1. INTRODUCTION

One of the main criteria used in carcase appraisal in the past has been carcase conformation. A considerable vocabulary of terms has been developed to describe conformation (that is shape) of the live animal or carcase. Such terms include the shape of the animal being described as; bulging or flat, blocky or leggy, convex or concave, curved or straight, wide or narrow, thick or thin, etc. Others convey differences in shape such as beef, dairy, exotic, dual purpose, etc.

"Lean meat in the right places" has been considered synonymous with "superior conformation" in the meat trade (Harrington and Kempster, 1977) and this view persists despite the work by Butler (1957) and Butterfield (1963a) which indicated that muscle weight distribution did not vary to any great degree in animals exhibiting vastly different shape. In brief, animals or carcases of "superior conformation" were believed to possess more desirable compositional, cut-out and eating quality attributes than those of "inferior conformation".

The majority of classification schemes throughout the world contain, or at some stage contained, a subjective or objective conformation score (U.S.D.A., 1965; Cuthbertson and Harrington, 1973; Pierce et al., 1974; Luckock, 1976 and Kirton and Colmer-Rocher, 1978). Harrington (1976) indicated that the classification scheme in Britain would not be viable without a measure of conformation, because of the emphasis attached to conformation by the trade.

Kirton (1976a) indicated that the inclusion of a conformation class for cattle in the New Zealand carcase grading and classification system made urgent the need to gather data to establish whether conformation was in fact related to carcase cut-out or any other factor of economic importance.

The major objective of this thesis was to provide additional information to a continuing programme on the possible effect of carcase conformation on meat quality. Previous projects achieved differences in conformation by use of different breeds (Taylor, 1974) and by selecting carcases of suitable "finish" within predetermined weight and length categories (McIntyre, 1977). The latter project used the Fleshing Index concept to further divide these carcases into high, medium and low conformation classes.

The current experiment was designed to provide information on carcase yield and meat quality from carcases perceived by the trade as belonging to a wide range in terms of conformation. It is recognised from the outset
that carcase weight and conformation are confounded in the experimental design. However constraints of resources (animals) and time (period of candidature) did not permit an experimental design allowing animals to be slaughtered at constant liveweight or constant age. To separate the effects of conformation from carcase weight it would have been necessary to use the different growth rates of the animals to take the animals to the same final live weight. If differences in conformation were still present between treatments, then other associated differences could be interpreted in terms of conformation differences. An alternative would have been to have produced a degree of overlap in carcase weight and to then have adjusted treatment effects by covariance for differences in carcase weight.

Sex and breed of animals are known to be the two major factors influencing carcase conformation and because of their association with fat deposition, ultimately carcase composition (see for example Kirton, 1974). As the cattle available for this experiment were of one breed (Hereford) and sex (steers) emphasis in the literature review has been placed on other factors which are known to influence conformation and composition.

The experimental work was also carried out in light of the proposed Australian Meat and Livestock Corporation's (A.M.L.C.) carcase classification scheme. Supplementary subjective and objective assessments were made of carcase classification in a bid to provide equally descriptive terms as those proposed by the A.M.L.C. (see Luckock, 1976). Particular attention was given to examining the resultant carcases in terms of yield of saleable meat and its eating quality as assessed by a trained taste panel.
II. LITERATURE REVIEW

Researchers and producers alike have for many years attempted to predict such variables as productivity, rate and economy of gain, distribution of lean meat (muscle plus intramuscular fat), carcase "quality", "value" and composition of the live animal and/or the resultant carcase from estimates of conformation (e.g. Brown et al., 1953; Jeffery and Berg, 1972; Kauffman et al., 1973 and Brown et al., 1979). Yao et al. (1953) and Kidwell (1955) indicated that conformation in cattle was one of the important bases in judging and selecting animals for breeding and production purposes and there is little evidence to indicate that this concept has changed significantly.

Brown et al. (1953) regarded conformation as influencing the price that buyers would pay for animals, or the ease with which animals could be sold. Harrington (1976) indicated that trade still puts emphasis on conformation, suggesting it may have some economic significance and concluded that a classification scheme that does not contain a measure of conformation would not be viable under British conditions.

From the desire to predict carcase composition by assessing conformation of the live animal/carcase has arisen a vocabulary of terms that are often ill-defined and complicated. Some of the more important interpretations of the meaning of conformation are reviewed in the following section.

2.1 Definition of conformation in the live animal

Kauffman et al. (1973), after reviewing the literature, referred to the assessment of conformation by these synonymous terms: shape, form, topography and topology. Furthermore, they stated that differences in the shape of the live animal (or carcase) could be described as being either bulging or flat, convex or concave, long or short, curved or straight, thick or thin and wide or narrow.

Previously Kirton (1964) had recognised that the term conformation or shape had different meanings to different people and pointed out that the term was often used to contrast well fed animals (good conformation) with poorly fed ones (poor conformation), and short, blocky animals (good conformation) with long, leggy ones (poor conformation). Barton (1967) defined conformation of the live animal as "... a characteristic which gives an external indication of the desirability of the carcase and its meat". Although Barton (1967) did not elucidate the phrase "desirability
of the carcase and its meat", in this context it is thought to involve factors determining - (a) the proportion of the carcase that is edible (cutability) and (b) the palatability-indicating characteristics of the lean or red meat. Barton (1967) also stated in his definition that "in the meat animal, the characters of blockiness, compactness, depth, shortness of legs, size, levelness of topline and underline, smoothness of outline and general symmetry have been the features of conformation traditionally taken into account in the assessment of meatiness".

Kauffman et al. (1970) confined the definition of conformation to "... those geometric dimensions of the live animal or carcase which reflect differences in appearance, and that are due to shape, size and position of the musculature, and how it relates to the skeleton". However, as will be described later, numerous workers have attempted to describe conformation of the live animal by means of various circumferences, linear and width measurements, usually with little success. The lack of success in this area does not necessarily conflict with the ideas of Kauffman et al. (1970), it does however, highlight the difficulty of describing the concept of animal/carcase conformation objectively.

Apart from the importance various sections of the meat industry have attached to conformation as a predictor of lean meat distribution, there is a firmly held belief that animals of superior conformation contain a greater proportion of high priced cuts. Tayler (1964) for instance, defined conformation as the proportion of joints of relatively high value in the carcase. Harrington and Kempster (1977) indicated that breeders and meat traders talk about animals and carcases with "lean meat in the right places". The conformation of the British beef breeds has often been claimed by the industry as the ultimate in beef shape, however, doubt has been cast on this concept of superiority by a number of workers (e.g. Butler, 1957; Callow, 1962; Butterfield, 1963a and Cole et al., 1964). These workers showed that animals of vastly different shape had similar muscle weight distribution, including muscles of the high priced cuts. Contrary to these results however are those of Berg et al. (1978 ) who found small significant differences in the proportion of muscles in all joints studied. Berg et al. (1978 ) noted that the experiment differed from most previous studies in that bulls were used rather than steers and a large number and more extreme types of sire breeds were involved. A further difference was that the carcases were reduced to commercial joints before being separated into bone, muscle and fat rather than the anatomical dissection of muscles described by Butterfield (1963b).
The term "type" has often been used to distinguish between functionally different groups of animals such as "dairy" and "beef" types (Fredeen et al., 1974), "dual-purpose" type (Black et al., 1938), "Zebu" type (Cole et al., 1964) and "exotic" type (Harrington and Kempster, 1977). Black et al. (1938) also used the term to describe differences in shape of animals, namely "taller" and "shallower" types. Although the terms "dairy", "beef", "dual-purpose", "Zebu", and "exotic" types describe functional differences, they are often used to suggest conformational differences. When comparing types such as "beef" and "dairy" animals, such a suggestion may be acceptable; however, if referring to "beef" animals only, the term may be misleading as variation in conformation exists between individuals of the same type and during the growth of the animal (Hammond et al., 1971).

2.2 Definition of conformation in the carcase

In general, similar terms are used to describe conformation in the carcase as the live animal. However, there are additional terms that have been used in association with conformation to describe the "thickness" of the tissue groups involved. Such terms as muscularity, fleshiness and fatness have been defined by de Boer (1975).

Muscularity was defined as the thickness of muscle (muscle fibres and intramuscular fat) relative to the dimensions of the skeleton. Fleshiness on the other hand described the thickness of flesh (muscle and intermuscular fat) relative to the dimensions of the skeleton, whereas de Boer (1975) used fatness to describe not only fat cover, but also kidney and pelvic fat development relative to the dimensions of the carcase.

Conformation (shape) has been defined in recent sources as the thickness of flesh (muscle plus intramuscular fat) and subcutaneous fat relative to the dimension of the skeleton (U.S.D.A., 1965; Hedrick et al., 1969; Luckock and Yeates, 1972; Cuthbertson and Harrington, 1973; Cuthbertson, 1974; de Boer, 1975; Harrington, 1976 and Harrington and Kempster, 1977). De Boer (1975) also indicated that while in very lean carcasses, muscularity, fleshiness and conformation are identical, these characteristics diverge with increasing fatness through the influence of deposited intermuscular and subcutaneous fat. Similarly, Tayler (1964) pointed out that as animals fatten, carcase conformation "depreciates" and both Hedrick (1968) and Kempster and Harrington (1979) recognized the possibility of scoring conformation higher in fat carcases and lower in carcases with less fat. Kempster (1977) indicated that when assessing conformation, adjustments to constant fatness are necessary to avoid confounding effects. However, the
The definition of conformation used above includes fatness as an integral component (see Fig. 2.1).

Fleshiness

Subcutaneous fat

Muscularity

Intermuscular fat

Muscle fibres

Intramuscular fat

Figure 2.1 The relationship between muscularity, fleshiness and conformation

The term "type" is sometimes used to describe carcase conformation just as it is in the live animal. A notable example of its use is in the Meat and Livestock Commission's (M.L.C.) classification scheme operating in Great Britain where five subjectively assessed classes allow carcasses to be subdivided basically into average and above and below average conformation groups. The below average conformation group is further subdivided to allow the "extreme dairy type" carcase to be highlighted while the above average group is subdivided to highlight the carcasses of "exceptional shape" described as "extreme beef type" (Cuthbertson and Harrington, 1973).

Harrington (1971) hypothesised that carcases of better shape have marginally better meat to bone ratios than those of inferior shape. In Harrington's argument he stated that carcases of vastly different shape, and of similar fatness, have different flesh thickness; the carcase of traditionally good shape has its musculature laid down over short thick bones, whereas the carcase of poor shape has its musculature laid down over longer, thinner, but not always, and not necessarily, much heavier bones. The results presented by Kempster (1977) representing many breeds and breed crosses confirmed Harrington's hypothesis. These results indicated a trend for breeds with better conformation to have higher saleable meat (deboned primal joints after standardized trimming of excess fat) to bone ratios at the same levels of external fatness. However, there were some breeds (e.g. Charolais) and crosses (e.g. Simmental cross) that had lower lean to bone ratios than would be predicted from consideration of their conformation alone. Other breeds (Welsh Black, Galloway and Angus crosses) had higher ratios than predicted. One explanation for this, proposed by
Kempster (1977), was the existence of breed differences in bone density of the type demonstrated by Fursey (1975) between Hereford and Jersey cattle of the same age.

As a general summary, conformation of the live animal or carcase may be defined as the thickness of muscle and fat relative to the dimensions of the skeleton. The ultimate aim of beef producers is (or should be) the production of an animal which will yield a carcase described by Butterfield (1976) as having the ideal composition for all markets: "maximum muscle, minimum bone and optimum fat". The proportions of saleable meat (muscle plus an optimum covering of fat) and bone (mostly unsaleable in the case of cattle) determine the retail yield of each carcase. The ratio of these two components is thus of considerable importance. The results of Kempster (1977) indicated a trend for breeds of better conformation to have higher saleable meat to bone ratios at comparable levels of fatness. At constant levels of fatness differences in shape are due mainly to differences in muscularity and/or fleshiness. However, as the level of fatness increases, these two parameters become more difficult to ascertain. The effects of conformation on carcase composition will be described further in Section 2.5.

2.3 Assessment of conformation in the live animal

Numerous procedures have been developed to determine the conformation of the live animal in an attempt to predict its carcase composition (reviewed by Barton, 1967 and Stouffer, 1969). The techniques of visual appraisal, body measurement and ultrasonic measurement will be reviewed in detail as they are of direct interest to the experimental work which is to follow. For a more comprehensive list of techniques available to estimate the composition of the live animal, the reader is referred to the review articles of Barton (1967) and Stouffer (1969).

2.3.1 Visual appraisal

It is considered that since the days of Robert Bakewell (1725-95) producers have become accustomed to assessing the breeding value, health and degree of finish (i.e. level of fatness) of their animals on the basis of appearance (Tulloh et al., 1973a). Visual (or subjective) assessments of conformation traditionally have taken into account those parameters presented in earlier descriptions by Barton (1967) and Kauffman et al. (1973) such as blockiness, compactness, smoothness of outline and general symmetry.

The major factors leading to the widespread use of visual assessment were outlined by Wilson et al. (1964) as the relative low cost and the ease and speed with which these assessments could be obtained. It is doubtless
due to these attributes that visual appraisal was regarded by Kallweit (1975) as the most widely adopted method of assessing conformation.

Obtaining visual assessments involves assigning a numerical or alphabetic score to the animal, this depending on the number of categories required. Examples of such scores have been documented by Walker (1962), where conformation of the live animal was assessed as very good, good, fair, and poor; Williams (1962) where one of 4 conformation "grades" (A to D) was recommended with further provision for 3 "sub-grades" (i.e. A+, A and A-); and Crouse et al. (1974) where conformation was assessed under the United States Department of Agriculture (U.S.D.A., 1965) standards to a third of a grade (i.e. high prime, average prime, low prime, high choice, etc.). In addition to scoring conformation on the appearance of the entire animal, Busch et al. (1969) applied values from 1 to 7 to various parts of the animal (e.g. fullness of rump, plumpness of shoulder etc.).

These examples illustrate not only the variability which exists in the scales and terminology used in assessing conformation in the live animal, but also give an insight into one of the major criticisms of this method of assessment; namely, the lack of uniformity with which standards can be replicated between places, over time and among individual assessors (Taylor and Rudman, 1963).

Investigators have indicated that trained appraisers can predict carcase quantitative characters such as edible product (muscle plus an acceptable layer of fat) with a moderate to high degree of reliability by visual appraisal of live-animal traits (Gregory et al., 1962, 1964; Wilson et al., 1964; Busch et al., 1969 and Lewis et al., 1969). On the other hand, Kallweit (1975) cited work by Rappen (1962) where the correlation coefficient between live judgment and carcase evaluation was extremely low (r = 0.04). Rappen (1962) carried out the work on a group of 28 young bulls, preselected by producers to give a homogeneous group (i.e. low variability). Although the numbers were small the point still remains that visual assessments of characters, such as conformation, made on the live animal are of doubtful use in a homogeneous population, compared to those obtained from a study such as that conducted by Crouse et al. (1974). Using animals representing a wide range of "biological" types (Hereford and Angus cows were mated to Hereford, Angus, Jersey, South Devon, Limousin and Simmental bulls) these workers showed that estimates of live animal characteristics were more highly correlated with the corresponding carcase characteristics when analysed over the entire population of 452 steers than when analysed within each of the breed groups. For example, the correlation coefficient of
conformation assessed in the live animal and the corresponding assessment in the carcase was 0.78 over the entire population compared with 0.54 within each of the breed groups.

In a recent study involving analysis of subjective body condition scores (indicating the degree of fat cover of an animal in relation to its size) Evans (1978) showed the importance of careful training of assessors and of periodic standardization exercises. He stated that not only did assessors differ in their implied calibration of the scoring scale (scoring consistently higher or lower) but they also differed in their interpretation of the subjective criteria (different distribution over the score classes).

Wheat and Holland (1960) used 12 graders, differing widely in experience and training, to assign a slaughter grade to each of 688 Hereford cattle. They reported that correlation coefficients between slaughter grades and carcase conformation (based on the dimensions of the carcase) ranged from 0.12 to 0.56 for the 12 graders and similar variability was reported by Wilson et al. (1964). Lewis et al. (1969) in an experiment involving 3 species (cattle, sheep and pigs) indicated that when live estimates (dressing percentage, U.S.D.A. quality grade, etc.) were statistically compared to actual carcase measurements, trained personnel could account for more than half the variation in carcase traits and that their estimates accounted for, on average, over twice the variation accounted for by untrained personnel. Thus variation between assessors is dependant not only on the degree of experience of the assessor, but also on interpretation by the assessor of the criteria.

Gifford et al. (1951), in a study carried out over a 10-year period in which Hereford cows were subjectively scored for conformation in the winter and summer by 4 judges, reported that judges were able to agree more closely with one another on a particular classification date than they were able to agree with their previous score. However, Gifford et al. (1951) went on to indicate that while there were highly significant differences in seasonal scoring levels, these seasonal differences accounted for less than 10 per cent of the total variation.

