, 4, 5, and 6 involved Southdown, Coopworth, Dorset Horn X Coopworth, Romney, and Border Leicester X Romney sheep, respectively.

[b] each band was calculated as the mean of 10 adjacent W/L values.

-- indicates no data available.

FIGURE 6.7 Mean changes in adjusted leg width to length ratios (W/L) with an increasing percentage of the distance from the distal to the proximal anatomical landmarks for carcasses from the high- and low-backfat selection lines. Of the 21 values shown the first 11 and the last 2 were significantly higher for the high-backfat line.

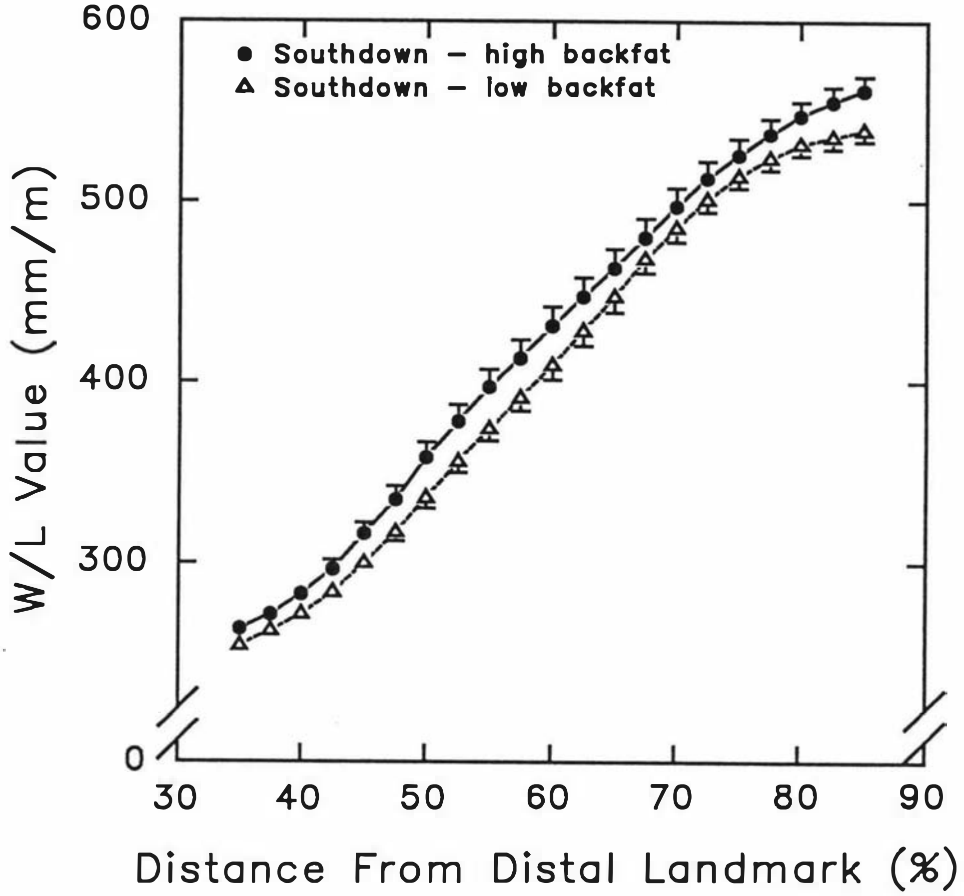


FIGURE 6.8 Linear regressions relating the standard muscularity index (MUSC(FL)) to B4 for the high- (L1) and low- (L2) backfat Southdown selection lines (Trial 1), the Coopworth (CPW, Trial 3), the Dorset horn X Coopworth (DSXCPW, Trial 4), the Romney (ROM, Trial 5), and the Border Leicester X Romney (BLXROM, Trial 6) groups.

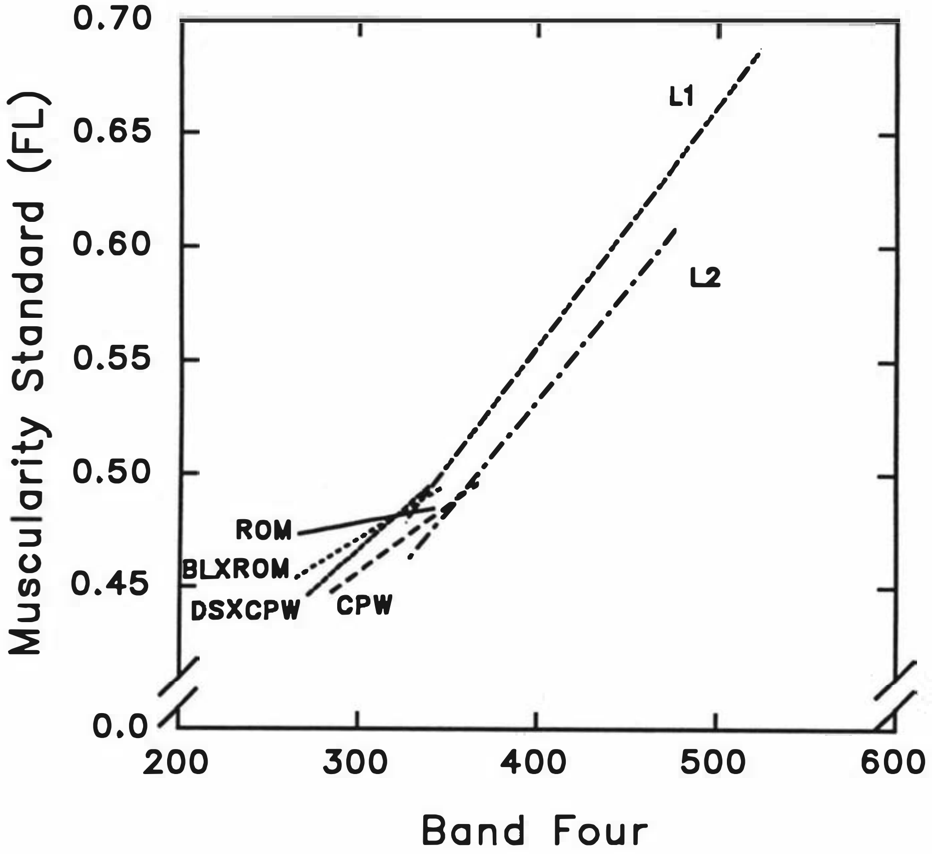


TABLE 6.8 Coefficient of determination ($R^2\%$) and Mallow's Cp values from fitting the 10 W/L values used to calculate Band 4 in multiple regression models for the five trials.

Trials[a]	No. of variables in model	$R^2\%$	Cp	W/L values in the model	$R^2\%$ for B4 alone
1	6	85	6.001	(W/L)no. 6,10,11,13,14,15	83
3	9	41	9.002	(W/L)no. 6,7,8,9,10,11,13,14,15	21
4	6	54	6.005	(W/L)no. 7,8,11,12,13,15	40
5	6	30	6.003	(W/L)no. 6,7,8,9,12,13	3
6	9	35	9.007	(W/L)no. 6,7,8,9,10,11,12,14,15	25

[a] Trial numbers 1, 3, 4, 5, and 6 involved Southdown, Coopworth, Dorset Horn X Coopworth, Romney, and Border Leicester X Romney sheep, respectively.

TABLE 6.9 The accuracy of potential predictors of standard muscularity (MUSC(FL)) when included along with carcass weight (CWT) in multiple regression equations. Measures of accuracy given are the coefficient of determination (R^2%) and the residual standard deviation (RSD) for the 5 trials.

	Trial number[a]														
	1			3			4			5			6		
Predictor(s)	Sig[b]	R^2%	RSD	Sig	R2%	RSD	Sig	R2%	RSD	Sig	R2%	RSD	Sig	R2%	RSD
Carcass weight alone															
CWT	***	71	0.045	***	52	0.020	NS	4	0.019	NS	8	0.017	NS	7	0.021
Carcass weight + Width to length ratios from photographs															
(W/L)6+CWT	***	87	0.022	***	60	0.019	**	40	0.016	NS	12	0.017	*	24	0.019
(W/L)7+CWT	***	87	0.022	***	59	0.019	+	21	0.019	NS	12	0.017	*	26	0.019
(W/L)8+CWT	***	86	0.022	***	61	0.019	**	48	0.015	NS	10	0.017	*	24	0.019
(W/L)9+CWT	***	86	0.023	***	59	0.019	**	52	0.014	NS	11	0.017	*	27	0.019
(W/L)10+CWT	***	85	0.023	***	59	0.019	**	47	0.015	NS	11	0.017	**	29	0.019
(W/L)11+CWT	***	84	0.024	***	59	0.019	**	46	0.015	NS	12	0.017	*	27	0.019
(W/L)12+CWT	***	83	0.025	***	59	0.019	**	44	0.016	NS	10	0.017	*	27	0.019
(W/L)13+CWT	***	80	0.027	***	59	0.019	**	41	0.016	NS	12	0.017	*	25	0.019
(W/L)14+CWT	***	78	0.028	***	59	0.019	**	38	0.016	NS	12	0.017	*	25	0.019
(W/L)15+CWT	***	78	0.028	***	58	0.019	**	40	0.016	NS	10	0.017	*	23	0.020
Carcass weight + Band 4 from photographs															
B4+CWT	***	85	0.023	***	60	0.019	**	44	0.016	NS	11	0.017	*	27	0.019

[a] Trial numbers 1, 3, 4, 5, and 6 involved Southdown, Coopworth, Dorset Horn X Coopworth, Romney, and Border Leicester X Romney sheep, respectively.

