SOME ASPECTS OF THE BONE-MUSCLE RELATIONSHIPS IN NEW ZEALAND LAMB AND MUTTON CARCASSES

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General impressions are never to be trusted. Unfortunately when they are of long standing they become fixed rules of life, and assume a prescripttive right never to be questioned. Consequently those who are not accustomed to original inquiry entertain a hatred and a horror of statistics. They cannot endure the idea of submitting their sacred impressions to cold blooded verification. But it is the triumph of scientific men to rise superior to such superstitions, to desire tests by which the value of such beliefs may be ascertained, and to feel sufficiently masters of themselves to discard contemptuously whatever may be found untrue.

Francis Galton.

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CHAPTER I

INTRODUCTION

The three main constituents of a meat carcass are bone, muscle, and fat, and of these the lean meat or muscle is of greatest interest and importance to the consumer. Bone represents an almost total waste and is hence considered as undesirable and as something which must be accepted with the desirable muscular tissue. In the words of Robert Bakewell, "You can't eat bone, therefore give the public something to eat." (Pawson, 1957).

The physical properties of muscle and bone are markedly different. Muscular tissue is compressible and hence difficult to measure with accuracy on a linear scale. The intimate association of skeletal muscle with other tissues makes its complete removal for accurate weight estimation both difficult and tedious. Bony tissue, on the other hand, lends itself more readily to the measurement of linear dimensions and weight.

The close physical association of the muscular and bony tissues in the animal body prompts the question as to the possibility of the existence of a similar quantitative relationship between these two tissues. The presence of a strong quantitative relationship between muscle and bone which would allow an accurate prediction of the amount of muscular tissue to be made from a knowledge of the weight and/or linear measurements of one or more bones would be of considerable value to producers and consumers of meat animals. In this respect the metacarpal and metatarsal or cannon bones are of particular interest as possible indices of the weight of muscular tissue in the carcass, in that these bones are not included in the carcass as the term is generally understood in New Zealand and Great Britain, thus obviating the necessity for any mutilation of the carcass in an attempt to assess the amount of muscular tissue. Although the availability of the cannon bones makes them a first choice in the search for a simple index of muscle, the bones of the carcass, and particularly those of the limbs, are also worthy of consideration as their very inclusion in the carcass suggests that they may be more closely associated in a quantitative sense, with the carcass musculature.

Investigations in the field of bone-muscle relationships have been made at various times by different workers. In the majority of instances the numbers of carcasses studied have been small, and because of this and other reasons the reports in the literature have frequently been conflicting. The present study is based on data from some 150 mutton and lamb carcasses, which, it is felt, provides a sounder basis than any hitherto for investigating the possibilities of using certain simple bone measurements to estimate the amount of muscular tissue in mutton or lamb carcasses.

CHAPTER II

REVIEW OF LITERATURE

1. LINEAR AND WEIGHT MEASUREMENTS AS INDICES OF THE PHYSICAL COMPOSITION OF CARCASSES

In enumerating the factors which handicap progress in the improvement of sheep, Rae (1946) places first the "lack of objective techniques for increasing productivity in wool and meat." The need for precise, simple, objective and reliable indices of carcass composition and of carcass quality has been realised for a considerable time, and although a large number of workers have applied themselves to this problem since the early studies of Lush (1926), it is doubtful whether any have produced an index which can justifiably claim to fulfil these requirements of precision, simplicity, objectivity and reliability.

(1) Linear Measurements on the Live Animal

Many attempts have been made to relate measurements made on the live animal to carcass composition, and to carcass measurements which are considered by some workers to be indices of carcass composition or carcass quality. The existence of a simple measurement, taken on the live animal, which would give a satisfactory estimate of carcass composition would be of inestimable value to the meat industry as a whole.

Height at withers appears to be one of the most satisfactory live-animal indices of carcass merit. This measurement has been used mainly on beef cattle and is frequently combined in a ratio with some other external linear measurement, or with live weight. Lush (1928), and Lush, Jones, Dameron and Carpenter (1930) used the ratio of heart girth to height at withers in an attempt to estimate the degree of fatness of beef carcasses, and to this end correlated the ratio with fatness, as estimated from dressing-out percentage and weight of caul fat. Knapp and Cook (1933) confirmed that this ratio was the best measure of "fleshing" in Shorthorn cows and calves. These workers also found evidence of breed differences between beef and dual-purpose steers in the ratio of live weight to height at withers and suggested the use of this second ratio as a measure of beef type. More recently Tallis, Klosterman and Cahill (1957) found that, of nine live-animal ratios studied, those of live weight to height at withers, and of live weight to body length, were the most closely related to carcass characteristics of beef steers. Height at withers and live weight have also been used by Brody and Ragsdale (1935) as a means of evaluating condition in dairy cattle. Black, Knapp and Cook (1938) found height at withers, in a weight-constant population, to be closely related to slaughter grade. In devising a method of determining slaughter grades of steers under field conditions Knapp (1939) demonstrated a curvilinear relationship between height at withers, live weight and slaughter grade, and computed a multiple regression equation, based on data from 167 steers of beef and dairy breeding, whereby grade might be estimated from height at withers and the logarithm of live weight. In reviewing performance recording in beef cattle Mason (1951) suggests that, where information relating to carcass quality *per se* cannot be obtained, grade may best be determined on the live animal by the ratio of body weight to height at withers, or by the multiple regression equation referred to above (Knapp, 1939).