Ternan et al. (1959) indicated that the repeatability of a number of subjective conformation scores on yearling steers over a period of 90 or 150 days (a period of fattening) was between 0.50 and 0.76. However, such an experiment was obviously confounding a treatment effect with an assessment of repeatability. Busch et al. (1969) showed that there were sizeable differences (e.g. $r = 0.25$ to 0.49) between live estimates of fat thickness and actual carcase fat thickness as assessed by 27 graders on 14 groups of steers over a 6 year period. Although
subjective assessments of conformation were also gathered on live animals, they were not presented as simple correlation coefficients with the same characteristic measured on the carcase. Mean correlation coefficients between estimated fat thickness and actual fat thickness for each of the 14 groups over the 6 years ranged from 0.46 to 0.62. However, to assume that these fluctuations were caused by differences in interpretation of the subjective criteria by the assessors would be dangerous as not only did the number of assessors in the "committee" vary from 4 to 13 over the 14 groups, but the number of assessors that matched those in previous "committees" was also variable.

Gregory et al. (1964) reported that intra-class correlations among three "graders" were larger for animals assessed in the first year of their experiment than in the second year (0.61 and 0.45 respectively for slaughter grade). This they attributed to the lack of time spent in orientation of the three graders prior to assessing the animals in the second year.

There is little conclusive evidence in the literature to show that individual assessors do vary over time when assessing live animal traits, although intuitively one would expect this to occur, particularly as the assessors gain experience. On the other hand, there is a great deal of evidence indicating the existence of variation between individual assessors in a wide variety of visual characteristics. However, such a problem can be minimized by careful training and periodic standardization of the characteristic being assessed as suggested by Evans (1978).

2.3.2 Body measurements

Live animal measurements have been used extensively in beef and dairy cattle to evaluate individual performance on production (Black and Knapp, 1936; Black et al., 1938; Yao et al., 1953; Brown et al., 1973a,b, 1979); "desirability" indicated by slaughter grade, carcase grade and dressing percentage (Cook et al., 1951; Kidwell, 1955); weight of wholesale cuts (Green, 1954; Green and Carmon, 1968); weight of edible portion - i.e. closely trimmed, partially boneless, retail cuts and lean trim (Busch et al., 1969) and carcase composition (Charles, 1974). Examples of the more common measurements used are: height at withers, width of hooks, length of body, circumference of round and circumference of cannon bone.

Fisher (1975a) indicated that shape could be regarded as being an integrated result of defining the relative sizes of various body measurements which is in keeping with the definition of conformation (shape)
proposed earlier. Numerous workers have used body (surface) measurements in conjunction to provide various ratios which have then been related to particular live animal and/or carcase characteristics (e.g. Yapp, 1923; Gregory, 1933; Black et al., 1938; Yao et al., 1953; Kidwell, 1955; Brown et al., 1956 and Ternan, 1959). The reason for using such ratios, or combination of body measurements, can best be illustrated by the statement of Lush (1928) (cited by Brown et al., 1956): "In the geometrical sense, the animal body is of such a complicated shape that any one or few measurements could approximate of it in only the crudest way". Gregory (1933) carried this idea further postulating that genetic agencies controlling linear skeletal development and muscle diameter were different, and possibly independent, from each other. He indicated that if this were the case the conformation of an animal could be expressed by measuring the round (patella to patella in a horizontal plane) and the height at the withers and expressing the two as a ratio. Therefore, when attempting to determine the composition of the animal body in terms of individual soft tissues it is a measure of shape which is required.

Fisher (1975a) indicated that measurements on live animals may be classified according to the anatomical structure defining them. The three categories into which measurements of the live animal were divided were:

(a) direct estimate of skeletal size (e.g. circumference of cannon, height at withers);
(b) measurements indicative of "fleshing" with the effect of bone size being either non-existent or negligible (e.g. circumference of hind leg, patella to posterior midline);
(c) estimates of the combined total variation produced by both bone and flesh variation (e.g. heart girth, width of shoulders).

Stouffer (1969) reviewed the techniques for estimating the composition of meat animals and stated that measurements that had a high degree of repeatability were associated with well defined anatomical reference points, whereas the measurements which are thought of as being closely related to muscling ("fleshing" measurements) showed the lowest repeatability. The results of Averdunk et al. (1971) and Fisher (1975b) confirmed this statement.

Stouffer (1969) and Fisher (1975b) indicated that there were three sources of error involved in taking any one measurement:

(a) correct identification and location of each reference point;
(b) anatomical distortion produced by changes in the animal's posture and muscular tone, and
(c) error in measurement of the located distance (operator error).

Of the 25 measurements twice-repeated on 15 Hereford steers by Fisher (1975b), the residual coefficient of variation ranged from 0.85 per cent (heart girth and height at withers) to 11.68 per cent (skinfold thickness of the brisket). Fisher (1975b) concluded that partitioning of the total error into the three categories mentioned above was difficult, and that each measurement involved different considerations. Skinfold thickness, for example, lacked defined anatomical end points and required constant pressure on the callipers across the skinfold (i.e. high proportion of total error would be attributable to a and c). On the other hand, the error in taking length measurements with a tape would be expected to increase as the size of the measurement increased since the tape must be applied to the body surface over a greater distance (i.e. high proportion of total error attributable to b). The results of Orme et al. (1959) can be used to verify this as estimates of repeatability varied from 0.43 to 0.99 depending on the ease of defining the reference points and the type of measurement involved (height, width, circumference etc.).

Cook et al. (1951), White and Green (1952) and Green and Carmon (1968) have studied the relationships between various live body measurements and carcase measurements and the wholesale cuts of beef. Cook et al. (1951) found that the relationships between body measurements and dressing percentage were variable, with some correlation coefficients being high enough to be statistically significant while the same group of measurements taken on a numerically smaller group of animals failed to produce results of the same significance. White and Green (1952) found that linear measurements were of value in estimating the weight of various wholesale cuts ($r = 0.5$ to $0.6$) whereas, Green and Carmon (1968) and Busch et al. (1969) in cattle and Spurlock et al. (1966) in sheep indicated that body measurements were of little value in predicting weight of wholesale cuts or edible product. Previously, in a review of studies of this kind, Orme (1963) concluded that the relationships between linear live animal measurements and estimates of carcase composition were not sufficiently high for productive purposes. This result can be attributed to the effect of variation of liveweight. When slaughter weight was statistically held constant in the re-appraisal of Buric's (1960) results by Green and Carmon (1968), they concluded that slaughter weight as a single predictor of weight of wholesale cuts, was as valuable as slaughter weight plus the linear measurements and discouraged
Further study of measurements for predicting the weight of wholesale cuts. However, Green et al. (1971) working with large numbers of steers whose actual liveweights were held within a narrow range of 22.7 kg (408 to 431 kg) found that live measurements were better predictors of wholesale joint weights than slaughter weight. Addition of slaughter weight into the list of independent variables in this case did not improve the accuracy of prediction.

Spurlock et al. (1966) indicated that methods of evaluating carcase composition of live animals should be rapid, inexpensive and accurate if they are to be suitable for widespread use. Tulloh et al. (1973a) suggested that surface measurements were tedious to collect and that investigators should be wary of collecting data that may be of limited value. Of all measurements made on cattle, liveweight would be the most widely used. Liveweight prior to slaughter (slaughter weight) has been correlated with such carcase traits as dressing percentage, weight of trimmed cuts and percent muscle, fat and bone in the carcase (see Table 2.1) of sheep and cattle.

The list of experiments cited in Table 2.1 is not exhaustive but it is interesting to note the significance of the correlation coefficients listed. Those examples showing the highest degree of relationship between liveweight and the carcase characteristic measured (e.g. Green, 1954; Spurlock et al., 1966; and Busch et al., 1969) involved animals of the same breed, whereas those experiments having significant, but less closely associated, relationships involved animals of different breeds or crossbred animals (Bracklesberg and Willham, 1968; Crouse et al., 1974; and Charles, 1977). This suggests that in animals of the same breed, slaughter weight is an accurate predictor of many carcase characteristics and that measurements on the live animal are of little additional value.

2.3.3 Ultrasonic techniques

The principles of the use of ultrasonics for estimating carcase composition in the live animals were outlined by Stouffer (1963) - in general, the method involves the use of high frequency sound waves which are inaudible to the human ear. The speed of transmission of the sound waves is sensitive to changes in density of the medium through which they pass and such changes in density cause reflection of waves back to the source. The time interval for this to happen is a function of the density and thickness of the tissue, thus allowing interfaces between tissues to be recorded and mapped.
Table 2.1 Observed relationships between slaughter weight and various carcase characters in sheep and cattle

<table>
<thead>
<tr>
<th>Reference</th>
<th>Species</th>
<th>No.</th>
<th>Correlation of slaughter weight with carcase characteristics</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green (1954)</td>
<td>beef cattle</td>
<td>50</td>
<td>Weight of round, trimmed loin and rib</td>
<td>0.95**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weight of round, trimmed loin, rib and crosscut</td>
<td>0.96**</td>
</tr>
<tr>
<td>Kidwell (1955)</td>
<td>beef cattle</td>
<td>64</td>
<td>Dressing percentage</td>
<td>0.58**</td>
</tr>
<tr>
<td>Orme (1963)</td>
<td>sheep</td>
<td>165</td>
<td>Carcase lean</td>
<td>0.70**</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Total fat</td>
<td>0.48**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total bone</td>
<td>0.60**</td>
</tr>
<tr>
<td>Spurlock et al. (1966)</td>
<td>sheep</td>
<td>31</td>
<td>Weight trimmed cuts</td>
<td>0.96**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Per cent trimmed cuts</td>
<td>-0.62**</td>
</tr>
<tr>
<td>Bracklesberg and Willham (1968)</td>
<td>beef cattle</td>
<td>51</td>
<td>Per cent muscle</td>
<td>-0.28*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Per cent fat trim</td>
<td>0.18*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Per cent bone</td>
<td>-0.33**</td>
</tr>
<tr>
<td>Green and Carmon (1968)</td>
<td>beef cattle</td>
<td>114</td>
<td>Chuck minus wholesale fat</td>
<td>0.94*</td>
</tr>
<tr>
<td>(Buric's 1960 data)</td>
<td></td>
<td></td>
<td>Rib minus wholesale fat</td>
<td>0.90**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Loin minus wholesale fat</td>
<td>0.88**</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Round minus wholesale fat</td>
<td>0.87**</td>
</tr>
<tr>
<td>Busch et al. (1969)</td>
<td>beef cattle</td>
<td>181</td>
<td>Edible portion</td>
<td>0.94**</td>
</tr>
<tr>
<td></td>
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<td>543</td>
<td></td>
<td>0.89**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>362</td>
<td></td>
<td>0.87**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>417</td>
<td></td>
<td>0.87**</td>
</tr>
<tr>
<td>Crouse et al. (1974)</td>
<td>beef and dairy crosses</td>
<td>452</td>
<td>Per cent retail product</td>
<td>-0.12**</td>
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<td></td>
<td></td>
<td>Overall correlation</td>
<td>-0.32**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Within</td>
<td></td>
</tr>
<tr>
<td>Charles (1977)</td>
<td>beef and dairy cattle</td>
<td>49</td>
<td>Per cent carcase beef (80% muscle, 20% fat)</td>
<td>-0.50**</td>
</tr>
<tr>
<td>Shelton et al. (1977)</td>
<td>sheep</td>
<td>102</td>
<td>Weight trimmed cuts</td>
<td>0.93**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Per cent trimmed cuts</td>
<td>-0.51**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Per cent fat trim</td>
<td>0.55**</td>
</tr>
</tbody>
</table>

* = \( P < 0.05 \); ** = \( P < 0.01 \).
The use of ultrasonics in measuring subcutaneous fat thickness over the 12th rib in cattle was first reported by Temple et al. (1956). Corresponding measurements of actual fat thickness taken on the carcase gave a correlation coefficient (averaged for 3 sites) of 0.63 between ultrasonic and actual fat thickness.

As well as measuring the thickness of subcutaneous fat, ultrasonics are also used to measure the cross-sectional area of the M. longissimus (eye-muscle) in cattle (e.g. Hedrick et al., 1962; Davis et al., 1964 and Wallace et al., 1977), in sheep (e.g. Shelton et al., 1977 and Thompson et al., 1977), in pigs (e.g. Price et al., 1960a and b and Anderson and Wahlstrom, 1969), and in beef carcases (e.g. Miles et al., 1972). Several workers have used ultrasonic equipment to estimate the area of fat overlaying the eye-muscle (Andersen, 1975 and Bass, 1979). Measurements of fat content of muscle samples from the carcase has also been attempted (Miles and Fursey, 1977), but it is the use of ultrasonics in predicting carcase composition from the live animal that is of importance to this review.

In general three important questions raise fundamental points with respect to assessment of carcase composition in the live animal by ultrasonics:

(a) How accurately can the measurement be repeated?

(b) How well does the live measurement predict the carcase measurement? and

(c) How well do these measurements predict carcase composition?

These three questions apply equally to the prediction of carcase composition by visual assessment and body measurements reviewed previously.

Comparisons between various types of ultrasonic equipment have been carried out and as discussion of this aspect is clearly beyond the scope of this review, the reader is directed to the work of Andersen (1975) for more detail.

There are two major areas which effect the repeatability of the ultrasonic measurements on the live animal:

(a) Differences in repeated measurements on the same animal (i.e. positional changes of the animal or instrument);

(b) Differences in interpretation of the measurements from photographic records (assuming that is the mode of recording).
Tulloh et al. (1973b) reported that with respect to the "Scanogram" (which produces a photographic record of the ultrasonic trace) there were significant differences between operators on some individual animals but over all animals there was no consistent, significant difference between operators. Campbell and Hervé (1971b) and Wallace et al. (1977) found no significant effect caused by different operators on the resultant area of the M. longissmus. Similarly, more recent work carried out by Bass (1979) using a "Danscanner" indicated that repeatability of measurements taken by the same trained operator and interpreter from scans taken at two different times on the same animal were high for both fat and fat plus skin depth over the middle of the eye-muscle $(r = 0.95, \text{RSD} = 0.64 \text{mm} \text{and} r = 0.95, \text{RSD} = 0.72 \text{mm}$ respectively), however, no estimate of repeatability was cited for eye-muscle area in this case.

Repeatability of interpreting the photographic records produced by the various ultrasonic machines has been studied by a number of workers (Miles et al., 1972; Tulloh et al., 1973b; Wallace et al., 1977 and Bass, 1979). Miles et al. (1972) used 9 interpreters (presumably experienced) and showed that whilst interpreters were consistent within themselves, in general their interpretation of ultrasonic scans for fat thickness, and depth, width and area of the eye-muscle, differed significantly from each other. Tulloh et al. (1973b) used two trained photo-interpreters and indicated that interpreter differences for fat thickness at the 13th rib site were not significantly different. However, there was a significant difference between interpreters of eye-muscle area at the same site (Interpreter B obtained consistently larger measurements than Interpreter A). Results cited by Wallace et al. (1977) and Bass (1979) (the latter using one trained and two untrained interpreters) confirmed the findings of Tulloh et al. (1973b) for rib-eye area estimation. Thus there is conclusive evidence to suggest that animals in any one experiment can be "scanned" by more than one operator, but interpretation of photographic records (if that is the recording medium) should be carried out by the same interpreter (or interpreters) in order to obtain the most accurate results.

The relationships between ultrasonic measurement of fat thickness and eye-muscle area and the corresponding measurements on the carcase have been well documented (see for example Barton, 1967; Campbell and Hervé, 1971a and Gillis et al., 1973). Correlation coefficients have ranged from 0.32 to 0.93 for estimates of fat thickness and 0.22 to 0.91 for estimates of rib-eye area. Such wide variations have been brought about by the use of a multiplicity of sites at which estimates have been taken (e.g. Hervé and Campbell, 1971; Tulloh et al., 1973b; Cuthbertson, 1975 and Wallace et al.,
1977), however, the majority of measurements are taken at the point where the carcase is to be quartered. Similarly, a number of different machines have been used to predict fat thickness and eye-muscle area, giving rise to different methods of interpretation (McReynolds and Arthaud, 1970 and Gillis et al., 1973). Another possible source of error in predicting eye-muscle area on the carcase was outlined by Stouffer et al. (1961) and Davis et al. (1964). This involves distortion of the *M. longissimus* (compressed at both ends) brought about by stresses applied by conventional hanging of the carcase. Errors in the measurement of fat thickness on the carcase are often caused by the method of hide removal (e.g. downward hide puller) where fat can be removed with the hide from the area over which ultrasonic measurements have been taken (Eveleigh, pers. comm.).

Davis et al. (1964) reported significant correlations between an ultrasonic estimate of eye-muscle area (lumbar region) and the weights of 5 selected trimmed wholesale cuts for 10 lot-fed Hereford steers (*r* = 0.71 to 0.88). However, an estimate of eye-muscle area made at the 12th/13th rib resulted in lower correlations (*r* = 0.54 to 0.80) and a corresponding estimate of fat thickness was not significantly correlated with the weight of trimmed wholesale cuts (*r* = 0.23 to 0.52). The weight range of the steers used by Davis et al. (1964) was 300 to 460 kg (663 to 1015 pounds) and there was no comparison made on a constant liveweight or carcase weight basis. Tulloh et al. (1973b) on the other hand, held liveweight constant statistically, and reported that eye-muscle area was not significantly correlated to the proportion of trimmed retail cuts in the left half of the carcase. When the effect of liveweight was removed, the partial correlation between an ultrasonic estimate of fat thickness (13th rib) and the percentage of trimmed cuts was negative (-0.48) and significant (*P* < 0.05). The same relationship with the percentage of dissected fat in the right side of the carcase (0.75) was statistically significant (*P* < 0.01). Wallace et al. (1977) in an experiment with 27 beef steers of mixed Hereford and Angus breeding indicated that eye-muscle area (estimated ultrasonically and on the carcase) was of little value in predicting primal and total retail yield in beef steers. A more comprehensive discussion of the direct measurement of fat thickness over the eye-muscle, eye-muscle area and its relation to carcase yield will be presented in a later section of this review (Sections 2.4.2.2 and 2.4.2.3).