[b] The significant levels refer to carcass weight for the first row and for the independent variable other than carcass weight for all other rows.

NS=P>0.10; +=P<0.10; *=P<0.05; **=P<0.01; ***=P<0.001.

TABLE 6.10 Means for selected W/L values (mm/m) and B4 for 12 carcasses when measured after projecting the slides so that the actual difference between the distal and proximal anatomical landmarks was 96,98,100,102,and 104% of the measured distance on the screen.

	Position[d]							
	96	98	100	102	104	effect	R^2%	RSD
(W/L)5	337	333	334	332	330	NS	95	10.7
(W/L)7	375	371	373	371	369	NS	98	8.0
(W/L)9	417	413	414	412	408	NS	98	8.5
(W/L)11	447	453	455	454	451	NS	97	10.0
(W/L)13	489	487	491	491	489	NS	99	6.7
(W/L)15	513^a	515^a	521^b	524^b	524^b	***	99	5.9
(W/L)17	527^a	533^a	540^b	546^c	549^c	***	98	6.8
(W/L)19	539^a	547^b	552^b	561^c	565^c	***	97	8.1
B4(W6-16)	439	439	441	441	437	NS	99	5.4

[a,b,c] Means within a row without the same letter in their superscripts are significantly different (P<0.05).

[d] Distance between distal and proximal anatomical landmarks relative to the true distance which is given as 100.

NS=P>0.10; ***=P<0.001.

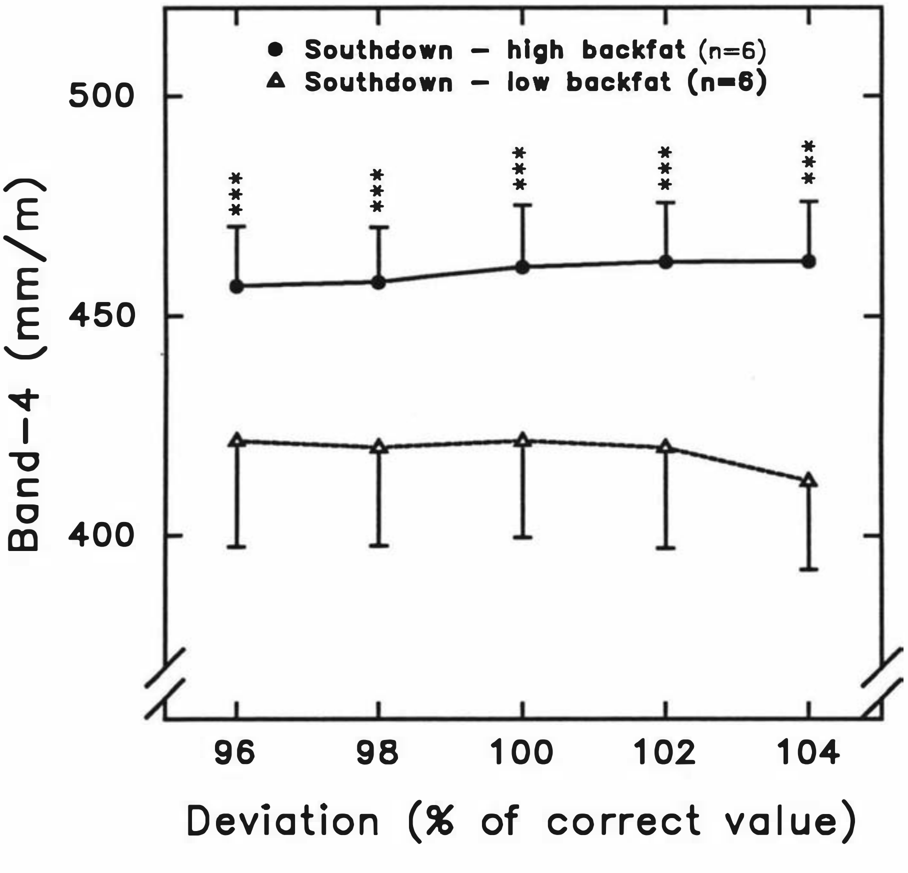
TABLE 6.11 Simple correlation coefficients (r X 100) between the different positions described in Table 6.10 for several W/L values and B4 of 12 carcasses.

	Correlations between measures separated by:									
	2pp's[a]				4pp's			6pp's		8pp's
	96/98[b]	98/100	100/102	102/104	96/100	98/102	100/104	96/102	98/104	96/104
(W/L)5	97	99	98	98	94	97	97	90	94	84
(W/L)7	98	99	99	98	97	99	98	97	97	93
(W/L)9	98	99	99	98	97	99	98	97	97	94
(W/L)11	93	99	99	99	93	99	99	93	98	92
(W/L)13	98	99	99	99	98	99	99	97	99	97
(W/L)15	99	99	99	99	98	99	99	98	99	97
(W/L)17	98	99	99	99	96	98	99	95	99	96
(W/L)19	94	96	99	99	97	94	99	97	96	96
B4(W6-15)	99	99	99	98	99	99	99	99	99	98

[a] pp's = percentage points.

[b] 96/98 = 96% location vs 98% location.

FIGURE 6.9 Changes in mean (± SE) values of B4 for 6 carcasses of each of the two Southdown selection lines when measured after projecting the slides so that the actual differences between the distal and proximal anatomical landmarks were 96, 98, 100, 102 and 104% of the measured distance on the screen.



DISCUSSION

The assessment of the accuracy of prediction

In assessing the relative importance of different statistical methods for evaluating prediction accuracy, Kempster *et al.* (1982) showed that the correlation coefficient is always influenced by the range of values in the sample on which it is based and thus is only satisfactory for comparing predictors within the same sample of carcasses. It is not, however, suitable for comparing the precision obtained in different samples of carcasses because those samples with a wider variation in the independent variable (X) will show higher correlation coefficients, other things being equal. They pointed out that, for comparisons between samples, the residual standard deviation (RSD) is a much better criterion because it takes into account variation in the dependent variable (Y) for the different populations. Similar conclusions were reached by Fisher (1990) and Savell & Cross (1991).

Kempster *et al.* (1982) also discussed the problem of bias in prediction equations, and referred to relationships which were represented by different equations in different samples as being unstable. Predicted values obtained by using inappropriate equations due to the instability of a relationship will be biased. Levels of instability may be assessed by testing for significant differences between equations in intercepts or slopes or both. However, Kempster *et al.* (1982) noted that for carcass composition characteristics intercepts frequently differ, but that significant differences in slope rarely occur unless there is a very wide variation among the animals being examined.

In the present study animals came from different trials, so different predictors within each trial were assessed first by simple correlation coefficients with standard muscularity. Then for those predictors with good correlation coefficients, additional investigations were carried out to identify the closeness of the relationships across the trials on the basis of RSDs. In addition the stability of relationships between trials was assessed by plotting the regression equations. Finally, potential predictors were evaluated by assessing their value over and above carcass weight alone. This is an important question from a practical point of view as carcass weight information will always be available and it is known that there is a significant positive relationship between carcass weight and muscularity (Purchas *et al.,* 1991; Chapter 3). Therefore the most useful additional predictor will be one that explains variation in muscularity that is not accounted for by carcass weight.

Prediction from individual muscles and commercial cuts

There was a trend for higher correlation coefficients between standard muscularity and muscularity based on less than 5 muscles as the number of muscles used increased. This trend is supported by results showing that the weight of total muscle in the leg or a group of muscles were more closely related to total side muscle than were the weights of individual muscles (Orme *et al.* (1960) for beef; Orme *et al.* (1962) for sheep; Butterfield (1964) for cattle; and Cole *et al.* (1976) for pigs).

Anous (1989) studied the relationships between M:B ratios of individual muscles and the total M:B ratio in the hind limb of 52 ram lambs of different morphological types slaughtered at a comparable stage of body development, and showed that the M:B ratios of the *M.biceps femoris* or *M.semimembranosus* to the femur bone weight had the highest correlations values with total M:B ratio in the hind limb. This agrees with the present study where muscularity based on *M.biceps femoris* or *M.semimembranosus* had higher correlations with standard muscularity than muscularity based on any of the other muscles examined, although Anous considered M:B rather than muscularity.

Other studies have shown that *M.biceps femoris* weight had higher correlations with side muscle weight than any other leg muscles examined (Orme *et al.,* 1960; Orme *et al.,* 1962; Butterfield, 1962; Butterfield, 1964; and Cole *et al.,* 1976). The results of the present study suggest that either *M.semimembranosus* or *M.biceps femoris* could satisfactorily be used to calculate muscularity values instead of the standard muscularity. This would represent a considerable saving in dissection time.

Combining the weights of two or more muscles led to little improvement in predictive ability for most trials. However, the largest improvements were observed when either *M.biceps femoris* or *M.semimembranosus* were combined with other muscles (eg. MUSC(FL3,1)).

In two trials where the weights of trimmed boneless commercial cuts were used to calculate muscularity values, muscularity based on the combined weight of the three cuts was about as accurate as muscularity based on four muscles (MUSC(FL4)). Each of the three individual cuts (knuckle, topside, and outside) in Trial 1 gave correlations similar to that for the 3 cuts combined, but in Trial 4, the outside cut gave the highest correlation. This difference between the trials may have resulted from using animals in Trial 1 with a wider range of slaughter weights. Purchas *et al.* (1992) found that muscularity and M:B ratio based on the sum of the weights of the knuckle, topside, and outside cuts, and femur length and weight proved to be good indexes that discriminated well between groups of bulls with contrasting subjective muscularity. Thus, the muscularity of the Piedmontese X Friesian and Belgian Blue X Friesian groups were significantly superior to the Friesian group, but the muscularity index did not differ between Piedmontese- and Belgian Blue-cross bulls.