Other workers have attempted to predict carcass composition and factors closely associated with carcass quality, as opposed to the determination of grade, from height at withers and other live-animal measurements. Hankins, Knapp and Phillips (1943), working with 135 beef and dual-purpose Shorthorn steers, related height at withers, heart girth, cannon bone circumference, and chest width, as measured on the live animal, to the carcass muscle:bone ratio, which they, and more recently Callow (1961), consider to be a useful index of carcass merit. None of the live-animal measurements was significantly correlated with the muscle:bone ratio of the carcass, indicating that carcass merit cannot be assessed on the basis of conformation as evaluated by such measurements. However, the fact that these workers could find no significant correlation between the muscle:bone ratio and the proportion of separable fat in the carcass suggests that the choice of this ratio as a criterion of carcass merit may not be altogether satisfactory.

In a study involving 153 steers Weseli, Good and Holland (1958) related live-animal measurements to loin eye area in an attempt to find a possible index which would be useful in predicting the degree of muscling in beef carcasses. However, these workers do not quote any relationships between loin eye area and total carcass muscle. The live-animal characteristics used in their particular study were an assessment of grade on the hoof, circumference of forearm, a subjective assessment of bone score, and cannon circumference. The highest correlation (r=0.30) was between cannon circumference and loin eye area. Other correlations between live steer characteristics, between live and carcass cannon measurements, and between carcass characteristics were little better. These workers concluded that live-animal measurements were not correlated closely enough with loin eye area to be of use in estimating the amount of muscular tissue in beef carcasses. They further added that, in general, live-animal measurements were not as useful indicators of carcass composition as expected.

These conclusions are in general agreement with those expressed by other workers. Backus, Dollahon, Taylor, Williams and Travis (1960) carried out similar studies on 294 steers of diverse breeding and previous treatment. The majority of the relationships presented by these workers are too low for predictive purposes, and the few high correlations are between variates which have little practical significance. The very large differences in correlation found between breed and treatment groups support the conclusions of Ternan, Kidwell, Hunter, Shelby and Clarke (1959) that relationships developed for one group cannot be successfully applied to others. These last-mentioned workers investigated relationships between live-animal measurements and conformation scores. They reported that zero order correlation coefficients were either not significant, or were too low to be useful. Correlations involving ratios or combinations of measurements were of similar worth, and multiple regression equations were ineffective in raising the accuracy of prediction to satisfactory levels. However, these workers submit that the ratio of length of rump to body length is worthy of further consideration.

Brookes and Harrington (1960) found chest girth and height at shoulder to be significantly related to the live weight of beef steers. Linear and multiple regressions on these variates were, however, considerably affected by plane of nutrition, and it was considered that those measurements exhibited little promise as estimators of live weight which could be generally applied.

Yao, Dawson and Cook (1953) found that the best general index of what they describe as "beef character" was given by the ratio of the product of width and circumference measurements to the product of height and length measurements. Their results showed, in agreement with those of Cook, Kohli and Dawson (1951), that the most satisfactory width measurement was that of the chest, that the circumference at the navel gave the best measure of girth, that height was best measured at the withers, and that body length was the most useful measurement in that dimension. Similar studies by Hankins and Beard (1944), Vanderstock and Salisbury (1946), Kidwell (1955), and other workers would suggest, however, that heart girth is more closely related to carcass characteristics than is circumference at the navel. Orme, Pearson, Magee and Bratzler (1959) working with steers, and Hetzer, Hankins, King and Zeller (1950), with pigs, have also established significant relationships between measurements taken prior to slaughter and various accepted indices of carcass quality. The conclusions of all the above workers may be summarised in the words of Hetzer et al. that "...although the predictive value of the measurements studied was not as great as might be desired ... certain body measurements offer possibilities of being a valuable tool in estimating carcass yields from the live animal."

With the exception of the work of Hetzer et al. (1950) on pigs, all of the studies discussed above have related to the carcass composition and carcass quality of cattle. Rae (1946) states that "...the major criticism which can be levelled against the use of body measurements in sheep is the fact that it is not known to what extent they indicate desirable body conformation, and carcass quality. To the best of the writer's knowledge (Rae), no investigation has been conducted into the problem of interpreting body measurements in sheep in terms of relationships to carcass quality."