The role of eye-muscle area estimated on the live animal, as a predictor of carcase muscling appears small. Berg and Butterfield (1976) indicated that eye-muscle area measured on the carcase accounts for only a small amount of variation in predicting total or per cent muscle and
"... as it does account for some of the variation in carcase muscling, and because it is relatively easy to obtain and because better simple and direct measures of muscling have not been devised, it continues to be advocated with other simple measures for estimating carcase composition". On the other hand, fat thickness estimated over the eye-muscle in the live animal and measured directly on the carcase has proven to be a useful predictor of carcase composition (e.g. Tulloh et al., 1973b and Wallace et al., 1977).

2.4 **Assessment of carcase conformation**

Brannang (1975) stated that the main purpose of measuring and scoring carcases should be to evaluate them in terms of "eatable" meat and economic value. However, he went on to say that what is accepted or appreciated (i.e. "quality") varies from time to time, from country to country and even district to district within a country. Harrington (1971) highlighted the changed attitude to conformation standards over time by contrasting standards published by the National Livestock and Meat Board in the U.S.A. Where initially uniformity in thickness was stressed, Harrington (1971) reported that the 1970 standards had stated that "... a heavily muscled, properly finished beef carcase will be somewhat irregular in contour because of the variations in the architecture of individual muscles in different parts of the carcase", and, "... the idea that has prevailed for many years that smooth, blocky, short, deep and compact beef animals produce the most desirable beef carcases has been proven to be an erroneous concept".

Brannang (1975) indicated that when describing carcases in biological terms, age, sex, carcase weight and degree of fatness appeared to be the most important traits while the value of carcase conformation seemed to be over-estimated. The change in attitude toward "smooth" and "compact" carcases has been brought about by the realization that these characteristics are principally influenced by factors other than muscling, the most important of which is fat deposition (e.g. Luitingh, 1962; Butterfield, 1963b and Kirton, 1964). Numerous workers have indicated that increased fatness contributes to the overall thickness and fullness of the carcase (e.g. Bray, 1964; Harrington, 1971; Kirton, 1976b and Kempster, 1977) and that this in turn results in increased conformation grade but decreased value per unit weight due to excess trimmable fat (Harrington, 1971 and Cuthbertson, 1974). As mentioned earlier, the present author considers carcase fatness to be an integral part of conformation per se but it has been shown by Luitingh (1962) that conformation is more influenced by fat than by muscle.
Both the beef classification scheme used in the United Kingdom and that proposed for Australia include a measure of conformation as well as of fatness; (Cuthbertson and Harrington, 1973; Luckock, 1976), the former subjectively and the latter objectively. Similarly, the U.S.D.A. in its grading scheme recognised in 1965 the need to identify within each "quality" grade (primarily intended to reflect differences in eating quality, but also giving consideration to conformation) differences in the yield of "useable" meat (Pierce et al., 1974), i.e. "yield" grade. In the U.S.D.A. system the yield grade or "cutability" of a beef carcase is currently determined by considering four characteristics, namely: (a) the amount of external fat, (b) the amount of kidney, pelvic and heart fat, (c) the area of the eye-muscle and (d) carcase weight and applying these four values to a mathematical equation derived from the detailed work of Murphey et al. (1960). The result identifies each carcase with respect to a 5 point scale (see Table 2.2).

Table 2.2 Per cent of boneless retail cuts from round, loin, rib and chuck by yield grades (Pierce et al., 1974).

<table>
<thead>
<tr>
<th>Yield Grade</th>
<th>Per cent of cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>52.4 or higher</td>
</tr>
<tr>
<td>2</td>
<td>50.1 to 52.3</td>
</tr>
<tr>
<td>3</td>
<td>47.8 to 50.0</td>
</tr>
<tr>
<td>4</td>
<td>45.5 to 47.7</td>
</tr>
<tr>
<td>5</td>
<td>45.4 and lower</td>
</tr>
</tbody>
</table>

Pierce et al. (1974) stated that while yield grades specifically identified differences in the yield of boneless, closely trimmed retail cuts from the round, loin, rib and chuck, in more general terms they identified differences in all the retail cuts of the carcase.

2.4.1 Visual assessment

Visual or subjective assessment of conformation has traditionally taken into account those parameters outlined by Barton (1967) and Kauffman et al. (1973). By far the most widely cited system for describing carcases ranging from desirable to poor conformation is that of the U.S.D.A. (1965). Other such descriptions have also been presented by Snewen (1961), Allen (1968), Cuthbertson and Harrington (1973) and Pierce et al. (1974). De Boer
et al. (1974) described a method used by the European Association for Animal Production (E.A.A.P.) which includes photographic standards for "fleshiness" and "fatness" of carcases. Schöen (1973, 1975) has described the principles of the Food and Agriculture Organization (F.A.O.) and World Health Organization (W.H.O.) recommendations on the development of meat standards in which it is proposed that both objective criteria (e.g. age, sex, weight, backfat thickness, etc.) and subjective scores (e.g. conformation, quality of cuts, musculature, fat tissue, bone, etc.) be employed. The need to maintain uniformity of standards between places, over time and among individual assessors are no less important when considering carcase standards than in the case of live animals (Section 2.3.1). The work of Gatherum et al. (1959, 1960a, 1960b and 1961) with pig carcases revealed some of the problems associated with visual classification. One of these problems the authors termed the "batch" effect; i.e. assessment of an individual carcase was likely to be affected by other carcases in the same group. Pomeroy (1975) stated that such an effect is important in relation to national classification schemes where, for instance, there is a wide variation in breed types and where particular breeds are locally dominant. To illustrate his point, Pomeroy (1975) stated that a Friesian carcase, appearing in an area where Aberdeen Angus were predominant, was likely to be assessed differently to that in an area where Friesians were predominant.

Williams (1969) in a comparison of 2 methods of visual assessment in lamb carcases pointed out that the efficiency of visual assessment could be greatly enhanced by improvements in the definition of carcase characteristics. He found that a system employing a uniform 7 point scale (which was purely descriptive) for all characteristics was more useful than traditional schemes in which a direct attempt was made at assessing quality or "saleability" based on a variable number of marks allotted to each item being judged (e.g. 10 marks for depth of fat over loin, 20 marks for eye-muscle depth etc.).

Using a similar 7 point scale to that of Williams (1969), Harries et al. (1974) showed for beef carcases that the performance of inexperienced judges could be improved by the use of photographic standards. Previously, Gatherum et al. (1961) had shown that the batch effect could be greatly reduced by providing the assessors with such standards.

2.4.2 Objective assessment

In order to overcome the subjectivity of visual assessment and to describe carcases objectively in terms of conformation, workers have taken a variety of carcase measurements. These include carcase length, length of leg, depth of chest, circumference of round and width of thigh (Naumann, 1952; Yeates, 1952; Tayler et al., 1961; Agricultural Research Council,
Methods of evaluating both sheep and beef competition carcases have attempted to avoid complete reliance on the subjective approach. Thus, Hirzel (1939) proposed a sheep carcase system in which 75 per cent of points were given for measurements (e.g. length of cannon bone, depth of eye-muscle and fat thickness over the eye-muscle) and the remaining 25 per cent for visual appraisal of such characteristics as shape of leg and colour of meat. A similar system based on 6 rather than 3 carcase measurements was proposed for lamb and mutton carcases by Starke and Joubert (1961).

In beef carcases Kneebone et al. (1950) described judging standards in which 70 per cent of the points awarded were designated to 5 carcase measurements (eye-muscle depth, fat depth over eye-muscle, leg length, fore and hind quarter weight and weight suitability). The remaining 30 per cent of points were awarded for visual appraisal of evenness of fat cover, colour and texture of muscle and fat and marbling of muscle. A similar 70/30 per cent distribution of points was adopted for the Australian Beef Carcase Appraisal System (A.B.C.A.S.) which aimed at placing carcases in order of merit based on their estimated commercial value: in this case an estimate of saleable meat in conjunction with other characteristics related to attractiveness to the buyer (e.g. colour and texture of fat and muscle) (Gifford, 1973). The A.B.C.A.S. system involves the recording of carcase weight, carcase length, eye-muscle area and fat depth over the eye-muscle. Points are awarded by calculating the percentage of carcase fat (for instance) from a table of predetermined average values and relating the result to a point score table. This system assumes that the relationships on which the points are awarded are uniform within and between all breeds being judged.

Measurements of carcase shape (such as those described previously) have been related to visual assessments of conformation by both Pierce (1957) and Goll et al. (1961). In each study there was a significant negative relationship between measurements reflecting skeletal size and conformation grade, and a positive relationship between measurements of carcase thickness and conformation grade however, similar findings could be inferred from the work of Kauffman et al. (1973) who visually selected cattle and pigs for extremes in shape (muscular and non-muscular). Measurements taken on the pelvic limb of the various animals showed differences consistent with the work carried out by Pierce (1957) and Goll et al. (1961).

Single and multiple carcase measurements give an indication of carcase conformation when considered in relation to carcase weight which is
in agreement with the definition of conformation suggested by de Boer (1975) and others; i.e. thickness of flesh and subcutaneous fat relative to the dimensions of the carcase. Kneebone et al. (1950) for instance, measured leg length and related this measurement to carcase weight in a system aimed at evaluating experimental and competition beef carcases. As leg length increased within a given range of carcase weights (e.g. 227 to 238 kg) the carcase was considered less "blocky" and points awarded were reduced accordingly.

2.4.2.1 Weight/length ratio

The concept of the "ponderal index" (i.e., the ratio of weight to length) was described by Thompson (1942) as "an index of build or bodily proportion". Yeates (1952) proposed a modification to the ponderal index whereby an estimate of carcase "fleshing" could be obtained by expressing the carcase weight on a per unit length basis and this system (referred to by Yeates as "fleshing index") was based on the regression of carcase weight on carcase length. The fleshing index indicates the relative thickness or thinness of the carcase as the weight by which a particular carcase is heavier (positive fleshing index) or lighter (negative fleshing index) than the average for its length. The method proposed by Yeates (1952) for beef carcases and Thwaites et al. (1964) for lamb and mutton carcases has been suggested as a means of providing an objective measurement of carcase conformation and such a proposal is in keeping with the definition suggested earlier in this review.

Although a high fleshing index gives an indication of a greater amount of soft tissue (both muscle and fat) surrounding the skeleton it does not differentiate between these two tissues. However, Yeates (1959) introduced a means of adjusting for overfatness which involved measuring fat thickness and the depth of *M. Longissimus* on the quartered carcase. In the case of "overfat" carcases (i.e. those where the ratio of the depth of *M. Longissimus* to fat thickness was less than 7) an amount, appropriate to the extent of overfatness was deducted from the fleshing index, the result being known as the "net fleshing index". This correction was based on data derived from a series of fat-trim dissections of three-rib-joints from 29 beef carcases i.e., fat in excess of that representing a ratio of 7 to 1 was removed from the three-rib-joint of overfat carcases and converted to an estimate of its whole-carcase equivalent using a modification of Hankin and Howe's (1946) sample joint technique (Yeates, 1959).

The relationship between carcase weight and length proposed by Yeates (1952, 1959) was based on data from 80 steer carcases of Hereford and Shorthorn breeding from two Australian export grades. McIntyre (1977) re-
examined the weight/length relationship in a study involving data collected from numerous beef carcase competitions held in eastern Australia over a period of 13 years (1960-1972) and involving a variety of beef breeds. The data covered a wide range in age, weight, length and "fat status" and only those carcases designated as having "suitable" fat status in terms of Australian domestic trade requirements (assessed after quartering, by eye judgement or actual measurement in doubtful cases of subcutaneous fat depth above M. longissimus) were selected for analysis. A total of 4,847 carcases satisfied the requirements and the equations of best fit involving regression of carcase weight and the log of carcase weight on carcase length accounted for 81 and 83 per cent respectively of the variation. The log transformation of the data did not add significantly to the precision of the weight/length relationship. Hence McIntyre (1977) used a simple linear weight length relationship as a description of conformation.

Tayler (1958) in Great Britain and van Marle (1968) in South Africa drew up separate weight/length relationships using slightly larger numbers of carcases than used by Yeates (104 and 192 respectively). van Marle (1968) reported a significant correlation (r = 0.93) between carcase weight and length in carcases within the weight range of 82 to 318 kg. Tayler (1958) indicated good agreement between fleshing index and visually assessed carcase grades and in a similar comparison involving 66 carcases of mixed sex and 5 breeds, Dumont (1977) recorded a strong positive correlation (r = 0.86). Butterfield (1965) and Harrington (1969) have also commented on the suitability of the method for describing carcase shape.

Harrington (1976) however, in a study involving 300 beef carcases from a number of breeds, explored the possibility of taking objective measurements (including the weight/length ratio) to describe conformation but found the correlations inadequate as can be seen in Table 2.3.

Table 2.3 Correlations between conformation, weight to length ratio and compositional variates from a sample of 300 mixed carcases (Harrington, 1976)

<table>
<thead>
<tr>
<th></th>
<th>Conformation</th>
<th>Weight/length ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simple</td>
<td>Correlation</td>
</tr>
<tr>
<td></td>
<td>correlation</td>
<td>at constant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>weight and fatness</td>
</tr>
<tr>
<td>Weight/length ratio</td>
<td>0.37</td>
<td>0.44</td>
</tr>
<tr>
<td>% lean</td>
<td>-0.17</td>
<td>0.22</td>
</tr>
<tr>
<td>% bone</td>
<td>-0.41</td>
<td>-0.27</td>
</tr>
</tbody>
</table>

(All correlations above 0.15 are significant at P < 0.001 level.)
23.

Harrington (1976) stated that in this case the weight to length relationship was less closely related to composition than a subjective estimate of conformation score.

In the classification schemes proposed by the A.M.L.C. for beef and sheep carcases, measurements of carcase weight and length have been included as a means of objectively assessing carcase conformation (Luckock, 1976; Moxham and Brownlie, 1976). Assessment of conformation in both the United States grading scheme and British classification scheme is made on a subjective (visual) basis and results presented by Harrington (1976) indicated that visual appraisal of conformation was slightly better in predicting carcass composition than objective appraisal (in this case the weight to length relationship).

2.4.2.2 Carcase fatness

The interdependence of conformation and carcass fatness has been well established in this review. Similarly, McIntyre (1977) concluded that consideration of fat status was of the utmost importance in the assessment of beef carcase conformation and that the smooth, regular contours preferred in earlier standards had been attained, to some extent at least, through deposition of fat in these contours.

Several workers have reported high negative correlations (range -0.58 to -0.83) between fat depth over the eye-muscle and the percentage of muscle in the carcase (including Ramsey et al., 1962; Butterfield, 1963b, 1965; Field et al., 1966 and Bracklesberg and Willham, 1968). Henderson et al. (1966a) also confirmed this finding and observed that measurement of fat depth over the eye-muscle was a better indicator of total muscle than was eye-muscle area (r = -0.79 and 0.36 respectively) which was in accord with Cole et al. (1962) and Ramsey et al. (1962).

Similar findings have been reported for the relationship between the percentage of retail yield (saleable meat) and fat thickness measured over the eye-muscle (e.g. Murphy et al., 1960; Brungardt and Bray, 1963; Henderson et al., 1966a; Abraham et al., 1968; Epley et al., 1970; Berry et al., 1973; Cross et al., 1973a; Crouse et al., 1975). Values for correlation coefficients ranged from -0.52 to -0.81 in the work cited. Crouse et al. (1975), using 786 steer carcases derived from crosses of Hereford and Angus cows bred to sires of seven different breeds reported that the individual trait most highly correlated with "per cent cutability" was fat thickness at the 12th rib. This is similar to the findings of Epley et al. (1970) who stated that fat thickness was equally as valuable as hot carcase weight in predicting the percentage of retail cuts while
rib-eye area was the least valuable. Crouse et al. (1975) also stated that the relationship was approximately the same whether considered over all sire breed groups or pooled within groups \((r = -0.76\) over all sire breed groups and \(r = -0.68\) for within sire breed group). It is possible that such a reduction in the relationship in this case was brought about by the fact that subcutaneous fat does not constitute a consistent proportion of total carcase fat in different breeds (Charles and Johnson, 1976). Therefore, at the same subcutaneous fat thickness one would expect to find breed differences in total carcase fat content. Associated with these differences in total fat content and due to the negative relationship between the proportion of muscle and measurements of subcutaneous fat over the eye-muscle, one would expect to find breed differences in total carcase muscle content. This in turn would result in variations in the proportions of saleable meat in the carcase.