This work with bulls using either the topside or the outside cuts alone in calculating muscularity gave the same results as all three cuts combined, but using the knuckle weight alone showed no group differences. Muscularity based on the knuckle cut or M.quadriceps femoris weight was also relatively poor as a predictor in the current trials (Table 6.3).

Prediction from carcass linear and eye-muscle dimensions

Relationships between standard muscularity and either the ratio of eye muscle depth to width, weight-adjusted EMA, or length adjusted carcass weight were poor, indicating that these would not be useful predictors. Similar measurements have also been shown to be poor predictors of carcass lean content in lamb (Kempster & Cuthbertson, 1977; and Wolf *et al.*, 1981) and beef (Kempster & Harrington, 1980; and Dolezal *et al.*, 1982).

In a survey of the carcass characteristics of the main types of the British lamb, Kempster & Cuthbertson (1977) found low correlations between eye-muscle area and lean:bone ratio (r=0.38). A similar low correlation was reported by Wolf *et al.* (1981) between eye-muscle area and lean:bone ratio (r=0.33) in crossbred lambs. For 68 steers and heifers ranging in carcass weight from 167.8 kg to 324.3 kg Dolezal *et al.* (1982) found poor correlations between muscle to bone ratio and *longissimus* muscle area, adjusted *longissimus* muscle area, adjusted *longissimus* muscle area/carcass length, and a subjective muscling score (r=0.50 to 0.59). Hankins *et al.* (1943) reported that correlations between M:B ratio and either length of hind leg, thickness of muscle and fat over rib, or the ratio of length of body to empty body weight had lower correlations (-0.07, 0.29, and -0.27, respectively) within beef type cattle than within dual-purpose type cattle (-0.28, 0.30, and -0.19, respectively), but in all cases the measurements were of little value as a means of predicting M:B ratio. Other studies showing the limitations of linear and area measurements as predictors of muscle to bone ratio or meat yield have been reviewed in Chapter 2.

Prediction from a calipers-holding device (CHD) and the photographic methods

These two methods were devised to obtain measures of leg thickness at fixed proportions of the distance between two anatomical landmarks that could be located easily and accurately. Provided such thicknesses reflected differences in muscle thickness they should be indicative of muscularity (as defined by De Boer *et al.* (1974)) when expressed relative to a skeletal dimension. Fisher (1990) found that measures of thickness in the area of the ischium (pin bone) were mainly indicative of muscling rather than fatness for cattle.

Correlations between width to length (W/L) ratios measured using the calipers-holding device (CHD) and standard muscularity were too low to be of predictive value, and were lower than similar values obtained from photographs. This was attributed to difficulties in using and adjusting the CHD. Particular problems were experienced in ensuring that the platform holding the calipers was horizontal and in ensuring that the CHD was anchored accurately at the distal anatomical landmark. Also, because the leg length or the length of the distance between the distal and proximal landmarks measurements were not available for all trials, the widths measured from the CHD were divided by carcass length to obtain a ratio of weight to length. Better results may have been obtained if a leg length had been used in place of carcass length. If further work is to be done with the CHD it is suggested that the first step should involve a test of the repeatability of measurements both within the same operator and between different operators.

In the present study the highest correlations between the W/L values from the photographic method and standard muscularity across the trials were obtained for widths located around the middle of the leg ((W/L)5 to (W/L)17). Dumont (1989) concluded after examining the conformation of the ham (proximal pelvic limb) of pigs using photographic diapositives of the medial and dorsal views that the best measurements of conformation were located in the distal third of the ham. In contrast, the highest correlations with M:B ratio were closer to the middle part of the ham. Relationships between widths and M:B ratios were generally higher for the dorsal view than the medial view. In the current work, only lateral view was used. Otherwise the method used by Dumont (1989) was similar to that in the current work with 26 equidistant points being constructed on the traced profiles after projecting the photographic diapositives of the medial and dorsal views of hams. Then, 26 transverse apparent diameters were drawn perpendicular to the line joining the calcaneal tuber to the cranial edge of the pubic symphysis.

Bands encompassing 10 W/L values were investigated because it was considered that they simulated the sort of area measurement that could readily be made using video image analysis provided the anatomical landmarks were located. However, the combining of 10 W/L values into a band did not improve the accuracy of prediction relative to the best of the individual W/L values (Table 6.9). Furthermore the accuracy of prediction of muscularity from Band 4 was appreciably lower than prediction from muscularity based on single muscles or cuts (Table 6.4). A weak feature of Band 4 as a predictor of muscularity was the instability of the regression relationships between trials and even between the two genetic lines within Trial 1 (Figure 6.8). Finally, the value of Band 4 as a predictor varied considerably between trials with a very low predictive value in Trial 5, particularly after the effects of carcass weight had been taken into account (Table 6.9).

The results reported here are generally consistent with those reported from two similar studies on beef that were described in detail in Chapter 2 (Sorensen, 1984; Eldridge, 1989). The difference between the current study and those of Sorensen (1984) and Eldridge (1989) is that the dependent variable being predicted was an objective measure of muscularity based on dissections rather than subjective scores or, in the case of Sorensen (1984), M:B ratio.

Whether it is better to use dorsal/ventral or lateral/medial views of the pelvic limb to evaluate muscularity is not clear from the literature. Many carcass classification or grading systems including the MLC (United Kingdom) and the New Zealand export beef systems use both dorsal and lateral views to subjectively assess carcass muscularity or conformation (MLC, 1975; NZMPB, 1992). The classification for lamb conformation and muscling classes by the MLC procedure and the New Zealand export lamb system are based on the dorsal view only (MLC, undated; NZMPB, 1992). A system for lamb carcass evaluation recommended by a committee of American Meat Science Association included dorsal views of lamb legs to illustrate differences in leg conformation for the purpose of lamb carcass contests (AMSA, 1979). In Australia, the Aus-Meat classification system for beef uses the lateral view for assessing muscling class (Hall & Brownlie, 1989). The Danish Meat Research Institute developed a method of measuring beef carcass conformation from a lateral view by means of Video Image Analysis (Sorensen *et al.,* 1988). De Boer *et al.* (1974) established reference methods for the assessment of carcass fleshiness by making photographic slides of beef carcasses from different angles (dorsal view, mid-way between dorsal and lateral, and between dorsal and medial).

Dumont (1989) reported larger variation between animals for width measurements from the dorsal view than from the lateral view for pig carcasses. Eldridge (1989), in contrast, reported higher correlations between the width of the thigh of beef carcasses from the lateral view and subjective scores taken by a team of assessors, than the width of the thigh from the dorsal view. The present study assessed the CHD and the use of photographs with only a lateral view. Consideration of other views may prove useful.

Although measurements from lateral photographs of legs proved to be only moderately effective as predictors of the standard muscularity in the current study, the lack of a higher accuracy did not appear to be due to errors in locating the anatomical landmarks. Experiments showed that errors in location larger than the sort that may be expected to arise had little effect on the size of the W/L or band values obtained.

SUMMARY AND CONCLUSIONS

1. Data from five trials involving 222 lamb and sheep carcasses were used to evaluate relationships between an objective muscularity index based on five muscles around the femur and femur length (MUSC(FL)) and several predictors. Predictors included muscularity based on individual leg muscles, muscularity based on commercial boneless cuts, eye-muscle measurements, carcass weight per unit length and linear measurements made on photographs of a leg or directly on the leg.
2. The accuracy of prediction was assessed on the basis of correlation coefficients and residual standard deviations and variation between regression equations in terms of their slopes and intercepts.

3. Of the individual muscles considered, either *M.semimembranosus or M.biceps femoris* were most accurate as a basis for muscularity measurement. Similarly the two best cuts as predictors were the topside and the outside cuts.

4. Carcass linear and eye-muscle dimensions were poor as predictors of standard muscularity.

5. Leg width to length (W/L) measurements obtained from a Calipers-holding device (CHD) or from photographs were assessed as predictors of the standard muscularity, but only those from photographs proved useful.

6. Individual (W/L) values or groups of (W/L) values combined as bands were moderately effective as predictors for some trials. However, the regression prediction equations varied between trials with regard to slope and intercept.

7. It is concluded that reasonably satisfactory objective measures of muscularity may be calculated from the weight of one dissected muscle or trimmed boneless cut and femur length. Some indication of muscularity may be obtained from linear measurements on intact legs, but more research is needed to identify the best way of doing this.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

Muscularity has been defined in Chapter 1 and 2 and the reasons for studying this characteristic are also given in both chapters. Muscularity provides an indication of muscle thickness relative to skeletal dimensions. It is not the same as the muscle:bone ratio which, along with fatness, determines carcass meat yield. Although increases in muscularity in meat animals are usually associated with higher M:B ratios, this has not always been shown to be the case.

The general objective of this study was to evaluate the proposed objective index of muscularity of Purchas *et al.* (1991) using sheep showing a range of muscularity levels as the experimental model. The seven specific objectives of this project that were outlined in Chapter 1 have been used to provide a framework below. For each objective an overall summary is given, together with conclusions. Within this section the standard muscularity calculated from the weight of the five muscles around the femur and femur length is designated MUSC(FL).