In the course of some work on the progeny testing of New Zealand Romney Marsh rams Rae investigated the relationships between live-animal measurements and certain carcass characteristics indicative of carcass quality. To the best of the present writer's knowledge this has been the only attempt to interpret body measurements of sheep in relation to carcass quality, and as such deserves due consideration here.

The height at withers measurement discussed above has been shown to be one of the most useful live-animal indices of beef carcass quality. Rae (1946) has shown that this is also true in the sheep, and his findings support the contention of Phillips and Stoehr (1945) that this measurement can be taken with a high degree of accuracy. Rae reported highly significant correlations ranging from 0.72 to 0.80 between height at withers, as measured on the live animal, and certain external carcass measurements of leg length, viz., length of fore cannon bone, length of tibia + tarsus, length of radius-ulna, length of leg from the symphysis pubis to the distal end of the tarsus, and leg length as measured and defined by Pálsson (1939). The lengths of the fore cannon and of the radius-ulna showed the highest correlation coefficients, as might be expected from the fact that these measurements form integral parts of the height at withers measurement. Rae concludes that "...although the correlation coefficients are not high enough from the point of view of predictive purposes, they definitely establish a strong relationship, as would be expected, between the height at withers and length of leg as measured in various ways on the carcass, and therefore vindicate the validity of the measurement."

Walker and McMeekan (1944) showed the product of length of tibia + tarsus and width of gigots (Pálsson's T x G index) to be closely related to the total weight of muscle in lamb carcasses (r=0.89 for certain grades), and also to the total weight of bone (r=0.93 for certain grades). As height at withers is closely related to length of tibia + tarsus it might be reasonable to expect at least a fair degree of relationship between height at withers and T x G, as an index of carcass quality. In such a case it might also be reasonable to anticipate the existence of a relationship high enough to be of predictive value between height at withers and the amount of muscle and/or bone in the carcass. Rae (1946) showed, however, that the correlation between height at withers and T x G was not significant.

A highly significant negative correlation ($r = -0.63$) between height at withers and total block test points has also been demonstrated by Rae. He points out, however, that a considerable portion of this relationship is due to the association between leg length and other features of the carcass which tend to lower overall quality, and also to the fact that 30 per cent. of the total carcass points are allotted to leg length. The standard error of estimate of height at withers (8.33cm) supplied by the regression on total block test points is too large to permit the equation to be used for predictive purposes.

In a report dealing with the physical definition of sheep, Turner, Hayman, Riches, Roberts and Wilson (1953) have expressed some dissatisfaction with the measurement of height at withers. These workers consider that this particular measurement is more time-consuming than any other, and that it is most affected by the posture of the sheep. One of the objects of taking this measurement is to obtain the ratio of depth of chest to length of leg, and Turner <u>et al.</u> have proposed an alternative and more direct measure of leg length, viz., the elbow to coronet measurement, for this purpose. They report that the elbow to coronet measurement error (2 to 3 per cent.) is lower than that of wither height (2 to 4 per cent.), and that it is more easily and more quickly taken.

Rae (1946) also investigated the relationships of other live-animal measurements to linear carcass measurements which might themselves be indices of carcass quality. The correlation between width of forequarter as measured prior to slaughter and again on the carcass ($r=0.53$) just failed to reach the level required for significance at the 1 per cent. level of probability. Correlations between width of loin, as measured on the live animal, and "length" of eye muscle (measurement A) and "depth" of eye muscle (measurement B), and between the width of hindquarters and width of gigots (measurement G), were all not significant.

Rae also studied the relationships between subjective gradings on the live animal and carcass measurements. It is sufficient to note here that highly significant correlations, but not of levels required for a reasonable accuracy of prediction, were demonstrated between Body As A Whole and Export Grade, live and carcass assessments of loin conformation, live loin grading and depth of eye muscle, live shoulder grading and carcass forequarter conformation, live shoulder grading and width of carcass forequarters, and subjective assessment of leg length and tibia + tarsus length. The correlation between live loin grading and "length" of eye muscle was not significant.

Various body measurements and arbitrary morphological ratings have been used at different times in attempts to estimate the degree of fatness in human subjects. The system of somatotyping devised by Sheldon (194) and later modified by Hooton (1951) is considered by Keys and Brožek (1953) to be of some use in the evaluation of fatness in the live human. The use of skinfold measurements, as described by Brožek and Keys (1950), and Keys and Brožek (1953) would seem however, to be more applicable to livestock than would somatotype ratings. This possibility has recently been investigated by Tulloch (1961) who related skin and skinfold measurements, made on the midside of steers immediately before slaughter, to the depth of subcutaneous fat on the cut surface between the tenth and eleventh ribs. His results indicate that such measurements have no value as indices of the degree of fatness in beef carcasses.