Brungardt and Bray (1963) measured subcutaneous fat thickness on the carcase at 6 positions from the third thoracic vertebra to the fourth lumbar vertebra as well as at points representing, \(\frac{1}{4}\), \(\frac{1}{2}\) and \(\frac{3}{4}\) the cross-sectional length of \(M.\ longissimus\) at the quartering position. The simple correlations of these measurements with per cent retail yield ranged from -0.64 to -0.73 with the highest coefficient being between an average of the 3 measurements at the quartering position and per cent retail yield. Correlation coefficients for the fat measurements and the percentage of fat predicted in the carcase (using a standard three-rib-joint) ranged from 0.60 to 0.65 with the measurement taken at the three-quarter position on the quartered carcase showing the best relationship. From these results it could be inferred that fat measurements at the quartering position reflect most accurately the percentage of carcase fatness.

It would appear that, in general, measurements of fat thickness made on the carcase are invaluable as predictors of the proportions of muscle and saleable meat in the carcase.

2.4.2.3 Eye-muscle area

A further method used to objectively assess conformation in the carcase involves measurement of the area of the \(M.\ longissimus\) at the quartering position (eye-muscle area). Tyler et al. (1964), in a study which involved 2 groups of 40 sides each varying widely in conformation, indicated that the carcases in the high conformation group had larger eye-muscle areas than those in the low conformation group. Cuthbertson (1974), in a study involving 300 beef and 435 lamb carcases of mixed breeding, reported that although the correlations between conformation class and eye-muscle area were not
sufficiently good enough to provide a realistic guide to muscle thickness on individual carcases \((r = 0.35\) for beef and \(r = 0.47\) for lamb), there was a trend for carcases of "good" conformation to have large muscle cross-sections in the loin as well as being heavier per unit length (see Table 2.4).

Table 2.4 Correlations between subjective conformation scores and \(M.\ longissimus\) area and the weight to length ratio in beef and lamb carcases of mixed breed types (Cuthbertson, 1974).

<table>
<thead>
<tr>
<th></th>
<th>Beef (n = 300)</th>
<th>Sheep (n = 435)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eliminating weight and % subcutaneous fat in side</td>
<td>Eliminating weight and % subcutaneous fat in side</td>
</tr>
<tr>
<td>Area (M.\ longissimus)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(beef - 10th rib)</td>
<td>0.35</td>
<td>0.47</td>
</tr>
<tr>
<td>(lamb - 12th rib)</td>
<td>0.43</td>
<td>0.28</td>
</tr>
<tr>
<td>Weight:length ratio</td>
<td>0.37</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Previously, when referring to lamb and mutton carcases, Thwaites et al. (1964) stated that at a given carcase length, high carcase weight could only be achieved by a high degree of development of either muscle cross-sectional area (and therefore total muscle volume and weight) or fatty tissue. If, on the other hand, fatness and carcase weight are held constant, Harrington's (1971) hypothesis that thickness of muscle may be influenced by its distribution over shorter, thicker bones in the case of individuals displaying "superior" conformation than carcases displaying "inferior" conformation, is valid.

Results reported by Carroll et al. (1964) from 8 Hereford and 8 Holstein steers indicated that Holstein carcases showed less thickness, plumpness and general compactness than Hereford carcases and had correspondingly lower conformation scores. Rib-eye area per unit of carcase weight was approximately 19 per cent smaller in Holsteins than Herefords with Holsteins being graded, on average, "standard" and Herefords "choice" for carcase conformation under U.S.D.A. Federal grading. Adams et al. (1977) found, in an experiment involving crossbreeding of 8 different sire breeds to Hereford dams, that the correlation between eye-muscle area per unit of carcase weight and U.S.D.A. conformation score was low and non-significant over all breeds as well as within the breeds studied \((r = -0.11\) and \(r = -0.06\) respectively).
The apparent conflict between the results of Carroll et al. (1964) and Adams et al. (1977) is doubtless due to the breeds used; Carroll et al. (1964) using pure bred animals of 2 breeds and Adams et al. (1977) using crossbred animals (except for 10 pure bred Herefords) of predominantly beef breeds. A further explanation for the lack of relationship between eye-muscle area (on a per unit carcase weight basis) and U.S.D.A. conformation score in the work of Adams et al. (1977) is the variation in the amount of fat measured on the carcase (range 7.6 mm to 14.7 mm) and thus included when comparing the carcasses on a per unit carcase weight basis. The correlation coefficients of interest in this case are those between carcase length and U.S.D.A. conformation score where a significant negative correlation was obtained over all breeds (r = -0.35, P < 0.01) as well as within breeds (r = -0.26, P < 0.05) indicating that as carcase length increased carcase thickness decreased (see Figure 2.2). These results are in agreement with those of Berry et al. (1972) who reported a correlation coefficient of -0.47 between conformation score and carcase length in 100 beef steer carcasses selected to be widely variable in carcase length.

Numerous workers have used the measurement of eye-muscle area in order to predict or estimate carcase composition in terms of "cutability", retail yield and total separable muscle for example (see Table 2.5). Results cited indicate that in the majority of cases eye-muscle area has a significant and positive relationship with the yield variable being studied, in terms of either mass or proportion of retail yield, separable muscle, etc.

In comparison, measurements of fat thickness are less well related to the actual weight of a given variable (e.g. retail yield, boneless cuts etc.) than eye-muscle area. However, when retail yield for instance is expressed as a proportion of carcase weight, fat thickness has a stronger relationship with the variable concerned than eye-muscle area. Explanation of this is probably due to the relationship between eye-muscle area and carcase weight reported by workers such as Cole et al. (1962), van Marle (1968) and Berry et al. (1972) where correlation coefficients between these two variables ranged from 0.51 to 0.73. In discussion of their results, Tuma et al. (1967) indicated that "Carcase weight, according to this and other studies, is a more accurate predictor of kilograms of retail cuts than any of the linear measures used" (r = 0.89, 0.46 and 0.10 respectively for carcase weight, M. longissimus area and fat thickness correlated with actual weight of retail cuts in the carcase). Tuma et al. (1967) also indicated that any relationship between eye-muscle area and retail cut-out was very likely a function of weight which is in agreement
Figure 2.2 Relationship between U.S.D.A. Conformation Score (U.S.D.A. Score), carcase length (C.L.) and eye-muscle area corrected to constant carcase weight (E.M.A.) and fat thickness (F.T.) measured at the 12th rib for 8 sire breeds (Hereford, H; Angus, A; Lincoln Red, LR; Brown Swiss, BS; Simmental, S; Limousin, L; Maine Anjou, MA.; Charolais, C). (Adapted from Adams et al., 1977)
with the results of Cole et al. (1960), Ramsey et al. (1962) and Fitzburgh et al. (1965).

Table 2.5 Correlations between various estimates of carcase yield with carcase fatness and eye-muscle area

<table>
<thead>
<tr>
<th>Reference</th>
<th>Carcase Yield Comparison</th>
<th>ra</th>
<th>rb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bracklesberg and Willham (1963)</td>
<td>Muscle (%)</td>
<td>0.42**</td>
<td>-0.58**</td>
</tr>
<tr>
<td>Brungardt and Bray (1963)</td>
<td>Retail yield (%)</td>
<td>0.45**</td>
<td>-0.71**</td>
</tr>
<tr>
<td>Cobb and Ovejera (1965)</td>
<td>Retail yield (%)</td>
<td>0.18</td>
<td>-0.36**</td>
</tr>
<tr>
<td>Miller et al. (1965)</td>
<td>Retail yield (wt)</td>
<td>0.72**</td>
<td>-0.14</td>
</tr>
<tr>
<td></td>
<td>Retail yield (%)</td>
<td>0.42**</td>
<td>-0.58**</td>
</tr>
<tr>
<td>Henderson et al. (1966a)</td>
<td>Total separable muscle (%)</td>
<td>0.36**</td>
<td>-0.79**</td>
</tr>
<tr>
<td></td>
<td>Total retail yield (%)</td>
<td>0.45**</td>
<td>-0.75**</td>
</tr>
<tr>
<td>Du Bose et al. (1967)</td>
<td>Boneless steak and roast meat (wt)</td>
<td>0.76**</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Boneless steak and roast meat (%)</td>
<td>0.31**</td>
<td>-0.51**</td>
</tr>
<tr>
<td>Abraham et al. (1968)</td>
<td>Boneless cuts (wt)</td>
<td>0.77**</td>
<td>0.43**</td>
</tr>
<tr>
<td></td>
<td>Boneless cuts (%)</td>
<td>-0.18**</td>
<td>-0.72**</td>
</tr>
<tr>
<td>Epley et al. (1970)</td>
<td>Total retail cuts (wt)</td>
<td>0.57**</td>
<td>0.42**</td>
</tr>
<tr>
<td></td>
<td>Total retail cuts (%)</td>
<td>-0.12</td>
<td>-0.71**</td>
</tr>
<tr>
<td>Crouse et al. (1975)</td>
<td>Cutability (%)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.18**</td>
<td>-0.73**</td>
</tr>
<tr>
<td></td>
<td>Cutability (%)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.47**</td>
<td>-0.76**</td>
</tr>
</tbody>
</table>

<sup>1</sup> within sire breed groups
<sup>2</sup> over all sire breed groups

Thus, eye-muscle area through its association with carcase weight is a useful predictor of variables such as the weight of total carcase muscle, but is far less valuable in predicting the same variable as a proportion of carcase weight. In this regard measurement of fat thickness over the eye-muscle is a more reliable predictor. Crouse et al. (1975) in an evaluation of traits used in the U.S.D.A. yield equation for predicting per cent "cutability" found that for 786 steer carcases derived from 8 sire breeds mated to Angus and Hereford cows, fat thickness was the most useful predictor of "cutability" within and over all breed groups. The percentage of kidney and pelvic fat was also useful, though of lower predictive value than fat thickness, within and over all groups, whereas carcase weight was
a good predictor within a breed group but poor over all breed groups and
*M. longissimus* area had the lowest predictive value of the four variables
studied.

Expressing carcase composition as a proportion of total carcase weight allows
comparison of breeds and weight ranges on a relatively equal basis. Since
Butterfield (1976) has defined desirable carcase composition as being achieved
when the proportion of muscle is at a maximum, bone is at a minimum and fat
at an optimum, it is thus appropriate that the majority of comparisons have
been made with variables expressed as a proportion of carcase weight. A more
accurate approach however would be to compare breeds at the same mean carcase
weight.

2.5 Relationship between conformation and carcase composition

Kauffman *et al.* (1970) stated that "superior" conformation at any given
weight is associated with carcasses which are relatively short but have
thick bulging muscles. In light of the earlier definition, carcase conformation
also depends on the degree of fatness of the carcase (unless some attempt is made
to correct for this) as does the proportion of saleable meat. Saleable meat
contains a proportion of fat depending on market preferences but lean meat
normally forms the largest component of saleable meat (Cuthbertson, 1974).

After detailed studies on carcase composition of cattle, sheep and pigs,
Callow (1949) concluded that "the major changes in anatomy of carcases
and in the chemical composition of their tissues largely depends on the
level of fatness in the carcase". Butler (1957), Pierce (1957), Kidwell *et al.*
(1959) and Goll *et al.* (1961) showed that finish (degree of fatness)
exerted more influence than conformation on the proportion of various cuts
in the carcase. Abraham *et al.* (1968) showed that when carcase weight
and fat thickness were held constant the partial correlation coefficient
between U.S.D.A. conformation score and the proportion of boneless steak
and roast meat in the carcase was -0.03. Thus, Abraham *et al.* (1968)
indicated that the relationship between conformation and yield of boneless
steak and roast meat in their data (r = -0.44) was due to the inter-relationship
of conformation with carcase weight and fatness.

McIntyre (1977) presented data from 75 carcases of high, medium and
low levels of conformation (determined by the fleshing index relationship)
from each of 5 carcase length groups ranging in length from 105 cm to 125 cm.
Fat thickness was held constant inasmuch as maximum levels were set, but no
trypt was made to hold fat thickness constant on a statistical basis.
Consequently, comparison over all length groups showed that as conformation
increased from low to high there were decreases in the percentages of muscle
and bone (7.6 and 2.8 per cent respectively) which were offset by a corresponding increase in the percentage of fat (10.4 per cent) determined from standard three-rib-joint dissections. Similarly, Barwick (1977) found in 273 lamb carcases that at constant carcase weight and 13th rib fat thickness, fleshing index was positively associated ($r = 0.31, P < 0.001$) with average fat depth (average of fat measurements taken at; anterior loin, posterior loin, shoulder and chump).

Thus it may be said that conformation (as it has been interpreted by the majority of researchers in the past) and its relationship with the weight and proportion of saleable cuts has been associated with the degree of carcase fatness. The fact that "good" conformation can be achieved by excessive fatness may explain the lack of association between conformation and carcase yield observed by many workers (for example, Stringer et al., 1965). Locking (1976) indicated that fat exerts more influence on the yield of retail cuts than does conformation which was also found by Goll et al. (1961), Bray (1964), Hedrick et al. (1969) and Kauffman et al. (1973). Hedrick et al. (1969) indicated that fatter carcases (range of fat thickness was 1.3 to 2.0 cm at the three quarter position on the quartered carcase) yielded 3.14 per cent less total retail cuts, 0.63 per cent less bone and 3.97 per cent more fat trim than leaner carcases (range 0.8 to 1.3 cm) when all retail cuts had been trimmed to a standard level of fatness. Carcases assessed as having "choice" conformation under U.S.D.A. standards yielded 1.13 per cent less total retail cuts, 0.83 per cent less bone and 0.2 per cent less fat trim than carcases graded "good". The results of Adams et al. (1977) shown in Table 2.6 also indicate that carcase fatness is a major factor in predicting carcase yield.

Table 2.6 Correlation coefficients between carcase cut-out traits and U.S.D.A. conformation score (adapted from Adams et al., 1977)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat trim</td>
<td>-</td>
<td>-0.71**</td>
<td>-0.94**</td>
<td>0.19</td>
<td>0.68**</td>
</tr>
<tr>
<td>Bone trim</td>
<td>-0.43**</td>
<td>-</td>
<td>0.44**</td>
<td>-0.24</td>
<td>-0.65**</td>
</tr>
<tr>
<td>Edible portion</td>
<td>-0.90**</td>
<td>0.01</td>
<td>-</td>
<td>-0.16</td>
<td>-0.56**</td>
</tr>
<tr>
<td>U.S.D.A. Conformation score</td>
<td>0.08</td>
<td>0.00</td>
<td>-0.08</td>
<td>-</td>
<td>0.30**</td>
</tr>
<tr>
<td>Fat thickness</td>
<td>0.46**</td>
<td>-0.38**</td>
<td>-0.34**</td>
<td>0.25*</td>
<td>-</td>
</tr>
</tbody>
</table>

* = significant, $P < 0.05$

** = significant, $P < 0.01$

Correlation coefficients above the diagonal are over all breed groups and those below are pooled within breed groups.
Tyler et al. (1964) and Martin et al. (1966) reported that when carcase weight and fat thickness were held constant, carcases with higher conformation scores, graded under U.S.D.A. standards, had higher "cutability" (yield of lean beef) than those with lower conformation scores. In carcases of extreme conformational "type" and having minimal fat cover Fredeen et al. (1974) reported a difference of 2.9 per cent in favour of beef over dairy types for the proportion of boneless trimmed retail cuts. Kauffman (1973) selected muscular and non-muscular steers of similar liveweight and with minimal fat cover and reported that muscular steers contained 1.6 per cent more ether extractable lipids (not significant), 2.3 per cent more fat-free muscle (P < 0.01) and 3.9 per cent less dissectible bone (P < 0.05) in the pelvic limb than non-muscular steers. There was a corresponding significant increase in the ratio of muscle to bone in muscular over non-muscular animals (3.8 and 3.0 respectively, P < 0.01). However, Kauffman et al. (1973) concluded that carcase shape significantly influenced composition but in a much smaller way than the effects of carcase fatness. Fredeen et al. (1974) concluded that maximum wholesale price differential that might reasonably be supported between carcases of extreme type (in this case beef and dairy type) would be in the order of 3 per cent. That is $1.00 per unit weight for "beef type" carcases compared to $0.97 for "dairy type" carcases.

Evidence from detailed dissection studies carried out on various breeds, differing markedly in conformation within species (Butterfield, 1963a; Fourie, 1965 and Bergstrom, 1968) showed that the distribution of muscle as a proportion of total muscle weight was relatively constant. This would indicate that variations in the proportions of high priced cuts, largely reflect variations in fat deposition and cutting lines. Butterfield (1976) commented that, depending on its amount and location, fat can be sold by the butcher for either the price of the choicest cut of beef or for a couple of cents per kilogram as trimmed waste. Similarly, Cuthbertson (1974) indicated that butchers try to use their skill to make the most of a carcase by adapting their lines of division of the cuts to individual carcase shape. Ultimately this would lead to additional variation in the yield of high priced cuts for instance and in the proportion of total muscle falling into these cuts.

Thus, the main conclusion from the above must be that any differences in the proportion of total muscle (which is influenced by the proportion of fat) are a result of variation in cutting lines rather than differences in the distribution of the muscle between different parts of the carcase. Similarly, Cuthbertson (1974) indicated that, whereas distribution
of muscle within the carcase may be considered relatively constant between breeds, the distribution of fat and the physical relationships of the muscles and bones may not be so constant, and hence, may introduce small but significant differences in the distribution of lean meat (muscle plus intramuscular fat).