Objective 1

With increasing carcass weight, MUSC(FL) increased at a decreasing rate so that there was an approximate linear relationship between MUSC(FL) and log carcass weight. The Southdown backfat selection lines diverged in MUSC(FL) from an early age with the high-backfat line rams having higher values throughout growth. The corresponding M:B ratio showed a similar pattern of change with increasing carcass weight but the pattern was parallel for the two selection lines.

Objective 2

Comparisons of muscularity in different anatomical regions showed higher values for rams from the high-backfat line for all regions investigated, but the difference was clearest in the femur region. The reasons for this may be related to the accuracy with which the five leg muscles can be dissected, and the fact that these muscles are more closely associated with that bone than for the other regions considered.

Objective 3

The low-backfat line had longer and larger bones at the same muscle plus bone weight. However, at the same bone length, bone shape of the femur and several other bones did not differ in a consistent way between the selection lines. Some dimensions of some bones differed between the lines, but these did not appear to be related to the differences in MUSC(FL).

Objective 4

The rams from the high-backfat line had a significantly lower proportion of intermediate fibres in the *M.semitendinosus* (by 2.6%) but a similar proportion of the other fibre types. There were no significant differences between lines in the patterns of change with carcass weight in total transverse section area, the mean muscle fibre transverse area or the total fibre number for *M.semitendinosus*. Although there was some increase in total fibre number immediately after birth, this was small compared with the increase in size of fibres during growth. The lack of a line effect on muscle fibre characteristics may have been because the muscle chosen did not differ between the lines in weight at a set muscle plus bone weight.

Objective 5

By using sheep showing a range of muscularity levels, MUSC(FL) and M:B ratios were shown to increase with increasing carcass weight, with the Southdown breed having a higher MUSC(FL) and M:B ratio than Texel-crosses, which in turn had higher values than other breeds and crosses. Texel-cross rams had higher MUSC(FL) and M:B ratios than Romney rams at the same weight. Within the Coopworth breed there was an advantage of females over males for MUSC(FL) and M:B ratio at a similar carcass weight. Dorset Horn-cross cryptorchids had a higher M:B ratio, but a lower MUSC(FL) than Coopworth rams at a similar carcass weight, indicating that these two characteristics can change independently. Other indexes of muscularity based on eye-muscle dimensions and length-adjusted weight did not always differ between groups in the same way as MUSC(FL), suggesting that they have limitations as indicators of muscularity.

Objective 6

Relationships between objectively measured MUSC(FL) and subjective assessments of muscularity or conformation in two trials with lambs and one trial with bulls were satisfactorily close. The corresponding M:B ratio was less effective as a predictor of subjective scores, and measurements based on eye-muscle dimensions and length-adjusted carcass weight were relatively poor. It is suggested that MUSC(FL) may be useful as an objectively-measured standard in carcass classification schemes.

Objective 7

In evaluations of potential predictors of MUSC(FL) that involved relatively simple measurements, it was shown that muscularities based on femur length and the weight of either *M.semimembranosus* or *M.biceps femoris* were the most accurate. MUSC(FL) was predicted almost as accurately from muscularities calculated from femur length and the topside and outside commercial boneless cuts. The indexes of muscularity calculated from carcass linear and eye-muscle dimensions were poor as predictors of MUSC(FL).

Leg width to length (W/L) ratios obtained from a calipers-holding device when assessed as predictors of the standard muscularity also proved to be poor predictors, but similar W/L measurements from photographs were useful. Individual W/L values or groups of W/L values combined as bands were moderately effective as predictors for some trials. However, the regression prediction equations varied between trials, indicating that more research is needed to evaluate the potential of this approach. The possibility of using W/L ratios as predictors of MUSC(FL) is attractive because of the likelihood that they could be measured on the intact carcass using video image analysis.

Overall, the results of the present research studies have demonstrated the usefulness of the general approach of measuring muscularity objectively by taking the square root of muscle weight per unit length of an adjacent bone and dividing this by bone length.

The availability of an objective measurement such as this should be useful as a means of the testing the repeatability and accuracy of subjective scoring procedures and in determining the extent to which muscularity is important in affecting the consumer acceptability of meat products.

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APPENDICES

Appendix 1

TABLE A1.1 Definitions of carcass linear measurements.

Measurement	Definition
1.Body length (LB)	From the point where the gambrel is inserted through the achilles tendon to a point just anterior to the point of the humerus (Moxham and Brownlie, 1976).
2.Leg length (T)	From the distal end of the tarsals to the centre of the tuberosity of the tibia, which is visible on the ventral aspect of the hanging carcasses (Palsson, 1939).
3.Gigot width (G)	Maximum width of the gigots, with the carcass suspended from the gambrel. The measurement was taken at right angles to the length of the carcass at a line level with the femoral trochanter (Palsson, 1939).
4.Maximum shoulder	Maximum width of the shoulder, measured at the level of the width (WF) scapula from one lateral surface to the other, using a caliper (Palsson, 1939).
5.Width behind shoulder (WTh)	Minimum width behind the scapula (Palsson, 1939).
6[a].Fat thickness (C)	The depth of subcutaneous fat over B at right angles to the skin (Palsson, 1939).
7[a].Fat thickness (J)	The depth of subcutaneous fat over the *M.obliquus externus abdominis* (Palsson, 1939).
8[a]Fat thickness (S2)	The depth of subcutaneous fat over the *M.latissimus dorsi* at apoint at right angles to the mid-line bone (Kirton *et al.*, 1967).
9[a].Tissue thickness	The depth of tissue over the surface of the rib at a point 110 mm (GR) from the mid-line (Frazer, 1976).
10[a].*M.longissimus* width (A)	The maximum width across the surface of the *M.longissimus*.
11[a].*M.longissimus* depth (B)	The maximum depth at right angles to the width measurement.
12[a].Area of *M. longissimus*	Area of the cut surface was traced on a tracing paper and the area was determined by using a digitising tablet and the Versacad programme.
13[b].Fat thickness (L3)	Fat thickness over the ventral edge of *M.gluteus medius* (Kirton and Johnson, 1979).

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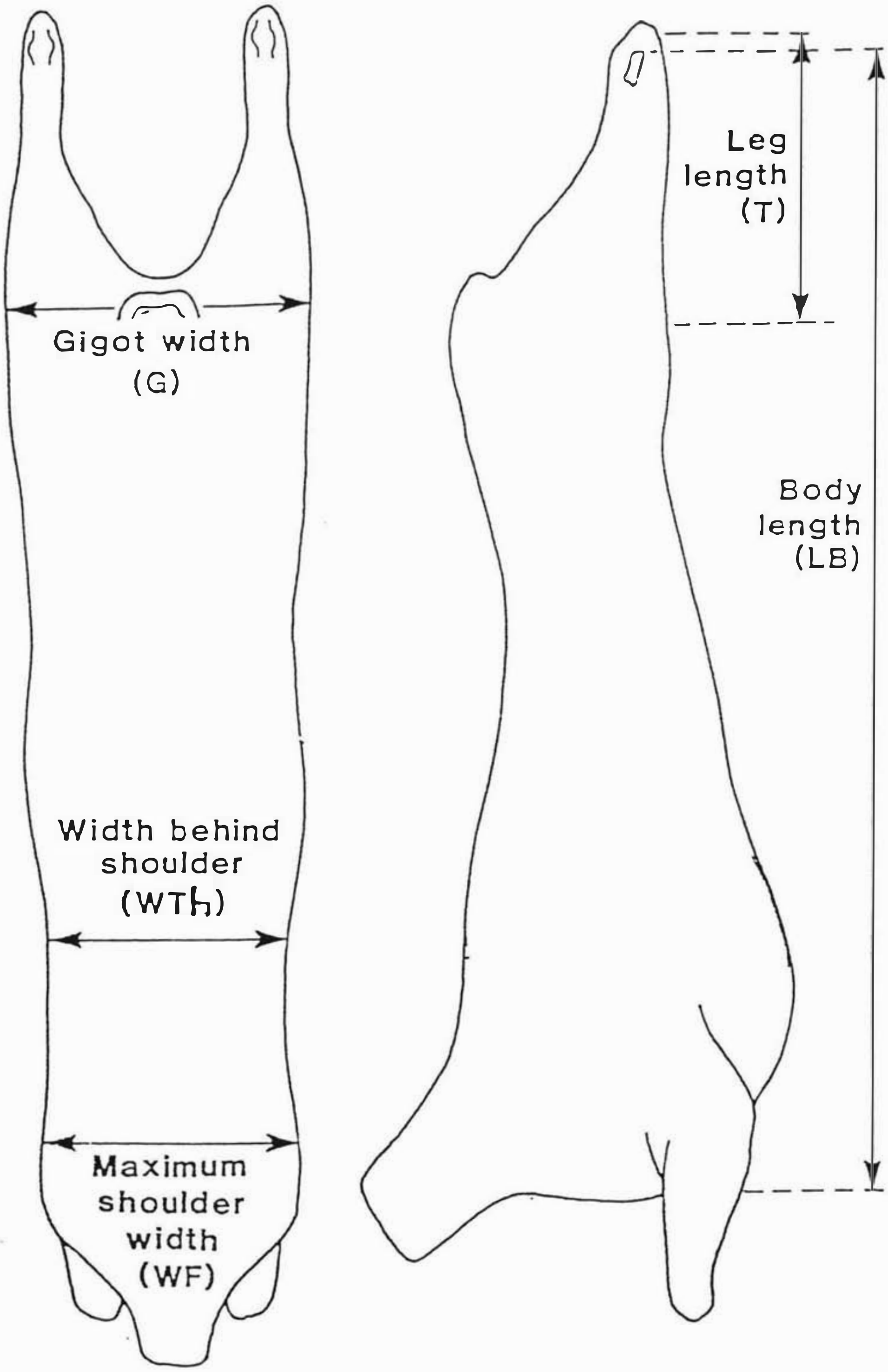
[a] Measurements were taken on the cut surface between ribs 12 and 13 (Figure 3.4)