It would appear from the above-mentioned work on cattle and sheep that there is no single linear measurement of the live animal which is sufficiently closely related to an economically important characteristic of the carcass to be of value in the assessment of carcass composition and quality. The conclusion drawn from a study of the use of body measurements in ascertaining fatness of steers might well apply to the whole field of carcass composition as determined from live-animal measurement: "The question of whether any measurement is sufficiently informative to be worth taking ... remains a debatable one." (Lush, 1928).

The use of backfat probes, developed by Hazel and Kline (1952) and of the Lean-meter, evolved by Andrews and Whaley (1954), comes under the heading of the estimation of carcass composition from linear measurements on the live animal. Probing techniques are also applicable to carcass studies, but being concerned with strictly internal measurements are more conveniently considered in a later section.

(2) Linear Measurements on the Carcass

External linear measurements of the carcass and internal linear measurements on the transverse section at the last rib have been widely used in the estimation of body composition in terms of bone, muscle and fat. Although Moulton, Trowbridge and Haigh (1921, 1922a) recorded certain linear carcass measurements in their studies of the body composition of cattle they did not possess the knowledge at that time to relate statistically the two sets of variables. Hankins and Ellis (1934), who investigated the relationship between measurements of the thickness of subcutaneous fat, as revealed on a longitudinally-split carcass, and the percentage of chemical fat in the edible tissue of pig carcasses, are generally credited with being the first workers to attempt the estimation of carcass composition from linear carcass measurements.

Much of the early work in this field was carried out by the Hammond School. Hirzel (1939) related certain linear measurements of mutton and beef carcasses at Smithfield Fatstock Shows to carcass composition, and developed indices whereby superior carcasses might be objectively selected, and which he also used in comparing breeds with regard to their suitability for meat production. Working with the sheep, Pálsson (1939) evolved a series of external and internal carcass measurements which he related to conformation and composition. Although his results were based on the study of a small number of individuals and do not now carry much weight, his system of measurement demonstrated the possibility of using linear measurements to estimate body composition, and to this end has been widely used during the past twenty years. Hammond made use of linear carcass measurements in his development of the Cambridge Block Test for lambs, which provides a simple and reasonably objective means of judging and describing the carcass (McMeekan, 1939). Robinson, Binet and Doig (1956) have also used external linear measurements as the basis of a grading system for lambs. McMeekan (1940, 1941), working with the pig, used a series of linear carcass measurements based on those of Pálsson (1939). McMeekan's work is also open to criticism on the grounds of the small numbers of animals used per treatment. Harrington (1958) has also pointed out that the stock used were closely inbred and all slaughtered at the same live weight. McMeekan's main contributions in the present connection were in the further development of the relationship between backfat thickness and total fatty tissue, and in the estimation of total carcass muscle from eye muscle measurements.

A consideration of the usefulness of such measurements as indices of carcass composition is most conveniently dealt with under the headings of the component tissues.

(a) <u>as indices of bone</u>

Of the three major tissues of the carcass, bone is the least important, the least valuable and in most cases the least in quantity, and it is therefore not surprising that less attention has been paid to the estimation of bone from carcass and other measurements than to the prediction of the other tissues. Pálsson (1939), McMeekan (1941), and Walker and McMeekan (1944) have all reported that external carcass measurements serve primarily as a measure of skeletal size and that such measurements are, in general, more closely related to skeletal weight than to the weights of either muscle or fat. Pálsson found that the length of tibia + tarsus (T) provided the best index of the weight of bone in the sheep carcass, although the later work of Walker and McMeekan suggests that the product of this measurement and width of gigots (T x G) is more satisfactory for predictive purposes. McMeekan has shown that in the pig the length of hind leg and length of forearm + fore trotter were the measurements most closely correlated with the weight of total bone. The ultimate conclusion of the above workers is, however, in agreement with the opinion expressed by Lush (1926), that bone weights, and combinations of bone weights and linear measurements provide more accurate estimates of total bone than do linear measurements alone.

(b) as indices of muscle

Pálsson (1939) has stated that external carcass measurements, as indices of total muscle weight, are only of indirect value. He found that leg length (F) minus length of tibia + tarsus (T), and width of gigots (G) x 100/F were the factors most closely correlated with weight of muscle as a percentage of skeletal weight. Walker and McMeekan (1944), who consider Pálsson's high correlations to be largely fortuitous, reported T x G to be the most satisfactory index of carcass muscle.