Fredeen et al. (1974) reported that the primary source of difference in lean yield in carcases with "minimal" fat cover was bone content, "dairy type" carcases having a 1.8 per cent higher proportion of bone than "beef type" carcases. Previously Martin et al. (1966) reported that in carcases paired on carcase weight, eye-muscle area and fat thickness at the 12th rib, those graded "choice" under the U.S.D.A. Federal scheme had significantly higher total muscle to bone ratio than those graded "standard" (4.55 and 3.90 to 1 respectively).

Kempster (1977) published data which indicated that breeds of better conformation had higher saleable meat to bone ratios at the same level of external fatness. Previously, Carroll et al. (1964) reported a significantly different muscle to bone ratio for Hereford steers which were assessed visually to have superior conformation to Holstein steers (4.80 and 4.35 respectively). Although not accompanied by assessment of conformation (visual or otherwise), Broadbent et al. (1976) found that Aberdeen Angus ("beef type" conformation) steers had significantly higher "lean" to bone ratio than Friesian or Ayrshire ("dairy type" conformation) steers (4.16, 3.56 and 3.45 respectively). They attributed this result to the lower proportion of bone in the side of the Angus coupled with similar proportions of side lean. On the other hand, in animals of the same breed (Hereford) McIntyre (1977) found no significant differences in muscle to bone ratios among the three conformation classes studied.

Kempster (1977) suggested that differences in bone structure appeared to be the most possible explanation for breed differences in muscle to bone ratio. Fursey (1975) found differences in bone density between Jersey and Hereford cattle of the same age and similar figures were calculated by Kempster (1977) for 850 steers of different breeds and breed crosses experiencing different feeding regimes. Although the results showed that differences in bone density were likely to exist between breeds the ranking of most dense to least dense varied within and between each of the feeding regimes. Kempster, however, did acknowledge that the results were calculated by obtaining weight and length measurements of the femur and humerus bones then making the assumption that the bones were cylindrical in shape.
Jones et al. (1978a) studied the effects of breed type, sex and age on the density of four bovine limb bones (humerus, radius/ulna, tibia and femur) on 255 sides of beef. The three breed-types were: "British beef-type" (purebreds and crossbreds among Hereford, Shorthorn, Angus and Galloway breeds), "beef synthetic" (mainly three-way crosses of Charolais, Galloway and Angus breeds) and "dairy beef-type" (animals containing more than 50% of the large dairy breeds e.g., Simmental, Holstein and Brown Swiss). The results from this study showed little significance between breed-type and bone density, however, bone densities were consistently lower (though not significantly so) for the "British beef-type" than for "dairy beef-type".

From analyses based on the 850 carcases from an M.L.C. breed trial Kempster (1977) reported that breeds (breeds included Angus, Hereford, Friesian, Simmental, Charolais, Limousin, Galloway and Luing) explained a substantial proportion of the variation in percentage saleable meat among carcases of the same weight, fat class and conformation class. Following this, Kempster found that conformation (as described in the M.L.C.'s beef carcase classification scheme) added usefully to the prediction of percentage saleable meat in the carcase when breed was unknown, but its contribution was much reduced when breed was known.

Thus it would appear that there is little or no relationship "within breeds", between conformation and composition, among carcases of constant fatness, however, it appears that there are "between breed" relationships of importance. This is thought to be due to differences in the muscle to bone ratio.
2.6 Relationship between conformation and eating quality

Reviews carried out by Pearson (1966) and Barton (1967) on beef and Kirton (1976b) on sheep suggested that no clear relationship exists between live animal conformation (appearance) and meat tenderness. Carpenter (1974) indicated that conformation per se was not related to eating quality and although this point is disputed by some, the conflict that exists can be seen as a likely result of breeding and feeding differences of the animals rather than conformation as such.

In a recent comprehensive review of factors affecting meat quality, Jeremiah (1978) made no specific mention of any effects of conformation per se. Tatum et al. (1980) obtained results from 471 feeder steers of unspecified breeding, lot-fed for 100, 130 and 160 days prior to slaughter and suggested that knowledge of feeding history may be a useful adjunct to, or substitute for, U.S.D.A. quality grade (conformation, maturity and marbling) when predicting beef palatability.

Previously, Campion et al. (1975) found that the components of U.S.D.A. quality grade accounted for no more than 10 per cent of the variation in taste panel assessments, with marbling score accounting for the greatest proportion within that 10 per cent variation.

Numerous workers have shown conformation to be a poor indicator of eating quality in general, and tenderness specifically (Tyler et al., 1964; Campion et al., 1975; Adams et al., 1977; Garcia-de-Siles et al., 1977a and McIntyre, 1977). Abraham (1974) and Carpenter (1974) along with others questioned the need for including conformation as a quality factor in the U.S.D.A. grading scheme, and consequently it has been excluded from the U.S.D.A. quality grade standards (U.S.D.A., 1976). The relationship between conformation and eating quality has often been confounded by breed, feeding regime, and age at slaughter (e.g. Koch et al., 1976; Adams, 1977; Garcia-de-Siles et al., 1977a and b; McIntyre, 1977 and Smith et al., 1977).

On the other hand Yeates (1962) implied that a positive association existed between conformation (as measured by fleshing index) and meat quality (denoted by tenderness, succulence and juiciness). In view of this and the fact that conformation is still held in high regard by a significant proportion of the meat trade in many western countries (e.g.
Australia and U.K.) one of the aims of the current study was to observe eating quality and yield of saleable meat from animals of the same breed and sex which had been grown along different pathways to slaughter at the same age (12 months). As acknowledged earlier, the experimental design adopted involved a confounding of slaughter weight and conformation. Although the design thus did not allow resolution of that particular aspect (in terms of scientific rigor), it did provide further information on the continuing practical question of differences between animals of varying carcase weight slaughtered at the same age.

As the means of achieving different carcase shapes in the current work revolved around feeding animals to achieve different rates of growth and then slaughtering them at the same age, it is necessary to establish the relationship between plane of nutrition and carcase composition.

2.7 The effects of slaughter weight, shape, sex, breed and nutrition on carcase composition

There are a number of factors, working singly or in conjunction that affect carcase composition, namely; slaughter weight, shape, sex, breed and nutrition.

2.7.1 Slaughter weight

Considerable work has been published on the effect of slaughter weight on carcase composition (see for example the material presented by Preston and Willis, 1974 and Berg and Butterfield, 1976). Although slaughter weight has a large influence on carcase composition it should not be considered independently of age, breed, sex and nutritional status.

Early work carried out by Moulton et al. (1922) indicated that a high plane of nutrition increased growth rate and that as a result animals reached the fattening stage at a younger age than those on a lower plane of nutrition. The result of this was that fatty tissue (carcase and offal fats) increased at a greater rate than muscular tissue from the age of 5½ months. Moulton et al. (1922) also noticed that a higher plane of nutrition gave an increased proportion of dressed carcase to weight of the live animal and reported that the weight of wholesale cuts increased with increasing liveweight and fatness. The proportion of wholesale loin, rib and round, increased, remained constant and decreased respectively with stage of fattening. These basic findings
have been supported by Callow (1948), for example, who extended the observations to sheep and pigs and found that in all three species the ratio between the weight of muscular tissue and bone increased throughout the fattening period but that the rate of this increase progressively declined as the percentage of fatty tissue increased.

Berg and Butterfield (1976) indicated that after reaching puberty, animals grown on a positive plane of nutrition tended to reach a stage where muscle growth slowed relative to fat deposition. Consequently, within a given breed, sex and at the same age, heavier animals tend to be fatter. Hedrick (1968) concluded that liveweight and stage of fattening had a greater effect on the physical composition of the carcase than the age of the animal per se.

As shown by Moulton et al. (1922) dressing percentage (the proportion of carcase weight to fasted live weight) increased with longer fattening periods and this was due mainly to an increase in the proportion of fat in the carcase (Callow, 1948). As mentioned in previous sections, fat is the major factor which contributes to low carcase cut-out and thus slaughter weight should coincide with a point where fat cover is optimal for the market concerned.

2.7.2 Shape

Shape or conformation, as indicated previously, has been regarded as synonymous with a high meat to bone ratio and/or high proportion of expensive cuts. Luitingh (1962) reported that unfattened or lean steers (350 to 950 lb) had a different conformation to steers that had been well finished (600 to 1200 lb). This, coupled with the theory formulated by Hammond (1932), namely, that the loin is an expensive and late maturing cut, has often led people to believe that the fattening of beef animals enhances the proportion of the more valuable cuts in the carcase. The results of Luitingh (1962) in fact suggested the contrary, that wholesale cut percentages were mostly influenced by fat distribution. The cuts where fat was deposited e.g., kidney and channel fat, thin flank and cod, brisket, plate and neck, formed a significantly (P < 0.001) larger percentage of the fattened than of the unfattened steer as did the prime rib, wing rib and loin. However, it must be pointed out that although these differences existed, the various cuts were not trimmed of any excess fat. The proportion of kidney and channel fat increased from an average of 1.39 per cent in unfattened steers to 2.10 per cent in fattened steers and deposits of this magnitude in subcutaneous depots could account for differences of the type reported above in the proportion of wholesale cuts.
British breeds of beef cattle have been considered by the trade as having the ultimate conformation for beef production, however, Butler (1957) showed Brahman cattle to have as good, or better, proportions of high priced cuts as Herefords. Similarly Cole et al. (1964) showed that dairy cattle were equal to beef cattle in proportions of high priced retail cuts and Butterfield (1963a) showed that animals widely different in shape were very similar in muscle weight distribution. Harrington (1971) concluded that animals of good conformation showed no advantage in yield of higher priced cuts or distribution of lean meat over animals of poorer conformation. Furthermore, Harrington (1971) stated that "good shape" per se was largely achieved by excess fat deposition which overshadowed small advantages in the meat to bone ratio.

2.7.3 Sex

A considerable body of evidence has been published on the influence of sex of the animal on the growth of body tissues and its subsequent effects on carcase composition and the distribution of weight between the tissues (see for example Kirton, 1974; Preston and Willis, 1974; Berg and Butterfield, 1976 and Jones et al., 1978b). As indicated in the introduction, the animals available for the current experiment were all steers, consequently sex of animal was not a variable and this aspect has thus not been extensively reviewed.

The following work perhaps summarises best the influence sex of the animal has on carcase composition. Jones et al. (1979) reported from a study involving unequal numbers of bulls, heifers and steers, that the most pronounced sex influence on carcase composition was exhibited during the fattening phase. From their results, fat deposition accelerated in the carcasses of heifers at a total side muscle weight of approximately 45 kg. Such an increase in fat deposition occurred at higher side muscle weights for steers and bulls (54 kg to 67 kg respectively). Similar results were reported previously by Berg and Fukuhara (1974).

2.7.4 Breed

Similarly to the situation reported in the previous section on the influence of sex of the animal on carcase composition; breed is well known to have an effect on carcase composition. The animals used in the current experiment were all Herefords.

Breed choice is of prime importance when attempting to meet the requirements of desirable carcase composition. The following summarizes briefly the major influence breed has on carcase composition and the interdependence on nutrition. Berg and Butterfield (1976) and more recently
Jones et al. (1978c) noted that breeds differed in the weight at which the fattening phase began. Berg and Butterfield (1976) speculated that there may also be differing rates of fat deposition during the fattening phase between breeds, consequently, breeds that are late fatteners and/or slow fatteners would be most desirable (in the case where the market required heavy carcases) in a situation where nutrition is good. This would allow heavy body weights to be attained before slaughter is made necessary by increased carcase fat. Conversely, where feed intake is restricted or the fattening period short, early maturing breeds can be used to produce a suitable slaughter animal.
2.7.5 Nutrition

Nutrition, particularly the level of intake of digestible nutrients (plane of nutrition), has the greatest effect on animal growth and carcase composition and as mentioned previously, the major effects are on growth rate and the proportion of fat in the carcase. Plane of nutrition has an obvious effect on liveweight gain as shown by Moulton et al. (1921) (see Figure 2.3), however, the major tissues of the animal body (bone, muscle and fat) have been shown to grow and develop at relatively different rates depending on the physiological age of the animal and the plane of nutrition (Callow, 1961; Guenther et al., 1965 and Waldman et al., 1971) which ultimately lead to animals whose carcases vary in composition (i.e. the proportion of bone, muscle and fat in the carcase).

There are two broad nutritional areas that directly affect carcase composition, namely:

(i) A positive plane of nutrition (i.e. animals fed above maintenance and gaining weight); and
(ii) A negative plane of nutrition (i.e. animals fed below maintenance and losing weight).

As the experimental work to follow dealt only with animals on a positive plane of nutrition, the area of weight loss and the possible compensatory gain that follows periods of weight loss will not be dealt with in this review.

McDonald et al. (1973) have succinctly defined maintenance energy as: "the energy requirement of the animal for those functions of the body immediately necessary for life". McDonald et al. (1973) also indicated that energy supplied by the food in excess of that needed for maintenance is used for various forms of production. From this it can be deduced that the area of production into which this energy is channelled will depend on the physiological state of the animal viz.: a young growing animal will store energy principally in the protein of its new tissues and a fattening animal will store energy principally in fat.

A great deal of work has been done on the effect of plane of nutrition on growth, development and carcase composition (see for example Callow, 1961; Guenther et al., 1965; Henrickson et al., 1965; Stuedemann et al., 1968 and Waldman et al., 1971). Generally, reviews of the growth process such as those of Hafez and Dyer (1969), Hammond et al. (1971) and Campbell and Lasley (1975) have shown that given favourable nutrition, growth of the young has followed a sigmoid (S shaped) curve. The characteristic shape of this curve is similar for growth in all biological populations and is obtained regardless of the parameter measured (see Figure 2.4).
Figure 2.3 Relationship between plane of nutrition and liveweight gain (adapted from Moulton et al., 1921).
Figure 2.4 Typical S-shaped growth curves of unicellular and multicellular plants and animals (after Campbell and Lasley, 1975).
During the period from birth to maturity, body composition changes considerably and Hammond (1944, 1960) and Palsson and Vergés (1952b) indicated that the order of tissue growth and development of the body follows a "trend of necessity" which also follows an outward trend, starting from the central nervous system, and progressing to the bone, tendon, muscle, subcutaneous and finally intramuscular fat tissues.

If growth and development of the beef animal is "normal", the growth patterns of carcase tissues will be similar to those shown in Figure 2.5 with fat comprising a small proportion of total carcase weight at birth and increasing with maturity (Callow, 1948 and Butterfield, 1963a). Muscle constitutes a high proportion of empty body weight at birth and this decreases as the fattening phase is entered. Bone, on the other hand, is an early developing tissue and constitutes a relatively high proportion of empty body weight at birth (Moulton et al., 1922). Although bone weight increases with increasing body weight it does so at a decreasing rate (Tulloh, 1964 and Waldman et al., 1971).

Mukhoty and Berg (1971), working with beef cattle, made comparisons of growth coefficients, (estimated using Huxley's (1932) allometric equation) relating muscle, bone or fat to muscle plus bone. Their results support the above concepts with growth coefficients for bone less than 1.0 (a so-called "low impetus" growth rate), for muscle slightly greater than 1.0 ("intermediate impetus") and fat generally above 1.1 ("high impetus"). Elsley et al. (1964) re-analysed the data of McMeekan (1940a, b, c) and Palsson and Vergés (1952a, b) on pigs and lambs respectively and concluded that the magnitude of the growth coefficient (calculated as above), reflected whether the tissue or part concerned was early or late maturing.

From extensive nutritional studies on growth and carcase composition in pigs McMeekan (1940a, b, c) concluded that the relative development of different tissues and organs could be greatly influenced by plane of nutrition, while Palsson and Vergés (1952a, b) came to similar conclusions following their work with lambs. The interpretation which McMeekan placed on his results was subsequently questioned by Wallace (1948). Wallace thought that the apparent differential effect of the treatments on the relationships within the tissues which McMeekan had highlighted was due to the fact that comparisons had been made at equal body weights rather than at equal tissue weights. In Wallace's view the proportion of each tissue in the joints was quite normal in relation to the total weight of that tissue in each animal. As an explanation of this Elsley et al. (1964) reported after the re-analysis of the results of McMeekan (1940a, b, c) and Palsson
Figure 2.5 Percentage of muscle, fat and bone in a typical carcase during growth (after Berg and Butterfield, 1976).
Vergés (1952a, b) that when the effects of variation in fat content were eliminated "No evidence has been found of any effect of plane of nutrition on total weights of bone and muscle relative to the weight of bone plus muscle together".

Callow (1961) found that plane of nutrition during the final fattening phase prior to slaughter had a significant effect. Steers were slaughtered when liveweights were reached that would yield an estimated dressing percentage of 57 per cent for each animal in the four treatments. Carcase weights were not significantly different for the four treatment groups and results showed that there was a significantly higher proportion of fat relative to muscle plus bone from animals on a high plane of nutrition to those on a moderate plane. Similar results have been reported by Hendrickson et al. (1965), Stuedemann et al. (1968), Sully and Morgan (1978) and Morgan (1979). In addition to these results Waldman et al. (1971) indicated that fat was deposited at a more rapid rate relative to muscle plus bone weight in steers experiencing a high plane of nutrition compared with those on a moderate plane of nutrition (see Figure 2.6).

Thus control of the level of fat relative to non-fat can be achieved by altering the plane of nutrition and Geay et al. (1976) found that for the same amount of metabolizable energy and the same carcase weight, the nature of the diet did not change the physical composition of the carcase whatever the breed. As has been shown in an earlier section, fat is the tissue that varies most in the carcase and obviously has the greatest influence on the proportion of carcase muscle and bone.