[b] Measurements were taken on the cross-section of the leg cut (Figure 3.4)

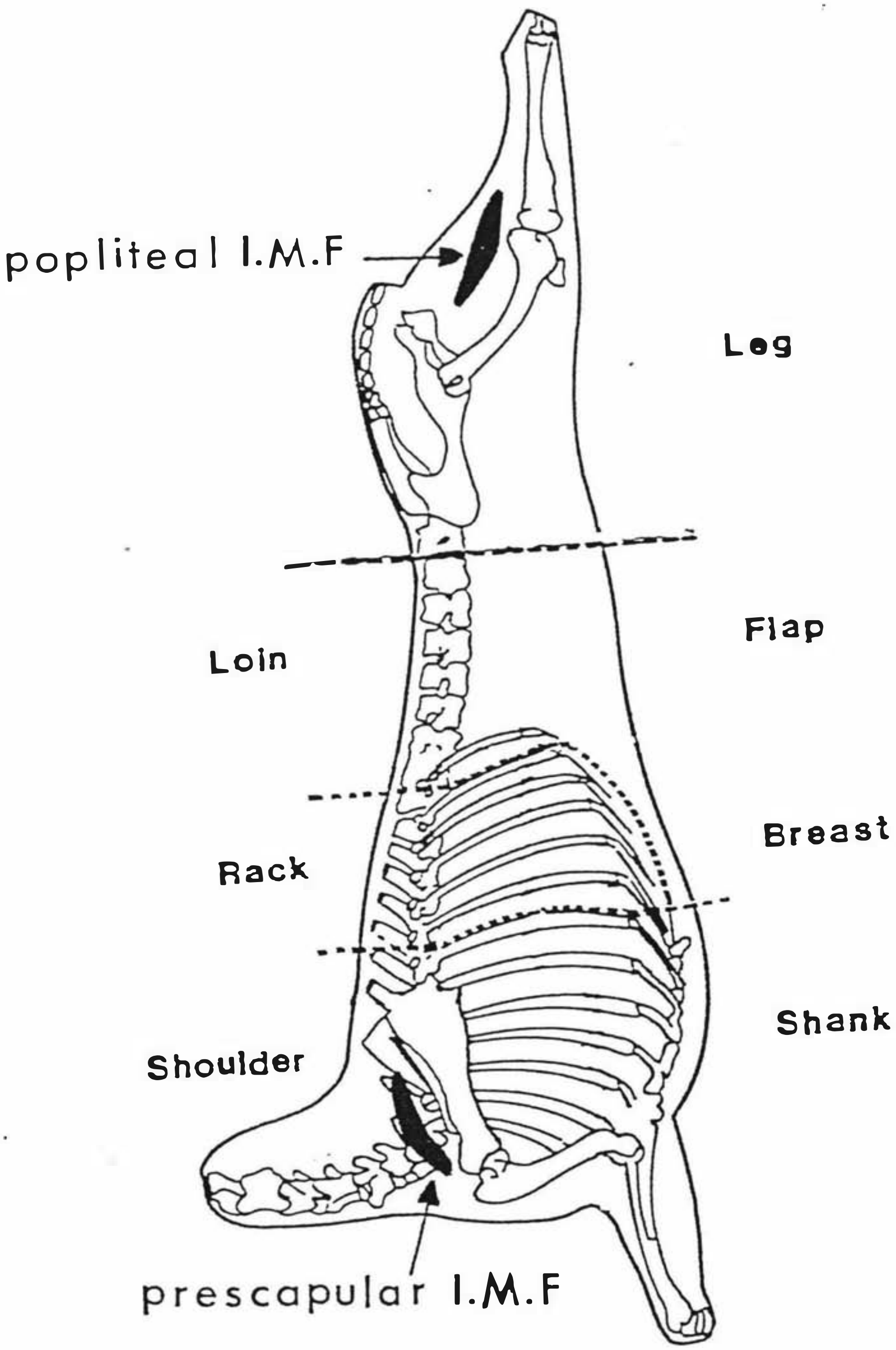
Appendix 1

FIGURE A1.1 A diagram indicating where measurements were taken on the hanging carcass.



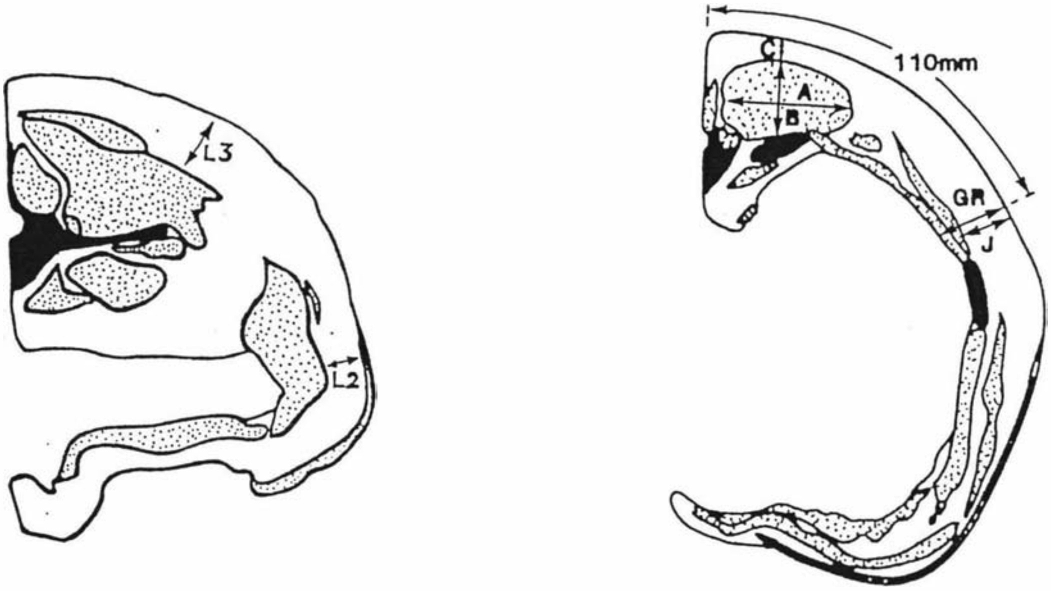
Appendix 1

FIGURE A1.2 A carcass showing positions of the standardised cuts (dotted lines). The locations of the two intermuscular fat depots (IMF) used in this study are also shown.



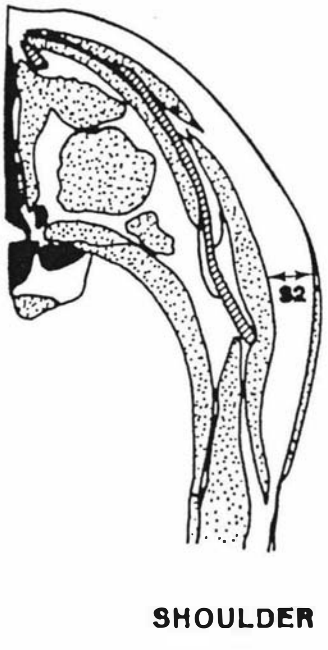
Appendix 1

FIGURE A1.3 Diagrams indicating where measurements were taken on three cut surfaces of the carcass. The shoulder cut was made between ribs 7 and 8, the loin cut was made between the 12th and 13th ribs, and the leg cut was between the last and second to last lumbar vertebrae.