The internal measurements most widely used as indices of total muscle are those obtained from the cross-section of the *m. longissimus dorsi* at the last rib. Such eye muscle measurements have considerable qualitative importance as well as their quantitative importance as indices of the weight of carcass muscle. The most commonly used eye muscle measurements are those of width, which is generally referred to as "length" (A), and depth (B). The shape index (100B/A) of the eye muscle was first used by Hammond (1936) as an indicator of muscular development in domestic animals. Pálsson used the A and B measurements as indices of muscle weight, and showed that A was the more closely correlated with weight of carcass muscle in lambs, whereas B was the better index in hoggets. This he ascribed to the late maturity of eye muscle depth. Shape index was not related to the weight of carcass muscle. He found (A + B) to be the best index supplied by internal measurements, and (L/10)(A + B), in which L measures body length, the best index provided by a combination of internal and external measurements. Walker and McMeekan failed to demonstrate any worthwhile relationships between A, B, or combinations of A and B, and total muscle, although B alone was moderately well related to 100 x weight of muscle/weight of bone. Working with pig carcasses McMeekan (1941) found very high correlations (r=0.93) between (2A + B) and other combinations of those two measurements, and the weight of carcass muscle. Whiteman and Whatley (1953) also made use of those measurements on pig carcasses, and reported the product (A x B) to be as good an index of total muscle as the measurement of eye muscle area determined by planimetry. In beef carcass, however, Bodwell, Harrington and Pomeroy (1959) found planimetry to be superior to the product of pure linear measurements, which, although highly repeatable, were not considered to be sufficiently accurate for experimental use.

Branaman (1940) reported the area of loin eye muscle to be "a fairly good index" of the lean meat content of lamb carcasses, but gave no correlation coefficients or standard errors of estimate to substantiate his claim. Kline and Hazel (1955), and Pearson, Bratzler, Hoefer, Price, Magee and Deans (1956) have demonstrated highly significant correlations between the areas of eye muscle on the tenth and last ribs, and the percentage lean cuts in pork carcasses. Fredeen, Bowman and Stothart (1955) have shown a similar relationship between area and percentage area of lean in the cut surface of the ham, and the amount of muscular tissue in that joint. Although no standard errors of estimate of muscle weight have been given by these workers, the correlation coefficients would suggest that the relationships quoted have only a limited amount of predictive worth. Working with beef carcasses Cole, Orme and Kinaid (1960) reported that the area of loin eye was associated with only 18 per cent. of the variation in the absolute weight of separable carcass lean. These workers also found that the relationships of various linear carcass measurements, including carcass length, leg length, and loin length, to the weight of muscular tissue were too low to be of any predictive worth. Goll, Kline and Hazel (1961) and Goll, Hazel and Kline (1961) could find no evidence from a study of 90 beef carcasses that loin eye area was closely related to items indicative of overall carcass value.

It is pertinent at this juncture to mention something of the attempts which have been made to estimate the weight of carcass muscle from the weights of certain entire muscles. McMeekan (1941) noted that in the pig there was a high degree of association (r=0.81) between the weight of the *m. psoas major* and the total weight of muscle in the carcass. Although this relationship is scarcely high enough for predictive purposes, the recent work of Orme, Cole and Kincaid (1959), and Orme, Cole, Kincaid and Cooper (1960) with beef cattle has produced some high correlations between the weights of individual muscles and total carcass muscle. While relationships with the *m. psoas major* (r=0.82) were not superior to that in the pig carcass, those with the *m. biceps femoris* (r=0.96), *m. vastus lateralis* + *m. vastus intermedius* + *m. vastus medialis* + *m. vastus femoris* (r=0.93), *m. semimembranosus* + *m. adductor* (r=0.92), and *m. longissimus dorsi* (r=0.92) were more satisfactory for predictive purposes. Orme, Cole and Kincaid report that the weights of the muscles studied in their particular investigation were found to be associated with from 63 to 92 per cent. of the variation in the weight of total separable carcass lean.

(c) *as indices of fatty tissue*

External carcass measurements are generally more closely associated with skeletal weight than with the weights of muscular or fatty tissues. Pálsson (1939) found that length of leg (F), which was negatively correlated with fatty tissue as a percentage of bone, provided the best index of all the external linear measurements. Although Henkins, Hiner and Simmons (1951), in a study of the meat characteristics of Karakul sheep, demonstrated that the measurements of body length, width and depth increased as the proportion of fat in the carcass increased, neither Pálsson with sheep, nor McMeekan (1941) with pigs, could find any relationship of predictive value other than that between external linear measurements of the carcass and the weight of fatty tissue. Walker and McMeekan (1944) consider external carcass measurements and degree of fatness to be unrelated. These workers state that "...since fat deposits are largely independent of skeletal development, and since the primary dimension in regard to fat depots is that of depth, it would be unreasonable to expect any close association between linear carcass measurements and the total amount of fat in the carcass. Any such correlations as might exist would necessarily be purely fortuitous."

Using linear measurements from the surface presented by a transverse section at the last rib Pálsson (1939) found that the sum of the thickness of backfat over the deepest part of the eye muscle (C), the thickest layer of fat over the rib (J), and the thickness of the fat over the muscle layer in the lower half of the rib (Y), provided the most accurate estimate of the weight of fatty tissue. Combinations of internal and external measurements, notably (L/10)(C + J + Y), gave better prediction of total fatty tissue than any combination of either internal or external measurements. Walker and McMeekan (1944) made no attempt to relate internal linear measurements to the amount of fatty tissue in the carcass. Although these workers used internal measurements as indices of carcass muscle they state that "internal measurements - such as those relating to fat depths at the last rib cut - undoubtedly offer better scope (as indices of fatty tissue, than do external measurements,) but they have not been considered ... owing to the impracticability of obtaining them except under special conditions."