There is still some question about whether plane of nutrition in cattle affects the weight of muscle relative to bone. Both Callow (1961) and Waldman et al. (1971) observed no increase in the muscle to bone ratio with increased growth rate whereas Guenther et al. (1965) reported an increase in this ratio. These results may conflict due to the different techniques used to derive the weight of muscle in the carcase. Whereas Callow (1961) and Waldman et al. (1971) used dissection techniques to estimate the amount of muscle in the carcase Guenther et al. (1965) boned each of the wholesale joints and then determined the proportion of fat and muscle in the deboned joint by chemical means. Their estimate of carcase muscle would obviously not include intramuscular fat which would be included in the estimates produced from dissection techniques.

Murray et al. (1972) found that for Angus steers grown at positive rates of growth (0.8 and 0.4 kg/day) to the same slaughter weight (a serial slaughter technique was used at 300, 330, 363, 400 and 440 kg liveweight)
Figure 2.6 Effect of plane of nutrition on fat deposition relative to muscle plus bone weight (adapted from Guenther et al., 1965).

the muscle to bone ratios were similar (4.70 and 4.55 respectively). However, animals raised on a high plane of nutrition (gaining 0.8 kg/day) followed by a period during which liveweight was held constant (the time being equal to that taken for the low plane group to reach the final slaughter weight), muscle to bone ratio fell but not significantly. Murray et al. (1972) indicated that although the proportion of muscle tissue increased during maintenance the rate of increase was relatively slower than that of bone. This is consistent with the model proposed by Berg and Butterfield (1976) which indicated that bone is the most resistant tissue to change during periods of nutritional stress and fat the least resistant.

2.8 The effect of plane of nutrition on the subsequent eating quality of meat

Within a given breed of cattle a higher growth rate invariably is associated with the deposition of greater quantities of fat in the carcase. Numerous workers have demonstrated that meat tenderness is independent of
growth rate (see for example Callow, 1961; Matthews and Bennett, 1962; Hendrickson et al., 1965 and Murray, 1970). The end-point of these experiments varied from slaughter at constant liveweight (Hendrickson et al., 1965), constant age (Matthews and Bennett, 1962) and an estimate of constant dressing percentage (Callow, 1961).

Conflicting results were reported by Purchas and Davies (1974b) who found that increased growth rates (0.75 to 1.05 kg/day) were associated with increased taste panel ratings for "meat quality" in Friesian steers. There were a number of factors that were confounded in the experiment, namely differences in the proportion of concentrate and chaff in the diet (80 per cent concentrate: 20 per cent chaff to 10 per cent concentrate: 90 per cent chaff) and final carcase weight. The degree of subcutaneous and intramuscular fat also varied for the six treatments. Other workers (Romans et al., 1965; Covington et al., 1970 and Berry et al., 1974) have indicated the existence of significant relationships between fatness of the animal and ultimate eating quality (assessed by a taste panel using tenderness, juiciness and flavour as criteria).

Two aspects in particular should be considered when the influence of fatness on eating quality is assessed, namely; marbling (intramuscular fat) and the amount of subcutaneous fat.

2.8.1 Marbling

Several workers have found low correlations between marbling and tenderness (Tuma et al., 1962; Blumer et al., 1963; Romans et al., 1965; Breidenstein et al., 1968; Parrish, 1974; Campion et al., 1975; Crouse et al., 1978 and Jennings et al., 1978). Crouse et al. (1978) reported that the amount of variability in taste panel tenderness accounted for by marbling was small (2 to 3 per cent). From their results Crouse et al. (1978) indicated that a 30 fold increase in marbling would be required to yield one unit change in taste panel tenderness.

Parrish et al. (1973) showed that internal cooking temperature of rib steaks (M. longissimus muscle at 12th and 13th ribs) was a much more important factor in palatability (as determined by a 10 member taste panel) than marbling (see Table 2.7). The interaction, however, between the degree of marbling with internal cooking temperature had essentially no effect on palatability characteristics.
Table 2.7 Mean values for palatability and Warner-Bratzler Shear of rib steaks with three degrees of marbling and three internal cooking temperatures (adapted from Parrish et al., 1973).

<table>
<thead>
<tr>
<th>Marbling Degree</th>
<th>Internal Cooking Temperature</th>
<th>Flavour</th>
<th>Tenderness</th>
<th>Juiciness</th>
<th>Overall Acceptability</th>
<th>W-B Shear (kg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slight Marbling</td>
<td>60°C</td>
<td>6.04</td>
<td>5.23</td>
<td>5.20</td>
<td>5.54</td>
<td>2.75</td>
</tr>
<tr>
<td>Modest Marbling</td>
<td>70°C</td>
<td>6.09</td>
<td>5.31</td>
<td>5.30</td>
<td>5.52</td>
<td>2.75</td>
</tr>
<tr>
<td>Moderately Abundant</td>
<td>80°C</td>
<td>6.15</td>
<td>5.33</td>
<td>5.28</td>
<td>5.56</td>
<td>2.77</td>
</tr>
<tr>
<td>Moderately Abundant</td>
<td>60°C</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

a rated on an 8 point scale (8 being most acceptable)
NS (Not Significant); ** (P < 0.01)

The degree of marbling was shown by Cross (1977) to have an effect on cooking time. Meat with small amounts of marbling required a significantly longer time to cook than meat with abundant marbling (28.08 min/100 g compared with 22.56 min/100 g). Machlik and Draudt (1963) indicated that decreased shear values and consequently increased tenderness values in beef M. semitendinosus were time and temperature dependent. Such findings are of obvious importance when samples are cooked for a constant time. Less obvious is the relationship where constant internal temperature is the end-point, when rate of cooking is the important factor.

Penfield and Meyer (1975) indicated that cores of M. semitendinosus cooked at a fast rate were significantly less tender (P < 0.01) than those cooked at a slow rate (tenderness was measured using a Warner-Bratzler Shear device). Although Penfield and Meyer (1975) found that the percentage of collagen solubilized was greater for the slower rate of cooking (5.92 per cent compared with 4.67 per cent) they concluded that this difference did not completely explain the increased tenderization of meat promoted by slower rates of cooking and suggested that endogenous proteolytic enzymes were playing a role in tenderization during cooking.

The relationship between cooking rate and degree of marbling may help to explain the small and variable results reported earlier. It should also be pointed out that although significant differences were recorded in taste panel assessments of meat with varying degrees of marbling, the ratings were always within the acceptable range. Jennings et al. (1978) for instance reported that meat having modest and above levels of marbling were
significantly more tender ($P < 0.05$) than those rated slight and below for marbling, however the difference in tenderness score was 0.5 of a unit (6.0 for modest and above compared with 5.5 for slight and below).

Davis et al. (1979) selected loin steaks from 80 carcases from a number of U.S.D.A. carcase grades that varied widely in tenderness and measured 17 chemical, physical and histological parameters; including intramuscular fat and of the 17 variables, those that contributed most in accounting for the observed variability in tenderness were fragmentation index, sarcomere length, intramuscular moisture percentage and soluble collagen percentage. Thus it would appear that the amount of marbling did little to contribute to the assessment of tenderness.

2.8.2 Subcutaneous fat

Recently there have been indications that subcutaneous fat may act as a regulator of tenderness (Merkel and Pearson, 1976; Smith et al., 1976 and Bowling et al., 1978). Smith et al., (1976) found in a study conducted on 40 lamb carcasses, that those carcases with increased quantities of fat chilled more slowly, sustained less shortening of sarcomeres (another indication that less cold shortening has taken place) and were more tender than those carcases having limited quantities of fat.

Bowling et al. (1977) reported that increases in fat thickness from 1.3 mm to 9 mm at the 12th/13th rib interface were associated with increased sarcomere length and taste panel tenderness ratings and decreased shear force requirements. Similarly, Bowling et al. (1978) showed that as the fat thickness increased from 1 to 7 mm shear force requirements decreased significantly ($P < 0.01$) and taste panel tenderness ratings increased significantly ($P < 0.01$). Carcases that have less subcutaneous fat are believed to chill more rapidly (Smith et al., 1974 and Merkel and Pearson, 1975) and thus are more susceptible to the pre-rigor toughening effects of cold shortening (Bowling et al., 1977 and 1978). Although increased fat thickness has been shown to influence rate of chilling, increased carcase weight should also be considered as having an effect on chilling rate and thus the degree of cold shortening. Herbert et al. (1978) indicated that the time taken to reduce deep butt temperature (the temperature of meat in the deep leg) to $10^\circ C$ with air at $0^\circ C$ ranged from 14 to 19 hr for 85 to 100 kg sides and from 16 to 20 hr for 100 to 115 kg sides, however, the effects carcase fatness and carcase weight had on chilling rate in this case were hard to evaluate.
2.9  **Type of diet and its influence on eating quality of meat**

There has been a great deal of work carried out on the effect of type of diet and time on a particular ration and its effect on palatability or eating quality. A selection of the more recent work includes Waldman (1971), Purchas and Davies (1974a,b), Bowling et al. (1977), Davies (1977), Reagan et al. (1977), Smith et al. (1977), Bowling et al. (1978), Cross and Dinius (1978), Dinius and Cross (1978), Harrison et al. (1978), Leander et al. (1978), Bouton et al. (1979), Ely et al. (1979) and Tatum et al. (1980). The majority of this work involved exposing animals to a diet (e.g. grass, grain and grass, grain only) for a constant period of time and comparing the results in terms of palatability or Shear values. Such experiments are obviously confounding factors such as growth rate, final carcase weight, subcutaneous fat thickness and degree of intramuscular fat brought about by the various rations.

Work carried out by Purchas and Davies (1974a) and Davies (1977) is considered typical of the bulk of the literature on this subject and has made an attempt to clarify the differences that have been shown to exist between cereal and pasture fed groups of animals. In initial work by Purchas and Davies (1974a), Friesian steers were grown to reach a fasted liveweight of 457 kg on either a predominantly cereal diet or a predominantly pasture diet for at least 160 days. Although cold carcase weight did not differ significantly between the two groups, those animals on the cereal diet had significantly more omental and intramuscular fat and greater (but not significantly different) subcutaneous fat depth at the 11th/12th rib interface. The mean age at slaughter was 69 days greater for the pasture group than that for the cereal group (567 days).

However, taste panel assessments of meat quality (topside roasts were used for taste panel assessments) did not differ significantly between the cereal and the pasture groups, although there was a slight advantage in favour of the cereal fed groups. Warner-Bratzler Shear values for meat taken from the same roasts used in the taste panel assessments were higher (not significantly) for the pasture fed groups (8.57 compared with 7.93 - units are not described in the text, therefore kilograms per unit area are assumed). Shear force values derived from steaks of *M. longissimus* and *M. semitendinosus* and subjected to different ageing, cooking and cold shortening conditions however showed consistent and significant reduction from animals receiving the cereal based diet. Purchas and Davies (1974a) suggested that the reasons for the decreased tenderness of the pasture fed group compared with the cereal fed group were, the smaller percentage
of intramuscular fat (-34 per cent), a higher mean age at slaughter (+69 days) and the possibility of being more prone to cold-shortening.

Davies (1977) repeated the experiment and included a group of steers with a restricted intake of grain, allowing a similar growth rate to animals on the pasture treatment. The animals were slaughtered at similar weights to those described by Purchas and Davies (1974a) and the ad libitum cereal groups. Two steaks were cut from M. longissimus for taste panel evaluation and were cooked to a similar internal temperature to the roasts in Purchas and Davies (1974a), 74°C. Results showed similar non significant trends to those for taste panel and Warner-Bratzler Shear values of the previous experiment. There was, however, a tendency for cereal fed animals to exhibit better taste panel tenderness scores than pasture fed animals with the restricted cereal group displaying intermediate values. Warner-Bratzler Shear values were lower for cereal fed than pasture fed and restricted cereal fed animals were again intermediate (Shear values of 15.6, 16.7 and 16.2 respectively, the units are assumed to be kilograms per unit area as they are not mentioned in the text by Davies (1977)). Two factors that may be considered to cloud results from experiments such as that of Purchas and Davies (1974a) are; the effect of slaughter at different ages where increased age may have an affect on the ultimate tenderness, and the relationship between carcase weight and the rate of cooling mentioned previously where cold-shortening may be induced by a faster rate of chilling.

The role subcutaneous fat thickness and intramuscular fat play in affecting the eating quality of meat is not clear as yet. Much work has to be carried out with respect to the partitioning of energy into various depots (tissues) in the carcase when animals are placed on rations varying in energy level.

2.10 Summary

There are many factors influencing yield and eating quality of the carcase and many members of the meat trade believe that carcase conformation (shape) is one of the most important of these. The literature review of this thesis has outlined the concept of conformation. There are many definitions of conformation existing in the literature, however in this thesis the term conformation is defined as the thickness of muscle and fat relative to the dimensions of the skeleton.

Fat is an integral part of the carcase and its labile nature makes assessment of carcase composition difficult. It is seen by the author as playing a major role in the expression of conformation in cattle and
thus exerts a strong influence on the yield of saleable meat. It has been stressed throughout this thesis that many factors working singly or together will affect carcase composition (e.g., slaughter weight, shape, sex, breed and nutrition) and that in the experimental design which will be described later slaughter weight and conformation are unfortunately confounded.

The relationship between carcase fat and eating quality of meat appears to be unclear. However, it would seem that subcutaneous fat may provide protection against cold-shortening during chilling and that a certain covering of fat is required to prevent the carcase drying out during chilling. The current experiment was designed to produce carcases of vastly different conformation and in keeping with the definition adopted for conformation a resultant range in fat content and cover would be expected. Consequently further information could be provided by this experiment on the role of conformation on the eating quality of meat.

The role of conformation in carcase classification and grading is varied. Claims have been made that the M.L.C.'s classification scheme would lack the support of the trade if an assessment of conformation had not been included (Harrington, 1976). Canada and the United States on the other hand have abandoned the use of conformation in their Standards. In the initial proposals for an Australian Beef Classification Scheme, a category which described shape was included, however, in "Update on Carcase Classification" (August, 1980) age, sex, fatness and weight were the only information recorded from the carcase.

The aim of the current experiment was to examine the relationships between carcase conformation and both the yield of saleable meat and its eating quality, and to examine the implications of conformation to the Australian Carcase Classification Scheme.
III. MATERIALS AND METHODS

3.1 Experimental Design

The broad aim of the experiment was to investigate differences in the yield of and eating quality of saleable meat associated with differences in conformation (shape). Ideally, to separate the effect of conformation from that of carcase weight an experimental design which incorporated slaughter at constant live weight as well as at comparable ages would have been preferred. However the number of animals available to the author did not permit this and, furthermore, in such a design animals on the lower treatment growth rates (0.34 kg/day) would have taken a period in excess of two years to reach the appropriate liveweights. Such a period of time was not available to the author and a compromise design, which involved confounding between the effects of carcase weight and conformation, was thus adopted.

The method used to obtain a range of animals with differing conformation scores involved weaning a group of 20 steer calves at three months of age and assigning them to one of four treatment groups, each having a different rate of growth representative of the wide range of conditions actually encountered in Australia. All animals were slaughtered at 12 months of age, and their carcases were then typical of the range normally encountered in the Australian domestic meat trade on the interface between the numerically dominant "vealer" and "yearling" classes.

Table 3.1 Expected growth rates for each of the four experimental groups

| Group | Expected growth rate |  
|---|---|---|
| 1  | 0.34 | 0.75 |
| 2  | 0.68 | 1.50 |
| 3  | 0.91 | 2.00 |
| 4  | 1.13 | 2.50 |
3.2 Pre-weaning management

Twenty male Poll Herefords, born between January 19 and February 28, 1977, were obtained from the Kirby Research Station, University of New England, Armidale. The experimental calves, the progeny of three bulls (siring, 8, 8 and 4 calves respectively), were weighed within 24 hours of birth and identified using pre-numbered ear tags ("Tag-ease", Leader). Following the birth of the last calf the whole group was weighed at fortnightly intervals until weaning. The calves were separated from their mothers immediately prior to weighing and returned to them immediately thereafter. Before weaning all the cows and calves were run together as a single mob under the same nutritional conditions.

3.2.1 Marking procedure

As it was desired to allow at least 14 days for recovery prior to weaning, the calves were castrated in two groups, 14 days apart. The actual castration-to-weaning interval varied from 15 to 35 days. At the time of the operation the calves were yarded, separated from their mothers, weighed, vaccinated against the major Clostridial diseases ("5-in-1" vaccine, Tasman Vaccine Laboratory), castrated surgically, tattooed and returned to their mothers.

3.2.2 Weaning procedure

As near as was practicable to 90 days of age (mean 92.5 ± 4.2 days; range 84-103 days), the calves were weaned. On the appropriate day each calf was yarded at 16.00h and weighed before being transported 4 km to the Vealer Unit at the University's Laureldale Research Station where they were placed in a yard overnight with access to water only then weighed again the following morning (09.00 h) (Avery Mobile Scales) to obtain an estimate of empty body weight.