LEG

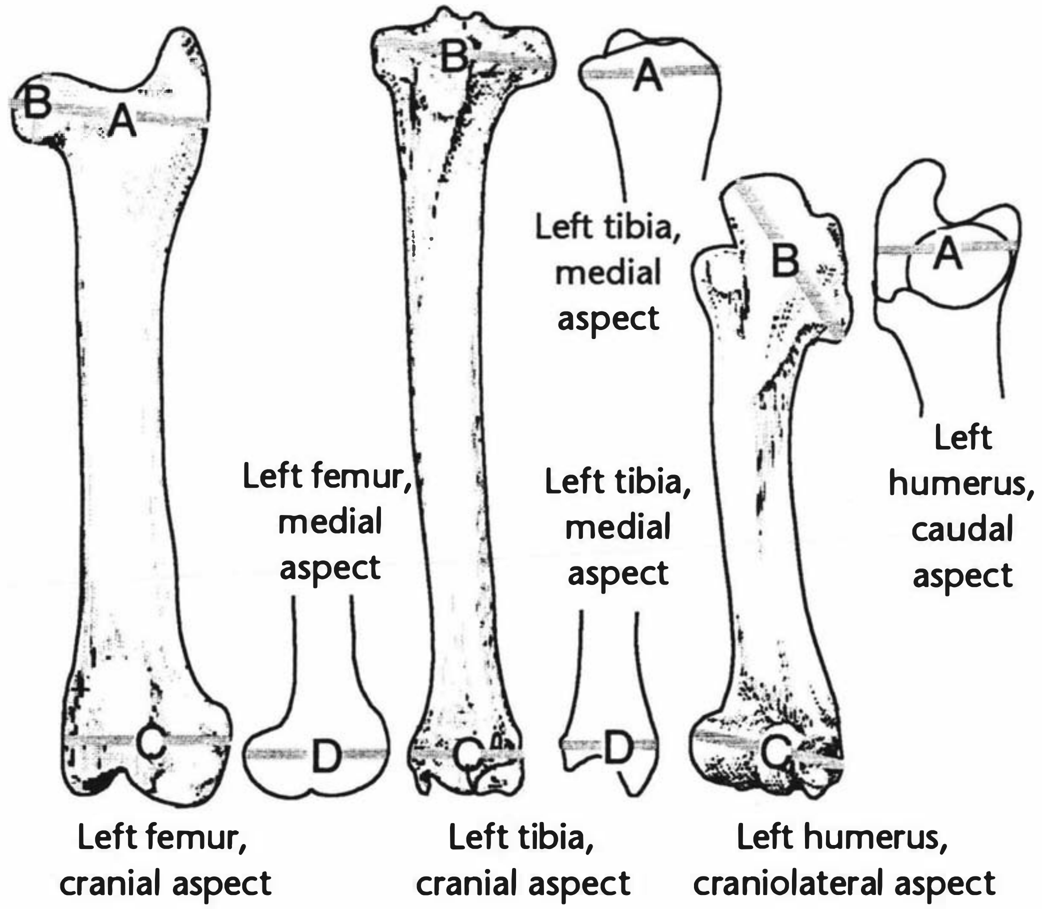
LOIN



SHOULDER

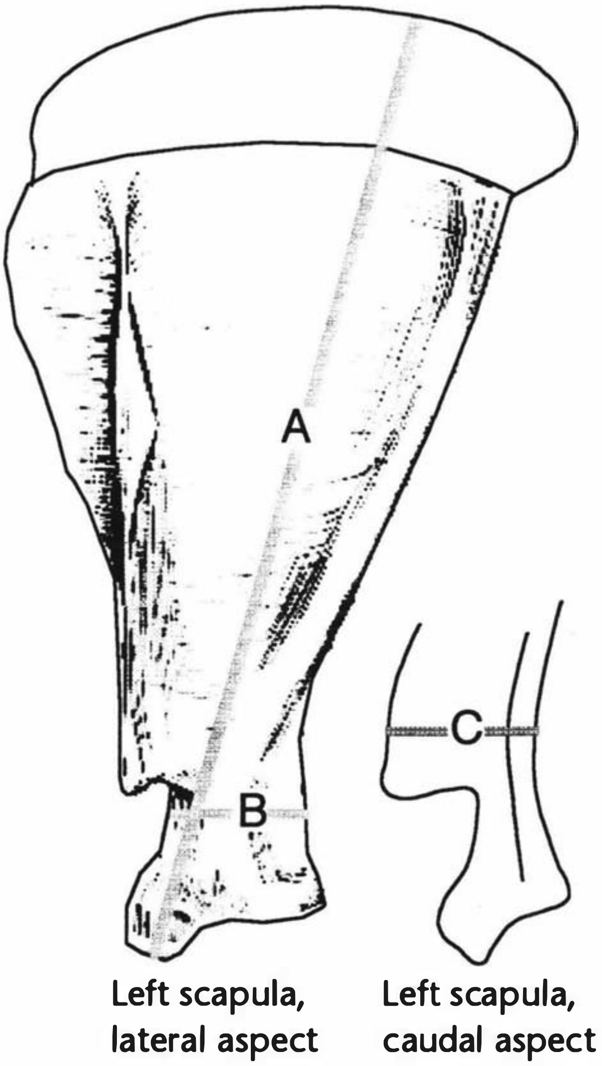
Appendix 1

FIGURE A1.4 Diagrams indicating where measurements were made for three bones.



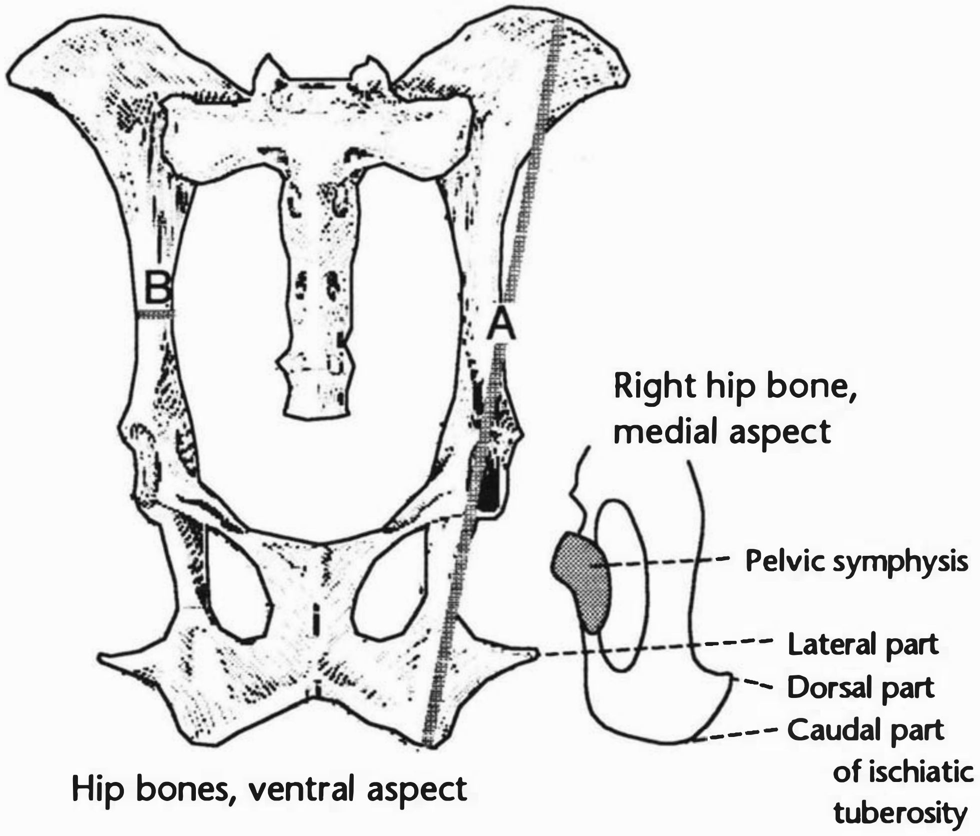
Appendix 1

FIGURE A1.5 A diagram indicating where measurements were made for the scapula bone.



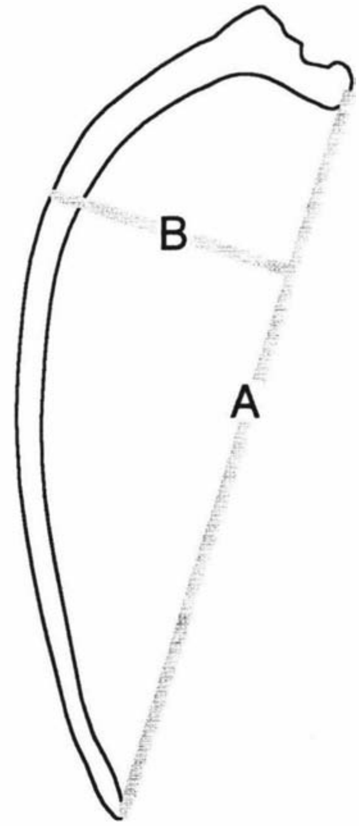
Appendix 1

FIGURE A1.6 A diagram indicating where measurements were made for the pelvic bone.



Appendix 1

FIGURE A1.7 A diagram indicating where measurements were made for the eighth rib.



Right rib, cranial aspect

Appendix 2

Table A2.1 Definitions for carcass muscularity, M:B ratio, B:A ratio, EMA ratio and carcass weight to length ratio.

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1. B:A ratio: The ratio of eye-muscle depth (B) to width (A) (an index of relative muscle depth).

2. EMA ratio: The ratio of the eye-muscle area raised to the power of 1.5 and carcass weight. Eye-muscle area was raised to a power of 1.5 to convert it from an area measurement to the equivalent of weight (assuming constant density), thereby making the ratio of this to carcass weight dimensionless.

   EMA ratio = EMA(cm^2)$^{1.5}$/carcass weight(kg).

3. CWT:L^3: The ratio of carcass weight in kilograms to carcass length in metres cubed. Carcass length was cubed to convert it from a length measurement to the equivalent of weight (assuming constant density), thereby making this ratio dimensionless.

   CWT:L^3 = Carcass weight(kg)/carcass length(metre)^3.

4. Muscularity (MUSC): A muscularity measurement based on an index of the average muscle depth of muscles surrounding a bone (eg. femur) relative to bone length (Purchas *et al.*, 1991).

Thus:
MUSC = Muscle Depth/Skeletal Dimension
= (Muscle depth index)/(Femur length)
Where:
Muscle depth index =Index of average muscle depth
=SQRT[(Weight of muscles)/(Femur length)]
and SQRT =Square root

This can be written as:
Muscularity =(SQRT (Muscles weight/Femur length))/Femur length

---

Appendix 3

TABLE A3.1 Means for liveweights, carcass weights, and the weights of non-carcass components of Southdown rams from both the high- and low-backfat lines within the 7 weight groups. All weights are as grams except live and carcass weights, which are in kilograms.