Measurements of the thickness of the layer of subcutaneous fat revealed when a carcass is divided longitudinally have long been taken as indices of the general level of fatness in the pig. Justification for this comes from the work of Hankins and Ellis (1934) who noted a correlation coefficient of 0.84 between the average of five backfat measurements taken between the shoulders and the ham, and the percentage of chemical fat. McMeekan (1941) also investigated the relationship between internal linear fat measurements and total fat in the pig, and found that the single measurement most closely correlated with the weight of fatty tissue was the thickness of fat over the eye muscle (C) as revealed when the carcass is cut at the last rib (r=0.97).

The scope of internal linear measurements as indices of fatty tissue has been extended by the development of the live probe by Hazel and Kline (1952, 1953) and of the Lean-meter by Andrews and Whaley (1954). Both devices, and particularly the Lean-meter, have produced simple, quick, convenient and reasonably accurate means of predicting total fat from linear backfat measurements, both in the live animal and in the carcass. Pearson, Price, Hoefer, Bratzler and Magee (1957), Holland and Hazel (1958), and Walker-Love, Cormack and Laird (1958<u>a</u>, 1958<u>b</u>)

have reported good results from the use of probing devices in pigs, but Temple, Stonaker, Howry, Posakony and Hazeleus (1956) found the Lean-meter unsatisfactory when used on live cattle, due to the lack of variability between readings and because of haemorrhage at the probe sites. Ulyatt and Barton (1961) have investigated the usefulness of the Lean-meter for predicting the physical and chemical composition of live sheep. Their results show that this technique may be used to estimate the thickness of subcutaneous fatty tissue of sheep with an accuracy similar to that reported for pigs, and considerably better than has been found to date with cattle. The thickness of subcutaneous fat is not, however, perfectly correlated with carcass composition, and it is largely because of this that Ulyatt and Barton conclude that while the Lean-meter technique will give a reasonable estimate of the composition of a group of sheep, it is not sufficiently accurate on an individual sheep basis. One weakness common to the use of all probing devices is the difficulty of defining accurately the points of insertion. Indeed, it is impossible to estimate certain backfat measurements frequently employed in carcass quality studies, as these are defined in terms of maximum and minimum depths of fat cover in various body regions.

Many other workers have used linear measurements in the estimation of total fat, but there are good grounds for treating such results with a degree of caution. Investigations into the use of backfat measurements in pig grading in Great Britain have shown that the method of butchering, time from slaughter, rate of cooling and other exogenous factors can seriously affect the value of such measurements (Harrington, 1958). Environmental factors acting before slaughter, e.g., plane of nutrition and rate of fattening, are also important in this respect, and King (1957) has presented evidence to show that each measurement has a degree of genetic independence. This could well explain the good agreement of results found within experiments, and the frequently conflicting results between experiments.

Aunan (1953) has expressed the opinion that linear measurements are not as reliable as physical separation and chemical anlysis in determining the fat content of a carcass. He added, however, that if the use of linear measurements to evaluate degrees of fatness in carcasses and cuts is based on sufficient numbers and representative samples, and if there is a high degree of association with the factors being measured, then it is an advantage to the investigator to include the method in his study.

* * *

The repeatability and accuracy of linear carcass measurements are of considerable importance where such measurements are used as indices of carcass conformation and composition in determining grade. Some factors influencing the accuracy of linear measurements have already been mentioned in connection with backfat thickness in pigs. Catherum, Harrington and Pomeroy (1956), in investigations of butchering, slaughter-house and curing techniques, have shown that similar considerations also apply to measurements of muscle, and that the *m. longissimus dorsi* is particularly prone to distortion. Such studies have shown that if measurements taken at meat works and bacon factories are to be of any value as indices, the conditions under which they are taken must be standardised as much as possible. Errors can be minimised by taking the necessary measurements at the shortest possible constant interval after slaughter.

Bodwell, Everitt, Harrington and Pomeroy (1959) have examined the use of some of Pálsson's more frequently used measurements on beef carcasses. These workers conclude that in all carcass investigations measurements should be taken on both sides and averaged. They also consider that in order to achieve a satisfactory degree of repeatability some redefinition and clarification of the points of reference are required. Bodwell, Harrington, Pomeroy and Williams (1959) have expressed the opinion that in cattle, and probably in other species also, the value of carcass measurements for predicting the yields of wholesale and retail cuts (i.e. for measuring variations in conformation) may have been over-emphasised. These workers further state that the high correlations between linear measurements and carcass characteristics, which have been demonstrated in many studies, need to be biologically intelligible before the measurement or combination of measurements is used in practice, and that detailed growth studies are required before such an understanding can be achieved. These comments are applicable to many studies.