3.3 Post-weaning management: The growth study

3.3.1 The experimental area

Five paddocks of approximately 1 ha were used to conduct the experiment, each paddock had ample shade and fresh water and a laneway connected each of the paddocks to a set of yards at the northern end of the experimental area. Also situated in this area was a hayshed, a feedshed and covered feed stalls (Figure 3.1) with the latter being used to feed the animals initially or on an individual basis when the need arose to accurately regulate feed intake and growth rate.
Figure 3.1 Plan of the experimental area - Laureldale Research Station.
The predominant pasture species in the area were Cocksfoot (*Dactylis glomerata* L.), Paspalum (*Paspalum dilatatum*), Perennial ryegrass (*Lolium perenne*) and White clover (*Trifolium repens*) and the dam adjacent to the southern end of the experimental area was used to irrigate these pastures from November 1977 to January 1978.

### 3.3.2 Post-weaning management

For the first 14 days, a period considered suitable for calves to recover from any weaning "check", all calves were allowed to graze during the day and were yarded at night and fed a mixture of average quality lucerne hay and an 18 per cent crude protein dairy meal concentrate (Fielders, Tamworth). All calves were gaining liveweight at the end of their 14 day period and at this time each was randomly allocated to one of the four treatment groups. The animals remained in these groups throughout the experiment unless the need arose to accurately regulate the feed intake and growth rate of an individual, at which time they were held in the feed stalls.

### 3.3.3 Allocation to treatment group

The liveweights of the animals at 60 days of age were stratified, divided into 5 groups of 4 animals and the numbers 1 to 4 were randomly allocated to each animal of the five groups. This method was adopted to produce four groups of five animals whose mean liveweights were as uniform as possible and the 60 day weight was chosen as the basis for randomization as it represented the latest weight, common to all animals, which was available at the time it became necessary to allocate the oldest animals to treatment groups.

### 3.3.4 Animal health

As animals arrived at the experimental area they were drenched with 10 ml "Nilverm" (I.C.I.), followed by 20 ml "Nilzan" when all the animals had been allocated to their experimental group and 40 ml "Nilzan" on September 12, 1977.

Following the weaning of the youngest animals the entire mob was treated for lice with 2.5 ml "Tiguvon Spot-on" (Bayer) applied to the rump and a similar dose was applied 18 days later. Due to a reinfestation a further dose was administered on June 14, 1977.

During the course of the experiment there were a number of outbreaks of pinkeye (contagious bovine ophthalmia) and a standard treatment was adopted to reduce the effect on the individual and to stop the spread of
the disease. Individuals noticed to have a watery discharge from an eye were yarded, the eye was checked for foreign bodies such as grass seeds and if none were present an intramuscular injection of 10 ml "Duplocillin" (Philips-Duphar Pty. Ltd.) was administered immediately, followed by a similar dose 3 days later. This treatment stopped any infection becoming acute and there was no recurrence of pinkeye in the 10 animals treated during the course of the experiment.

A number of animals in Group 4 became lame toward the end of the experiment due to excessive hoof growth and this problem was rectified by paring the hooves of the affected animals.

3.3.5 Maintenance of growth rates

The rates of gain described in Table 3.1 were obtained by manipulating pasture intake and in the case of the higher growth rate groups, by feeding an 18 per cent crude protein dairy meal concentrate (see Appendix 1). Pasture intake was regulated by means of strip grazing with an electric fence (Groups 1 and 2) and the concentrate was fed to Groups 3 and 4 in troughs in their paddocks, allowing 0.5 m of trough space per animal (Pryor and Gartner, 1973).

Group 4 was fed concentrate ad libitum throughout the trial, whereas the animals in Group 3 were supplemented with a measured amount of the same feed daily, this amount was dependant on the mean growth rate of the group for the previous week. The amount of concentrate consumed daily by Group 4 was measured at various times throughout the trial.

3.4 Live animal measurement during growth

3.4.1 Liveweight

A small trial was conducted to ascertain the reliability of weighing the cattle directly off-pasture or after an overnight fast under the conditions of this particular experiment. On alternative nights the animals were yarded at 17.00 h and held without access to either food or water until they were weighed at 09.00 h. The animals were then returned to their respective treatments and weighed directly off-pasture the following morning at 09.00 h. This procedures was repeated 3 times and after subjecting the results to an analysis of variance it was thought unnecessary to fast the animals overnight before weighing and the following procedure was thus adopted for the routine weighing of the animals. At weekly intervals (starting at 09.00 h) the animals were yarded and weighed (to the nearest lb, the results were then converted to kg) treatment by treatment (working in reverse order the following week) and returned to
their respective paddocks. These weekly weighings were used to determine the feed requirements for each of the groups with respect to their expected growth rates during the following week.

3.4.2. Body measurements

During the experiment body measurements were recorded at monthly intervals and unless stated otherwise were taken from those developed by the Agricultural Research Council (A.R.C., 1965). Measurements were taken on the left side with the animal standing squarely as follows:

(A) Height at withers. The height at the highest point of the withers between the shoulders (A, Figure 3.2(a)). Measurements were taken with the aid of a horizontal bar moving on a graduated framework.

(B) Height at sternum. The height at the lowest point of the sternum behind the foreleg, taken with a measuring stick (B, Figure 3.2(a)).

(C) Depth of chest. A modification of the A.R.C. (1965) measurement was adopted; the difference between A and B was used as a measure of chest depth (C, Figure 3.2(a)).

(D) Heart girth. The circumference of the body immediately behind the shoulder blades, made using a cloth measuring tape (D, Figure 3.2(a)).

(E) Length of back. Measured from the process of the second thoracic vertebra to a point perpendicular to a line between the tuber coxae (Figure 3.2(b)).

(F) Width at "hooks". Measured between the extremities of the tuber coxae with a set of calipers (Figure 3.2(b)).

(G) Anal fold thickness. The anal fold, consisting of the skin and subcutaneous fat situated between the point of the ischium and the base of the tail (G, Figure 3.2(c)) was measured by the method of Charles (1974).

3.5 Pre-slaughter live animal measurements

3.5.1 Final off-pasture liveweight

Four days prior to slaughter the animals were removed from pasture at 09.00 h, weighed in the manner previously described, repeated the following morning and a mean of the two weights taken.
Figure 3.2 Diagrammatic representation of points used in measurement of the live animal.
3.5.2 Fasted liveweight

Measurements of fasted body weight were obtained in order to facilitate the later calculation of dressing percentages. Consequently, animals due for slaughter were yarded at 17.00 h the day before being transported to the abattoir, left overnight without food or water, weighed at 09.00 h the next morning and then returned to pasture prior to being transported to the abattoir later in the day.

3.5.3 Body measurements

Four days prior to slaughter the animals were yarded, photographed and the routine body measurements described in Section 3.4.2 were taken with the following additions:

(H) Height at pelvis. Measured from the anterior edge of the sacrum between the hips with a measuring stick (H, Figure 3.2(a)).

(I) Round measurement. Measured from the anterior external point of one patella to the corresponding point on the other patella passing under the tail (Gregory, 1933) with a cloth tape (I, Figure 3.2(c)).

(K) Fat thickness at 13th rib. Measured using a "Scanobu" (Model 731A, Ithaco Inc.) at a point estimated to be three quarters of the distance across the eye-muscle on the left side of the unclipped animal (K, Figure 3.2(a)).

Fat thickness at the 13th rib was measured on all 20 animals by means of a "Scanogram" (Model 721, Ithaco Inc.) one week prior to the first four animals being slaughtered. This estimate of fat thickness was made over the 13th rib on the left side of the unclipped beast by scanning in a downward direction (L, Figure 3.2(a)) and a similar estimate of fat thickness was made using the "Scanobu".

3.5.4 Visual assessment of fatness

Included in the N.S.W. Livestock Reporting Scheme is a 5 point visual assessment of fatness for live animals (1 - very lean to 5 - very fat). The Department of Agriculture of New South Wales (Anon, undated) presented photographs of typical carcases and cross-sections at the quartering position, along with line diagrams (both lateral and posterior) of animals associated with corresponding carcases. Table 3.2 shows the fat thickness over the rib associated with each of the visually assessed fat categories.
Table 3.2  Approximate range of fat measurements used to describe each fat category in young cattle (Anon, undated).

<table>
<thead>
<tr>
<th>Visual fat category</th>
<th>Approximate fat thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 very lean</td>
<td>0-2</td>
</tr>
<tr>
<td>2 lean</td>
<td>3-5</td>
</tr>
<tr>
<td>3 medium</td>
<td>6-8</td>
</tr>
<tr>
<td>4 fat</td>
<td>9-11</td>
</tr>
<tr>
<td>5 very fat</td>
<td>&gt; 12</td>
</tr>
</tbody>
</table>

In the current experiment and one week prior to the first four animals being slaughtered four judges were given a sheet containing the above information and asked to score each of the animals. The animals were walked through a race and assessed at random.

3.6 Slaughter procedure

The steers were slaughtered as close as practicable to 12 months of age (mean 372.7 ± 6.5 days; range 365-382 days) and a standard procedure was adopted. Four animals (the oldest from each group) were transported 40 km to Guyra Regional Abattoir the afternoon prior to slaughter, denied food and water overnight and were slaughtered the following morning at approximately 10.00 h.

The animals were stunned with a captive bolt pistol and bled, the fore and hind canons, head and hide were removed prior to the carcase being eviscerated, halved, each side inspected and trimmed of any bruising before being washed and weighed. The hot carcase weight included the tail, kidney and pelvic fat, kidneys and diaphragm and was recorded to the nearest kilogram.

3.7 Carcase measurements

After weighing, the carcases were placed in a chiller (2°C) where the following measurements were taken on the right side of each conventionally hung, hot carcase:

(1) Carcase length (A.M.L.C. classification scheme) was measured from the bottom of the hook in the hock to the anterior edge of the first rib at a point as close to
to the vertebral column as possible (A-B, Figure 3.3).

(2) Fat depth (A.M.L.C. classification scheme) was measured at the three quarter position between the 12th and 13th rib. If the fat selvage was damaged at this point the fat depth measurement was taken at the first undamaged point at 5 cm intervals posterior to the 12th/13th rib. The measurement was taken using a sharpened steel ruler which was graduated in millimetres.

(3) Carcase length (fleshing index) was measured from the pubic symphysis to the anterior edge of the first thoracic vertebra (E-F, Figure 3.3).

(4) Depth of chest (de Boer et al., 1974) was measured at the level of the 5th rib from the ventral edge of the spinal canal of the posterior aspect of the body of the fifth thoracic vertebra to the ventral aspect of the middle of the body of the sixth sternebra (C-D, Figure 3.3).

From the data collected on the hot carcase the following parameters were calculated:

(1) Dressing percentage was calculated as follows:

\[
\text{Dressing percentage} = \left( \frac{\text{Hot, washed carcase weight (kg)}}{\text{Fasted liveweight (kg)}} \right) \times 100
\]

(2) Gross fleshing index (Yeates, 1952) was determined using the weight/length regression of Yeates and McIntyre (unpublished data): i.e., \( W = 5.69L - 460 \) where \( L \) = carcase length (cm) and \( W \) = average carcase weight (kg) at that carcase length. Hot carcase weight and carcase length (E-F, Figure 3.3) were used to estimate the number of kilograms by which a particular carcase was heavier (positive fleshing index) or lighter (negative fleshing index) than the average carcase of its length.

(3) Another estimate of gross fleshing index was determined by reworking the data collected by McIntyre (1977) on approximately 3000 commercial Hereford steer carcases. These data were analysed for the range of 90 to 115 cm in carcase length (carcase length ranged from 91 to 113 cm for the experimental animals). A total of 1527 carcases were in this range and the linear weight/length regression
Figure 3.3 Carcase measurements. A-B, Full carcase length (Luckock, 1976); C-D, Chest depth (de Boer et al., 1974); E-F, Carcase length (Yeates, 1952).
model yielded the following equation:

\[ W = 4.41L - 310 \ (R^2 = 0.614) \]

3.8 Classification of carcases

3.8.1 A.M.L.C. classification scheme

The 20 carcases were classified using the objective criteria developed by the A.M.L.C. as reported by Luckock (1976) namely: age, sex, weight, fatness (fat score) and weight/length relationship (conformation score).

Six age categories (based on dentition) existed and are described in Table 3.3 along with the average age of eruption of teeth as reported by Sisson and Grossman (1953). Presence or absence of eruption of the 5th molar was noted in the slaughter animals.

Table 3.3 A.M.L.C. classification codes of dentition and average age of eruption of teeth

<table>
<thead>
<tr>
<th>Description</th>
<th>Code</th>
<th>Average age at eruption (Sisson and Grossman, 1953)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk teeth - no fifth molar</td>
<td>(0)</td>
<td></td>
</tr>
<tr>
<td>Milk teeth - fifth molar erupted</td>
<td>(1)</td>
<td>1 -1(\frac{1}{2}) years</td>
</tr>
<tr>
<td>Two permanent incisors</td>
<td>(2)</td>
<td>1(\frac{1}{4})-2 years</td>
</tr>
<tr>
<td>Four permanent incisors</td>
<td>(4)</td>
<td>2 -2(\frac{1}{4}) years</td>
</tr>
<tr>
<td>Six permanent incisors</td>
<td>(6)</td>
<td>3 years</td>
</tr>
<tr>
<td>Eight permanent incisors</td>
<td>(8)</td>
<td>3(\frac{1}{2})-4 years</td>
</tr>
</tbody>
</table>

Sex was recorded using the numeral code shown in Table 3.4 and as all animals in the experiment were steers they were coded 3.

Table 3.4 A.M.L.C. classification codes for sex of animal

<table>
<thead>
<tr>
<th>Description</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steer/bullock or ox</td>
<td>(3)</td>
</tr>
<tr>
<td>Heifer</td>
<td>(5)</td>
</tr>
<tr>
<td>Cow</td>
<td>(7)</td>
</tr>
<tr>
<td>Bull</td>
<td>(9)</td>
</tr>
</tbody>
</table>

As the dressed carcases in the current experiment did not conform fully with the A.M.L.C.'s definition of a standard beef carcase (see Appendix 2)
adjustments were made to obtain hot carcase weight when the appropriate data were collected at the time of carcase cut-out.

The depth of fat at the 12th/13th rib is reported as being a good indicator of overall carcase fatness (see literature review). As well as a direct measurement of fat thickness at this point on the hot carcase each carcase was also described by a fat score which was derived from a multiple regression equation (Luckock, pers. comm.) using fat depth, carcase length, carcase weight and dentition category as variables.

At the time of the current work the A.M.L.C. proposed that each carcase would be described by a 7 point scale for fatness derived by the above equation however, the results from the 20 carcases in this experiment were not rounded but were left in decimal form.

The weight/length relationship, based on the fleshing index principle (Yeates, 1952) was used as an objective measurement of carcase shape however, the A.M.L.C. proposed adjusting this relationship for increasing carcase fatness and weight by combining these two factors with carcase length to give a weight/length category.

The A.M.L.C. carcase classification scheme envisaged 4 weight/length categories to describe carcase shape; the details of which are determined in a similar fashion to the fat score described above. Carcase length (A-B, Figure 3.3) was an additional variable to those described for calculating fat score and the results were not rounded to produce a 4 point scale but were left in decimal form.

3.8.2 M.L.C. classification scheme

The Meat and Livestock Commission (M.L.C.) in the United Kingdom currently use a subjective classification scheme to describe beef carcases and the characteristics on which this is based are similar to those included initially in the A.M.L.C. classification scheme; namely, age, sex, weight, fatness and shape of the carcase (Harrington, 1976).

Carcase fatness and shape are determined by subjective assessment on the basis of the categories shown in Figure 3.4. Fatness is described on a 7 point scale (leanest to fattest) and shape on a 6 point scale (best shape to worst shape). The experimental carcases were classified using the M.L.C.'s classification criteria and as no trained assessors were available the subjective procedures were followed with the aid of photographic standards.
Figure 3.4 Grid showing the fatness and shape categories of the M.L.C. beef carcase classification scheme (Harrington, 1976).
3.9 Carcase assessment

The carcases were held in the chiller at 2°C for approximately 3 days after which time they were removed, quartered between the 12th and 13th rib by a member of the abattoir staff and transported to a chiller (2°C) at the Department of Animal Science, University of New England.

3.9.1 Measurements on the quartered carcase

On arrival at the laboratory several additional carcase measurements were taken:

(a) Cold carcase weight was measured by weighing each of the quarters separately on a set of beam scales (Avery Pty. Ltd.) to the nearest 100 g. Quarters that were not cut up immediately were weighed at 0900 h on subsequent days.

(b) Eye-muscle area was estimated by taking duplicate tracings of M. longissimus at the quartering position on the forequarter of both the right and left sides. The tracings were later passed through a Paton Electronic Planimeter (Paton Industries South Australia Pty. Ltd.) and a mean of 5 readings on each tracing was taken.

(c) Fat depth (mm) over the M. longissimus was measured at three points (Figure 3.5) at the quartering position on both the right and left forequarters of the carcase.

(d) Leg length (de Boer et al., 1974) was measured from the medial malleolus of the tibia in a straight line to the pubic symphysis (E-G, Figure 3.6).

(e) Width of leg (de Boer et al., 1974) was measured with a calliper and was taken as the maximum width between the outermost points on the medial and lateral surface of the leg (H-I, Figure 3.6).

Finally, the right fore and hindquarters were photographed, taking care to standardize the position and height of the camera.