	Live Wt.	Carcass Wt.	Head& Feet	Skin& Wool	Liver wt.	Spleen wt.	Lungs& Treacha	Empty Foregut	Empty Intestine
1	3.964	1.701	729.1	577.3	90.9	6.092	92.06	49.3	122.9
2	12.725	6.258	1285.9	1208.3	264.1	25.892	186.15	255.2	640.8
3	23.883	10.664	2100.8	2150.0	421.7	37.275	281.67	782.3	142.5
4	38.433	17.471	3115.5	3133.3	904.8	74.958	511.67	1378.3	813.6
5	53.467	27.350	3425.0	4341.7	966.5	82.775	552.40	1668.1	899.5
6	64.083	34.925	3825.0	4458.3	1170	111.81	623.42	2015.6	923.4
7	68.687	36.925	3891.5	4700.0	979.2	94.500	585.20	1981.0	191.3
ALL	36.352	18.448	2561.3	2850.4	670.6	60.270	395.63	1120.4	350.5

	Heart wt.	Kidney wt.	Kidney wt.	Omental wt.	Testes wt.	Others wt.
1	34.67	28.24	20.33	8.3	4.62	39.7
2	72.33	62.00	65.17	77.0	16.92	277.5
3	121.83	84.19	99.42	168.3	129.33	383.6
4	192.33	135.46	132.08	308.2	304.17	729.8
5	249.42	149.34	624.75	1094.3	618.33	1197.8
6	284.75	200.54	836.58	1613.2	502.58	1760.4
7	265.12	173.27	1114.0	1748.2	530.25	1642.0
ALL	169.81	116.29	378.15	665.2	304.41	822.5

Appendix 3

TABLE A3.2 Means for carcass linear dimensions (mm) of Southdown rams from both the high- and low-backfat lines within the 7 weight groups.

	LB	T	WTh	G	WF
1	466.4	95.96	71.00	91.50	83.64
2	672.1	129.46	113.17	165.92	135.25
3	833.9	150.50	139.67	202.25	163.00
4	985.8	175.62	169.50	230.25	198.75
5	1061	180.62	210.00	251.83	243.08
6	1078	182.04	232.33	271.08	266.75
7	1115	187.19	239.25	276.50	268.88
ALL	876.1	155.85	164.27	209.57	191.81

	S2	B	A	EMA	C	J	GR	L3
1	--	12.021	26.529	--	-- --		--	--
2	2.508	23.167	42.438	8.433	1.458	3.375	5.312	4.750
3	3.937	25.167	52.021	10.964	1.708	3.042	4.417	5.000
4	3.417	29.000	58.729	14.299	2.333	2.917	5.917	6.396
5	17.341	33.063	59.771	21.108	7.420	13.09	17.71	17.396
6	12.950	38.233	66.258	20.258	10.62	19.04	27.72	24.108
7	12.156	40.063	64.250	19.630	9.250	21.09	26.88	23.750
ALL	8.384	28.104	52.287	15.556	5.242	9.750	13.94	12.968

Appendix 3

TABLE A3.3 Means for cut weights (g) and water and fat percentage in *M.longissimus* of Southdown rams from both the high- and low-backfat lines within the 7 weight groups.

	L&R leg	L&R loin	L&R rack	L&R shoulder	Water%	Fat%
1	600	152	134.8	792	--	--
2	2187	746	513.2	2784	75.300	2.0222
3	3781	1407	917.7	4404	74.487	2.8295
4	5969	2331	1570	7593	74.352	3.3214
5	8600	3998	2791	11797	72.110	5.5827
6	10860	5595	3615	14645	71.825	6.4702
7	1143	6148	3774	15335	70.891	7.8568
ALL	5943	2749	1809	7836	73.294	4.4936

Appendix 3

TABLE A3.4 Means for muscle fibre number in a cross-sectional area of 0.36 μm^2 for the three muscle fibre types (red, intermediate and white) for a middle subsample of *M.semitendinosus* that was frozen within 2 to 3 hours of slaughter. The second part of the table gives mean areas, fibre numbers, and sizes for the other *M.semitendinosus* that was sampled post rigor for Southdown rams from the high- and low-backfat lines within the 7 weight groups.

	Red fiber no.	Intermediate Fiber no.	White Fiber no.	Total Fiber in the square
1	160.0	107.00	92.333	346.67
2	98.91	63.957	55.174	216.87
3	76.58	49.917	49.500	176.00
4	59.33	41.292	33.542	134.17
5	43.71	47.750	35.583	127.08
6	51.08	32.583	25.167	108.83
ALL	70.18	49.840	42.192	161.39

	Fresh Muscle Area (A1)	Fixed Muscle Area (A2)	Fixed Sample Muscle Area (A3)	Wax Embedded Muscle Area (A4)	Histological Square Area (A5)	Muscle fibre number in (A5)	Mean fibre area in (A1)	No. of fibre in (A1)
1	1.35E+08	96145456	1.69E+08	1.10E+08	152100	805.09	463	317250
2	4.00E+08	3.13E+08	1.69E+08	1.58E+08	152100	333.83	673	633483
3	6.39E+08	4.19E+08	1.69E+08	1.61E+08	152100	242.00	1036	626753
4	9.75E+08	7.24E+08	1.69E+08	1.71E+08	152100	152.42	1369	730568
5	1.21E+09	8.92E+08	1.69E+08	1.69E+08	152100	127.73	1715	718370
6	1.54E+09	1.11E+09	1.69E+08	1.54E+08	152100	93.75	2552	626931
7	1.37E+09	1.27E+09	1.69E+08	1.55E+08	152100	111.50	1636	856681
ALL	8.77E+08	6.65E+08	1.69E+08	1.54E+08	152100	269.45		

Appendix 3

TABLE A3.5 Means for leg characteristics and dissected tissue weights (g) of Southdown rams from both the high- and low-backfat lines within the 7 weight groups.

	B.Trim Total leg Wt	A.Trim Total leg Wt	Leg Length Wt	Rump Cut Wt	Knuckle Cut Wt	Topside Cut Wt	Outside Cut Wt	SM Muscle Wt	ST Muscle Wt
1	285.0	266.0	173.60	18.58	35.33	38.17	26.36	19.92	7.64
2	1073.2	955.0	250.00	81.50	132.33	165.80	111.92	90.10	32.25
3	1938.5	1669.9	297.83	159.17	236.75	300.00	202.17	159.75	60.25
4	3066.3	2635.2	335.00	269.08	357.58	473.58	325.17	255.17	103.42
5	4369.8	3827.1	353.50	378.08	510.42	623.33	442.50	349.75	141.50
6	5534.6	4398.3	346.58	481.17	583.58	763.42	552.75	427.25	181.33
7	5687.9	4793.8	358.63	517.00	599.75	769.13	602.13	424.00	173.25
ALL	3008.9	2570.9	302.56	259.84	338.37	431.56	312.92	237.70	97.41

	BF. Mus Wt.	QF. Mus. Wt.	AD Mus. Wt.	Glutus Mus. wt.	Total Distal Muscle	SC. Fat Wt.	IM. Fat. Wt.	IMFat Depot Wt.	Lymph Node Wt.
1	20.00	33.92	8.33	15.42	28.75	12.50	27.67	1.692	0.1417
2	81.92	124.08	36.33	62.08	99.92	112.42	128.83	9.225	0.4417
3	150.42	225.67	68.92	124.75	173.08	205.83	206.42	13.108	1.1500
4	236.00	338.25	102.33	210.67	252.75	331.25	311.50	21.992	1.6833
5	335.33	428.08	155.42	290.42	349.50	507.58	365.25	33.225	2.0167
6	420.83	552.17	158.75	361.33	409.67	1173.8	91.58	50.925	2.8417
7	417.50	559.62	166.88	350.13	410.13	1308.5	569.00	53.037	2.7875
All	228.43	311.29	96.20	194.71	238.06	482.36	301.59	24.829	1.5200

	Total Fat Wt.	Total Muscle Wt.	Total Bone wt.
1	40.5	164.2	73.17
2	241.8	617.4	179.42
3	412.1	1200.2	283.58
4	642.8	1930.4	415.92
5	872.7	2457.8	466.08
6	1764	3188.0	534.00
7	1957	3159.8	537.75
All	791.8	1749.7	346.60

Appendix 3

TABLE A3.6 Means for rack and shoulder characteristics and dissected tissue weights (g) of Southdown rams from both the high- and low-backfat lines within the 7 weight groups.

	Rack Wt.	SC Fat WT.	IM Fat WT.	Verte. Bone WT.	Ribs& Cartl. WT.	Muscle WT.
1	61.5	3.78	9.27	8.125	7.36	31.50
2	243.7	25.09	47.19	18.092	22.24	122.50
3	450.1	46.08	85.50	32.450	40.59	232.08
4	757.8	80.75	120.33	48.833	73.20	416.08
5	1393.7	327.17	282.83	65.325	99.92	599.33
6	1800.9	438.58	420.50	72.567	132.0	720.00
7	1870.9	476.83	492.13	67.700	127.5	675.00
ALL	893.2	185.90	194.06	43.579	69.04	385.73

	Shoud. Wt.	B.Br. Muscle Wt.	T.Br. Muscle Wt.	Br. Muscle Wt.	Sup.Sp. Muscle Wt.	Infr.Sp &Di. Muscle	Muscle Around R&U	IMFat Depot Wt.	Lymph Node Wt.
1	380.8	3.075	19.50	2.900	11.38	12.23	20.42	--	--
2	1329.1	10.667	69.50	8.508	40.33	46.22	60.75	40.00	2.1273
3	2153.8	18.025	104.67	12.967	64.13	80.78	92.08	58.92	2.8667
4	3638.4	29.917	166.92	19.350	113.50	145.92	145.92	69.00	4.9667
5	5721.1	40.658	235.17	25.192	136.50	202.83	196.58	131.08	5.6917
6	7303.5	50.850	281.83	28.150	166.92	265.33	226.67	218.42	5.9417
7	7657.3	52.362	284.25	28.775	182.25	273.04	229.00	238.00	8.3125
ALL	3844.7	28.215	160.06	17.437	98.11	140.30	134.26	120.49	4.8284

Appendix 3

TABLE A3.7 Means for bone weights and dimensions of Southdown rams from both the high- and low-backfat lines within the 7 weight groups. All weights and dimensions are as grams and millimetre, respectively, except bone area, which are in square centimetres.