The general conclusion regarding the use of linear measurements as indices of carcass composition may be summed up in the words of Bratzler (1958), who, in reviewing fifty years of progress in meat research stated that "no single measurement or combination of measurements taken of the carcass have shown satisfactory relationships to grade or carcass composition."

(3) Live-Animal And Carcass Weights

Lush (1928) has stated that "...the animal body is of such a complicated shape that any one or few measurements could approximate a description of it in only the crudest possible way ... Certainly no one measurement or small group of measurements can approach weight in completeness as a description or in economic importance... The information yielded by measurements should be regarded as supplementary to and confirmative of the inferences drawn from weight changes rather than as a substitute for the information gained from studying the weights alone." Warwick (1958), in reviewing fifty years of progress in beef cattle breeding, expressed the opinion that insufficient attention has been paid to this statement.

Another plea for the worth of weight measurements has been made by Lush and Copeland (1930), who contend that "...the principal objection to the extensive use of body measurements...

seems to be not their inaccuracy but their inadequacy to describe the animal in a complete way... . For most purposes a very few measurements considered in relation to each other or in relation to weight seem as much as would be really useful in contributing to the general picture of the animal and of the changes which occurred in it."

More recently other workers have considered the relationship of live weight and carcass weight to carcass composition. In most cases the aim of these studies has been to determine the amount of fatty tissue in the carcass. In outlining the successive changes in composition of the carcass which take place during growth Pálsson (1955) and Pomeroy (1956) have both indicated that, in the mature animal at least, live weight and carcass weight are largely affected by the amount of fatty tissue in the carcass. Wilson (1957), in an investigation of the carcass composition of the East African dwarf goat, demonstrated that, within any given treatment and for any given sex, fat has a higher standard error than any other component of carcass weight.

In beef cattle studies White and Green (1952), Green (1954), and Green, Jessup and White (1955) have found live weight to be more closely associated with the weights of wholesale cuts than was any single linear measurement on the live animal. Dawson, Hiner and Madson (1955) also made use of live weights in the evaluation of beef and dual-purpose cattle for meat production. The superiority of weight measurements as indices of carcass composition has been stressed by Orme (1959) who, in a study of linear measurements and live weight, demonstrated that loin eye area and the weight of separable carcass lean, which he used as indices of carcass quality, were more a function of live weight than of any linear measurement.

Information relating to the sheep comes from the work of McMeekan and Clarke (1942) and Clarke and McMeekan (1952a) who demonstrated that, within weight and quality grades of New Zealand lamb and mutton carcasses, there is a decrease in the proportion of bone and muscle, and an increase in the proportion of fat with increasing carcass weight. These findings are supported by the work of McMeekan (1940, 1941) on pig carcasses. As a result of studies on the determination of the nutritive value of New Zealand lamb and mutton carcasses Shorland, de la Mare, Sorrell and Barnicoat (1947) concluded that carcass weight could be used to simplify the determination of carcass composition. They add, however, that the applicability of this technique is limited, and that such an approach would not distinguish between animals of different breed, sex, or growth rate. Further evidence of the influence of fatty tissue on the carcass weight of ewes has been presented by Smith-Pilling and Barton (1954). Kirton (1957) has also demonstrated very strong relationships between these variates and has computed regression equations for predicting the weight of fatty tissue in the carcass from carcass weight.

Barton and Kirton (1958a), working with data from 98 mature Romney sheep and 70 Romney and Romney-Southdown cross lambs, correlated carcass weight with the weights of carcass fatty tissue, carcass muscular tissue, and other variates. Their results show that in mature sheep, carcass weight is more closely correlated with the weight of fatty tissue (ewes, r=0.94; wethers, r=0.94) than with the weight of dissectible muscle (ewes, r=0.87; wethers, r=0.84) despite the fact that in both sexes muscular tissue forms a greater proportion of carcass weight than does fatty tissue. However, the standard errors of estimate associated with the respective regressions on carcass weight indicate that this variate provides a more accurate prediction of the weight of muscular tissue (ewes, $S_{y.x}$=2.21lb; wethers, $S_{y.x}$=2.26lb) than it does of the weight of dissectible fat (ewes, $S_{y.x}$=2.86lb; wethers, $S_{y.x}$=2.76lb) notwithstanding the closer correlation of the latter to carcass weight. In the two lamb classes there is little difference between the correlations of carcass weight with dissectible fat (ewe lambs, r=0.87; wether lambs, r=0.94) and with dissectible muscular tissue (ewe lambs, r=0.89; wether lambs, r=0.95). The corresponding standard errors of estimate again show that muscular tissue can be predicted within closer limits (ewe lambs, $S_{y.x}$=1.36lb; wether lambs, $S_{y.x}$=1.04lb) than can the weight of fatty tissue (ewe lambs, $S_{y.x}$=1.72lb; wether lambs, $S_{y.x}$=1.26lb). These results indicate that, in certain circumstances, carcass weight may provide a reasonably accurate, simple, objective and reliable index of carcass composition in general, and in particular of the weight of muscular tissue in the carcass.