3.9.2 Yield of retail joints

The right half of the carcase was cut into commercial joints by 3 trained butchers as described by the Meat and Allied Trades Federation of Australia (1972). The jointing procedure is illustrated in Figure 3.7.
Figure 3.5 12th/13th rib interface showing the position of the three fat thickness measurements. 
(A = 3/4 position; B = 2.5 cm from lateral edge of M. longissimus; C = 2.5 cm from medial edge of M. longissimus; Shaded area = eye-muscle area).
Figure 3.6 Carcase measurements (E-G, leg length; H-I, leg width).
Figure 3.7 Jointing procedure adopted (Meat and Allied Trades Federation of Australia, 1972).
The butchers randomly selected quarters to cut up. Each quarter was weighed before the cut-out commenced and as each joint was removed it was weighed prior to being partitioned into bone, saleable meat, saleable trim, fat trim and inedible trim (Figure 3.8). With the exception of the sirloin all joints were boned out. The sirloin had the 13th rib removed and the remainder (including the chine bone) was cut into steaks approximately 2 cm thick on a bandsaw and the fat covering trimmed to an "acceptable" level (0.6 cm approximately). The silverside was trimmed to an "acceptable" level of fat cover but was not cut into steaks. The perinephric (kidney) and retroperitoneal (channel) fat were removed and weighed along with the kidney.

To determine if the level of trimming was constant between and within the treatments groups a measurement of fat thickness remaining on ten sirloin steaks (T-bone) after trimming was taken. This joint was chosen, as a standard location at which to measure fat thickness could be adopted and this location was 5.0 cm from the medial edge of the chine bone.

3.9.3 Muscles sampled

The left carcase side remained in the chiller till 96 hours post mortem after which time the following samples were removed.

(a) Standard three-rib-joint as described by Hankins and Howe (1946).

(b) M. triceps brachii.

(c) M. semitendinosus.

(b) and (c) were removed according to the method of Butterfield and May (1966). The muscles were cleaned of any external fat, weighed, placed in labelled plastic bags and frozen (-20°C) until required for analysis. Following the removal, weighing and photographing of the three-rib-joint the M. longissimus was dissected out and treated in a similar manner to the former samples. The remainder of the three-rib-joint was weighed and frozen in a labelled plastic bag.

The remainder of the left carcase side was cut into commercial joints. Those joints affected by the removal of muscle samples were: ribs, blade and silverside respectively. Any fat removed from the muscles at the time of dissection was weighed and added to the total weight and fat trim of that joint. The resulting joint was treated in the same manner as the corresponding joint of the right side, however for the blade and silverside the weight of dissected muscle was added to the saleable trim of the joint. This meant that for these joints comparison could be made between the right and left side in terms of total edible product (saleable meat + saleable trim). Comparisons
Figure 3.8 Partitioning of commercial joints.
between the rib joints from both carcase sides were abandoned as the amount of fat trim removed with the three-rib-joint was not able to be calculated.

3.9.4 Dissection of the three-rib-joint

The three-rib-joint (minus the M. longissimus) was removed from the freezer and weighed to determine the weight loss during the period of freezing, the joint was allowed to thaw for 4 hours at room temperature under damp towels after which it was dissected into muscle, fat and bone. Cartilage and connective tissue which could be readily separated were included with bone and the weight of each tissue recorded.

3.10 Subjective and objective assessment of meat quality

3.10.1 Sampling of muscles

The frozen muscles were sampled in a standard way prior to being thawed and cooked. The length of the M. semitendinosus and M. triceps brachii was measured in the frozen state and the muscle sawn at a point corresponding to 50 per cent of this length. A tracing of the cross sectional area of the muscle was taken at this point prior to obtaining a sample for cooking by measuring 7.5 cm toward the caudal end of the muscle and making another cut (see Figure 3.9).

In the case of M. longissimus the sample for cooking was obtained by measuring 7.5 cm from the caudal (11th rib) end and sawing through the frozen muscle (see Figure 3.9). At the same time a 1 cm slice was removed from the remaining sample and placed in a labelled plastic bag for later hydroxyproline analysis. The remaining muscle was also placed in labelled plastic bags and returned to the freezer for later chemical analysis.

3.10.2 Sample preparation

The frozen muscle samples for cooking were weighed and allowed to thaw at room temperature (15°C) for 24 hours before being dried and reweighed to yield an estimate of thaw loss. In the case of M. semitendinosus and M. longissimus the entire thawed sample was used for cooking, meaning that there was a marked between-muscle difference in the weight of sample that was cooked. For M. triceps brachii however, the sample (after thawing) was reduced to a constant weight of approximately 225 g.

3.10.3 Cooking procedure

A thermocouple needle was inserted into the central portion of the sample which was then immersed in peanut oil preheated to 160°C. The thermocouple was connected to a reference bath and a 12 channel recording unit
M. triceps brachii and M. semitendinosus

![Diagram of M. triceps brachii and M. semitendinosus]

50% of muscle length

cranial  1 cm  7.5 cm  caudal

1  2  3  4

M. longissimus

![Diagram of M. longissimus]

1 cm  7.5 cm

1  2  3

9th rib  11th rib

Figure 3.9 Sampling procedure adopted for experimental muscles (1 and 4, used for chemical analysis; 2, used for connective tissue assessment; 3, used for cooking).
(Speedimax; Leeds and Northup) which had previously been calibrated to indicate the temperature at the needle point. When the temperature at the centre of the meat sample reached 65°C the sample was removed from the cooking oil. After the meat sample was removed from the oil the internal temperature continued to increase for a short time and the maximum temperature reached at the centre of the meat was also recorded. Cooking time and the time from removal of the meat from the oil until maximum internal temperature was reached were recorded with a stop watch after which the meat sample was drained of any excess oil and placed in a refrigerator at 2°C.

3.10.4 Preparation of the cooked meat sample

After approximately 16 hours the cooked sample was removed from the refrigerator and weighed to estimate the cooking loss. Test samples were prepared using an apparatus consisting of two scalpel blades fixed 1.0 cm apart. Sampling was carried out by removing a 1.0 cm slice from the medial portion of the cooked sample, trimming off the hardened outer layer and layer of oil penetration and cutting a number of strips (1.0 x 1.0 cm in cross section) parallel to the direction of the muscle fibres. The strips were reduced to 2.0 cm in length for subjective and objective evaluations. Subsequent 1.0 cm slices were removed from either side of the first medial sample until sufficient strips were obtained (Figure 3.10).

3.10.5 Taste panel assessment

Members for the taste panel were drawn from postgraduate students and staff of the Department of Animal Science, University of New England. Prior to the commencement of taste panel evaluation of the muscles obtained from the experimental animals a number of trial runs were conducted to familiarize members with the procedures and to eliminate any of the members who were unreliable in their response to samples of "known" quality and with respect to other members of the panel. Following these trial runs the taste panel was reduced to 8 members (3 of whom had no prior taste panel experience).

Of the three muscles collected from each carcase, taste panel assessment of quality was made on each of the 20 samples of a particular muscle before another muscle was assessed. The order in which the 20 samples were allocated to each session was the same as the order of slaughter.

At each session individual panelists were presented with four stoppered glass vials each containing a meat sample, the vials being labelled with symbols (*, #, Δ and θ) to reduce any bias that may have been inferred by using numbers (1, 2, 3, ... ) or letters (A, B, C, ... ). The order in which the panelists received the four samples was determined by
Figure 3.10 Sampling procedure of cooked muscle.
using two 4 x 4 latin square designs which were randomized before each session. The panelists were asked to score each of the meat samples on the following criteria; tenderness, connective tissue (residue), flavour and overall acceptability, on a nine point hedonic scale (Figure 3.11). Sessions were initially held once daily (1100 h) but this was increased to twice daily (1100 h and 1600 h) when it was found that a number of panel members would be absent.

3.10.6 Warner-Bratzler Shear determinations
An objective assessment of meat tenderness was made using a Warner-Bratzler Shear device (cross head speed approximately 20 cm/min). The maximum force required to shear the 1.0 x 1.0 cm strip of sample, perpendicular to the direction of the muscle fibres was recorded in kilograms and the mean of nine shears calculated.

3.10.7 Objective determination of juiciness
Triplicate cooked samples of approximately 1 g were accurately weighed, placed on a 15 cm Whatman No.541 filter paper (preconditioned in a desiccator) with the muscle fibres perpendicular to the filter paper, covered with a sheet of aluminium foil and placed between two sheets of perspex in a "Carver" laboratory press, under pressure of approximately 103,000 kilopascals for one minute. The outlines of the pressed meat and the expressed juice were traced onto transparent paper, the areas were measured using a compensating polar planimeter and from this an objective measure of juiciness was given by:

\[
1 - \frac{\text{area of pressed meat}}{\text{area of expressed juice}}.
\]

This quantity was referred to as the water holding capacity by Miller and Harrison (1965).

The weight of the pressed meat cake was also recorded and per cent expressible juice was calculated by:

\[
\frac{\text{initial sample weight} - \text{pressed sample weight}}{\text{initial sample weight}} \times 100
\]

3.11 Chemical analysis
3.11.1 Sampling procedure
The muscles assigned for chemical analysis (see Figure 3.9) were removed from the freezer, placed in sealed plastic bags and allowed to thaw at room temperature (20°C) for 16 hours. The samples were double minced using a hand operated mincer which had a cutting plate with 6 mm holes, the
<table>
<thead>
<tr>
<th>Tenderness</th>
<th>Amount of Connective Tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 very tender</td>
<td>9 none</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>7 tender</td>
<td>7 slight</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>5 average</td>
<td>5 moderate amount</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>3 tough</td>
<td>3 large amount</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1 very tough</td>
<td>1 very large amount</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flavour</th>
<th>Overall acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 very strong</td>
<td>9 very good</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>7 strong</td>
<td>7 good</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>5 moderate</td>
<td>5 moderate</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>3 slight</td>
<td>3 poor</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1 none</td>
<td>1 very poor</td>
</tr>
</tbody>
</table>

Comments: ____________________________

________________________

________________________

________________________

Figure 3.11  Taste panel score sheet.
mince was returned to the plastic bag and the moisture lost during thawing was reincorporated by hand. A sub-sample of approximately 30 g was taken by randomly grab sampling approximately 5 g of mince from the bulked sample until the required weight was obtained. This subsample was used to determine the total moisture content and the percentage of intramuscular fat. A similar method of sampling was adopted to obtain approximately 15 g of minced muscle for determination of pH and estimating free water.

3.11.2 Determination of total, free and bound water

Triplicate samples (approximately 5 g) of finely minced muscle tissue were accurately weighed into Whatman cellulose extraction thimbles (28 mm by 80 mm) which had been oven dried at 100°C for one hour, cooled in a desiccator and weighed. The thimbles were then placed in a freeze drier for 30 hours as this was considered to be the minimum time required to dry the samples to a point where no appreciable further reduction in weight occurred (Figure 3.12). The thimbles were reweighed and total water content was calculated as the percentage of weight loss from the fresh muscle tissue.

\[
i.e., \% \text{Total water} = \frac{\text{Fresh weight} - \text{Freeze dried weight}}{\text{Fresh weight}} \times 100
\]

Free water was determined by accurately weighing in triplicate approximately 1 g of finely minced muscle tissue and placing each sample between a 15 cm Whatman No.541 filter paper and a sheet of aluminium foil before being inserted between perspex plates in a "Carver" laboratory press for 1 minute at approximately 20,000 kilopascals pressure. The filter papers had previously been conditioned for moisture content in a desiccator and the resulting pressed meat cake was accurately weighed, the percentage of free water being calculated as follows:

\[
\% \text{Free water} = \frac{\text{Weight fresh sample} - \text{Weight of pressed meat cake}}{\text{Weight of fresh sample}} \times 100
\]

Bound water was calculated as the difference between total and free water, i.e.

\[
\% \text{Bound water} = \% \text{Total water} - \% \text{Free water}
\]

3.11.3 Ether extract determination of chemical fat

The samples previously freeze-dried to determine the total water content of the muscle were subsequently used for determination of chemical fat by a slight modification of A.O.A.C. (1970) method 7.048. In the current work the samples were freeze-dried, the extraction solvent was petroleum ether (X222, Shell Co. Aust.) and extraction was carried out over a 24 hour period (approximately 144 extraction cycles of the Soxhlet apparatus). After
Figure 3.12 Drying curve determined for beef muscle in the freeze-drier used in the current study.
extraction the thimbles were oven dried for 30 min at 100°C, cooled in a desiccator and weighed, the fat content of the muscle samples was determined by weight loss following extraction and expressed as a percentage of fresh weight.

$$\% \text{ Fat} = \frac{\text{Freeze dried weight} - \text{Weight following ether extraction}}{\text{Fresh weight}} \times 100$$

3.11.4 Determination of muscle pH
A 15 g sample obtained by the method described in Section 3.11.1 was allowed to stand at room temperature (20°C) for 2 h in a glass stoppered vial. A measurement of pH was taken directly on the sample using a pH meter (Radiometer, Copenhagen) with glass electrode G213C, by inserting the electrodes approximately 1 cm into the mince and allowing 5 min for the machine to equilibrate before taking a single reading.

3.11.5 Determination of the collagen content of muscle
Although samples were collected from the three muscles hydroxyproline analysis was only carried out on minced M. longissimus (see Section 3.10.1) using the techniques described by Goll et al. (1963). The muscle was trimmed of any external fat and the epimysium and double minced using a hand operated mincer with 6 mm cutting plate.

Triplicate 1 g samples were placed in 20 ml 6N HCl, allowed to stand at room temperature (20°C) for 16 hours and then boiled for 4 hours. Neuman and Logan (1950) reported that maximum values of hydroxyproline were reached after autoclaving for 3 hours at 340 kilopascals pressure and did not decrease after 8 hours hydrolysis. However, the yield of hydroxyproline under the conditions prevailing during the current experiment declined after 4 hours hydrolysis.

The method and reagents used from this point were as described by Goll et al. (1963). After the addition of the colour reagent the samples were allowed to sit at room temperature for 30 min and per cent light transmission read at 5600 $\mu$ on a Unicam SP 600 Spectrophotometer.

A standard curve was produced in the range of 0 to 5.0 $\mu$g hydroxyproline per ml and was observed to be linear from the origin to 1.5 $\mu$g/ml. Morgan (1972) reported values for the collagen content of M. longissimus from animal approximately 12 months old as being 0.57 per cent on a fresh weight basis and these values are comparable with those of Wilson et al. (1954) and Loyd and Hiner (1959) for animals of varying age and grade. As results of this order yield approximately 0.8 $\mu$g hydroxyproline per ml only the linear portion of the standard curve was used to produce an equation for
determining the amount of hydroxyproline in the current samples. The resulting equation was \( Y = 3.342 - 0.034X \) where \( X \) is per cent light transmission and \( Y \) is \( \mu g/ml \) hydroxyproline. Collagen content was calculated from the hydroxyproline content by multiplying by a conversion factor of 7.25 (Goll et al., 1963) and the results were expressed as percentages of fresh weight.

3.12 Histological samples

3.12.1 Sampling procedure

Two to three grams of raw and cooked muscle were collected from the 3 muscles at various stages: A sample of \( M. \) longissimus was obtained from the medial position on the 11th/12th rib interface of the "discarded" 12th rib section during removal of the three-rib-joint. Similar samples of \( M. \) semitendinosus and \( M. \) triceps brachii were obtained from the thawed muscle sample prior to cooking. Following cooking a 2.0 cm strip of all 3 muscles was obtained from the medial slice removed. All samples were stored in 10% buffered formalin for later histological study.

3.12.2 Measurement of muscle fibre diameter and sarcomere length

Approximately 1 g of sample was placed in 100 ml of physiological saline (0.9% NaCl) and homogenised for 20 sec in a top drive macerator (Townson and Mercer Ltd.). The homogenate was filtered and a sample of the fibres mounted on a microscope slide in a drop of 50% glycerol, a cover slip was placed over the mount and sealed.

A projecting microscope (Leitz Wetzlar, Germany) was used to project the muscle fibres onto a wall (the scale of the projection was 10 microns equal to 100 mm), and from this projection fibre diameter was measured in millimetres and sarcomere length was derived by counting the number of sarcomeres within a 5 cm (50 \( \mu \)) interval and using the following formula:

\[
\text{Sarcomere length (\( \mu \))} = \frac{50}{\text{Number of sarcomeres counted in a 5 cm interval}}
\]

As the variation in muscle fibre diameter was large a sample of 50 muscle fibres was measured. Sarcomere length was a much less variable parameter and only 20 observations were made on each mounted sample. Scanning the slide was carried out in such a way that individual muscle fibres were measured only once.

3.13 Statistical methods

Unless otherwise stated the data were analysed by two-way analysis of
variance (1/cell) as described by Snedecor and Cochrane (1967). The sources of variation tested for significance in the analysis were: replications and treatments. The sum of squares due to replications was removed from the total sum of squares as the animals had been allocated to treatments by a process of stratified randomization according to liveweight (see Section 3.3.3). The residuals were examined for heterogeneity of the error components after each analysis, and where necessary the appropriate data transformations were carried out before further analysis of variance. Significant differences between means were evaluated using the 5 per cent Studentized range. All analyses of variance were performed using the NEVA programme developed by Professor E.J. Burr, Department of Computing Science, University of New England.

Simple correlation coefficients were calculated using the BAR3 programme developed by Professor E.J. Burr.