	Femur							
	Wt.	Length	Circum.	Prox. end(A)	Prox. end(B)	Dist. end(A)	Dist. end(B)	Area
1	20.66	83.35	31.081	14.883	27.233	26.825	29.900	0.451
2	49.22	112.59	40.812	19.900	37.112	33.496	38.892	0.8552
3	77.52	134.78	50.646	21.783	44.079	37.650	44.588	1.2408
4	112.29	156.07	61.792	22.696	50.329	41.475	48.725	1.7161
5	124.99	162.19	64.250	23.129	51.221	40.754	48.858	1.9822
6	133.99	165.94	66.375	23.938	52.796	40.717	48.321	1.9105
7	142.82	168.45	67.500	22.700	53.231	42.869	48.600	2.1936
ALL	104.69	148.92	58.037	22.337	47.828	39.295	46.197	1.6177

	Tibia							
	Wt.	Length	Circum.	Prox. end(A)	Prox. end(B)	Dist. end(A)	Dist. end(B)	Area
1	18.13	93.68	31.167	23.675	29.633	13.383	23.458	0.5481
2	39.62	123.45	37.625	30.117	37.967	15.942	28.650	0.7034
3	60.19	144.95	44.083	33.517	42.367	16.800	30.850	1.0075
4	88.22	169.98	50.183	37.283	45.492	16.883	31.967	1.4242
5	99.63	175.75	52.292	38.758	46.967	17.292	32.775	1.4169
6	109.1	177.87	55.625	39.067	47.958	17.450	33.800	1.4287
7	112.5	181.69	56.375	38.362	47.125	17.587	32.450	2.0644
ALL	73.48	151.02	46.284	34.199	42.270	16.421	30.470	1.1797

	Pelvis			Metacarpal			Rib 8		
	Wt.	length	cir.	wt.	length	cir.	wt.	length	cur.
1	11.18	88.38	26.042	9.723	65.04	31.833	1.408	71.05	23.542
2	34.63	126.99	34.583	18.741	81.75	37.979	4.408	100.87	33.392
3	59.09	159.28	42.792	24.850	91.81	42.750	13.618	129.28	43.200
4	90.91	186.43	49.208	33.428	104.82	49.208	15.000	159.94	50.750
5	105.16	195.61	51.708	36.296	104.67	51.417	19.733	166.03	55.842
6	129.47	204.20	56.125	38.258	105.07	52.563	26.992	176.27	59.150
7	135.14	213.79	55.438	38.287	111.30	49.438	27.462	179.31	60.537
ALL	78.08	165.51	44.612	28.736	95.2	45.312	14.931	138.56	45.970

	R&Ulna			Humerus					
	Wt.	length	cir.	Wt.	length	cir.	Prox. end(A)	Prox. end(B)	Dist. end(A)
1	14.442	94.80	33.625	14.87	72.01	30.083	26.358	26.817	22.142
2	31.775	123.55	40.750	37.19	96.42	39.292	35.092	35.267	27.508
3	46.158	141.58	47.667	57.44	113.29	48.083	40.300	42.975	30.100
4	68.242	167.94	56.417	85.51	129.92	56.792	45.758	49.300	31.833
5	78.008	174.77	60.383	97.31	133.67	60.625	46.450	50.800	31.482
6	87.042	176.00	64.083	110.7	136.67	64.042	48.542	53.458	33.200
7	88.938	177.02	64.250	114.3	139.00	64.188	50.388	53.862	33.362
ALL	57.744	149.50	51.864	71.89	116.19	51.256	41.414	44.179	29.754

	Scapula				
	wt.	length 1	length 2	cir.	Prox. end (A)
1	7.750	83.10	64.57	32.775	10.833
2	24.583	121.09	91.99	41.583	16.483
3	38.158	146.32	112.03	49.750	22.367
4	63.133	175.64	129.80	57.417	28.325
5	76.783	183.44	137.83	60.333	31.975
6	102.2	195.38	145.07	64.292	35.542
7	104.96	199.57	148.74	63.125	36.550
All	57.480	155.71	117.07	52.235	25.484

Appendix 3

TABLE A3.8 Means for muscularity values and M:B ratios for several parts of the leg and the shoulder together with some other shape ratios of Southdown rams from both the high- and low-backfat lines within the 7 weight groups.

	B/A Ratio	EMA Ratio	CWT/L Ratio
1	0.45045	--	2.5282
2	0.54711	3.9510	2.7363
3	0.48331	3.4306	2.6323
4	0.49534	3.1028	2.6346
5	0.55586	2.6442	2.8344
6	0.57768	2.6129	3.0329
7	0.62400	2.3773	2.9851
ALL	0.52886	3.0576	2.7583

	MUSC (R&U)	MUSC (HUM)	MUSC (SCA1)	MUSC (SCA2)	M:B (R&U)	M:B (HUM)	M:B (SCA)
1	0.15198	0.25604	0.19793	0.28921	1.3949	1.6962	3.0190
2	0.17930	0.31449	0.22061	0.33347	1.9116	2.3905	3.5296
3	0.17982	0.30464	0.21447	0.32044	1.9928	2.3564	3.7992
4	0.17569	0.31445	0.21920	0.34480	2.1405	2.5396	4.1364
5	0.19131	0.35428	0.23379	0.35860	2.5151	3.0888	4.4341
6	0.20393	0.37617	0.24145	0.37721	2.6087	3.2679	4.2284
7	0.20340	0.36880	0.23936	0.37213	2.5826	3.2025	4.3561
ALL	0.18264	0.32489	0.22305	0.34077	2.1428	2.6212	3.9076

	MUSC (FEM)	MUSC (TIB)	MUSC (HIB)	MUSC (FEMC)	MUSC (LEG)	M:B (FEM)	M:B (TIB)	M:B (HIB)	M:B (LEG)
1	0.38346	0.18299	0.14587	0.44042	0.10321	4.223	1.5507	1.3638	4.0717
2	0.50466	0.23053	0.17414	0.58591	0.02664	7.414	2.5241	1.7997	2.6225
3	0.51689	0.23812	0.17565	0.60048	0.01634	8.631	2.8750	2.1224	3.1055
4	0.52296	0.22738	0.18061	0.61371	0.01029	9.266	2.8740	2.3314	3.1410
5	0.57845	0.25279	0.19646	0.68117	0.00676	11.192	3.4913	2.7648	2.8559
6	0.62058	0.26998	0.20680	0.72622	0.00615	13.059	3.7586	2.8122	1.8349
7	0.60480	0.26175	0.18988	0.72296	0.00544	12.232	3.6497	2.6126	1.7170
ALL	0.53138	0.23644	0.18092	0.62175	0.02498	9.355	2.9260	2.2404	2.8164

Appendix 4: A description of the step-by-step procedures followed to prepare boneless leg cuts:

1. Start with a bone-in leg that has been separated from the loin by a horizontal cut on the hanging carcass between the last and second to last lumbar vertebrae.
2. Remove any loose flap, loose fat, channel fat, and that part of the tail that protrudes. Remove the three muscles running cranially from under the pelvis (*M.psoas minor, M.psoas major, M.iliacus*) and all soft tissue medial to the hip bone.
3. Cut through the slip joint between the sacrum and the hip bone (a curved cut from the medial side).
4. Remove the hip bone.
5. To remove the rump, cut a straight line through the middle of the ischiatic lymph node and against the dorsal/caudal corner of the triangular intermuscular fat depot located lateral to *M.psoas major* and cranial to the *M.quadriceps femoris*. This cut will run a few mm cranial to the exposed proximal head of the femur. The rump cut contains part of *M.biceps femoris, M.gluteus medius, M.gluteus accessorius* and *M.gluteus profundus*.
6. To remove the knuckle, cut into the femur bone along the seam between the *quadriceps femoris* and *biceps femoris* and follow around femur and remove *M. quadriceps femoris* plus *M.sartorius*. Trim the fat around, remove the *M.tensor fasciae latae* and the patella.
7. To remove the topside, cut around the femur to its distal end, and then cut along seams between *M.gastrocnemius* and *M.semitendinosus*. Trim fat around and on top of this cut. The topside cut contains *M.semimembranosus, M.adductor* and *M.gracillus*.
8. To remove the outside/silverside, cut across at the distal tip of the *M.biceps femoris* and follow the seam between *M.biceps femoris* and *M.gastrocnemius* and then around the bone. Trim fat from around the edge, remove silverside connective tissue sheet and any subcutaneous fat when muscle can not be seen through it. This cut contains *M.biceps femoris* (except that part on the rump) and *M.semitendinosus*.