These workers add, however, that for the detection of small differences in the carcass composition of experimental animals, and in the evaluation of treatments which are likely to affect carcass composition differentially, more accurate methods of analysis than carcass weight per se are required. It is also doubtful whether the regression equations presented by these workers for the prediction of carcass composition could be applied to breeds of sheep other than those used in this particular study.

Cole, Orme and Kincaid (1960) noted a correlation coefficient of 0.77 between the weight of beef carcasses and the amount of separable lean, but their report contains no information regarding the prediction of the latter from a knowledge of carcass weight.

At various times workers engaged in the study of the body composition of humans have attempted to relate body weight to the amounts and proportions of the various body tissues. Standard height-weight tables have been used to a large extent in the past, and are still used to a limited extent at the present time, for life insurance purposes and by the medical corps of the Armed Services. It appears, however, that live or body weight is not a satisfactory index of body composition in man. This particular approach to the study of body composition in the human has been severely criticised by Keys (1947, 1955), Brožek (1956), and Brožek and Keys (1950a, 1950b). The grounds for this criticism may be expressed in the words of Keys and Brožek (1953) who state that"...the fact that the constituents of body weight, fat, water, etc., may vary widely in their percentage contribution to the total constitutes the fundamental limitation to interpretation of body weight."

This same inherent biological variability between individuals is commonly regarded as the major obstacle to the establishment of a precise, simple, objective and reliable index of body composition in animals, and in view of this it is not unreasonable to extrapolate the general conclusions of Keys and Brožek to include the ruminant. Although the studies on human body composition are open to criticism on account of the almost insuperable difficulty of obtaining human cadavers in adequate number for statistical analysis, the wide variation which exists in the constituents of the animal body must place a limitation, similar to that specified by Keys and Brošek, on the use of body or carcass weight as an index of composition. The apparent anomaly in the usefulness of body or carcass weight as an index of composition in animals, and the unsatisfactory nature of body weight as an index in man, may also lie partly in the greater accuracy and degree of certainty demanded in human studies. Such weight measurements satisfy the conditions of simplicity and objectivity in both man and beast, but the definition of the remaining qualifications, viz., precision and reliability, may differ according to the subject under consideration and the purpose of the study.

(4) Weight and Linear Measurements of Bone

In spite of the considerable interest shown during recent years in the possibility of using some measure of bone size or bone weight as an index of muscle development, this idea is not new. Lush (1926) stated that "...the whole problem of size of bone in its relation to meat value, to the desirabilities of cattle as feeder cattle and to the desirability of cattle for range-beef production is a large one."

Before reviewing what little work has been done on the estimation of carcass composition and particularly the amounts of muscular tissue from bone weights and linear measurements of bones it will be advantageous to consider the classical approach to and interpretation of bone-muscle relationships.

The first investigation of the relationship between bone and muscle in sheep carcasses was made by Hammond (1932), who demonstrated that"...the relation of muscle to bone is not a fixed one, but may vary with age and sex." In his consideration of the effects of sex he noted that"...the relation of bone weight to muscle weight shows greater differences than the relation of bone length to muscle weight," and concluded that "...the effect of testicular secretions is not only to thicken bone but also to thicken muscle, but not, however, in proportion to the thickening taking place in the bone...although development proceeds further in the ram than in the ewe, the proportion of muscle to bone is not increased because of the extra thickening of the bones in the former." In discussing the effects of age on the bone-muscle relationship in sheep Hammond stated that "...the 'leg' muscles, and to a greater extent the 'thigh' muscles, increase in proportion to the tibia with age...the femur increases in weight more than the tibia with age, ...but...when the different rates of growth in the two bones are allowed for there still exists a difference in the rate of growth between 'thigh' and 'leg' muscles; so that muscles not only show a relation to the growth of the bone they surround, but they show it in an exaggerated form."

Hirzel (1939), in his study of carcasses entered in Smithfield Fatstock Shows, reiterated the opinions expressed by Hammond (1932) that length of bone is opposed to carcass quality, and that bone thickening is accompanied by an increase in the weight of the muscular tissue adjacent to the particular bone. Hirzel concentrated his attentions on bone length and thickness, as he considered that "bone weight may be to a certain extent camouflaged by a shortening and thickening of the bone." In discussing breeding policy Hirzel stated that "a thickening of the bone in shortening it, with no weight reduction, is preferable to reducing the weight of the bone in a carcass by making the bones thinner. Actually then it is rather the long bone, than the somewhat heavy bone that is objected to, particularly in mutton."

In his studies of meat qualities in the sheep Pálsson (1939) made extensive use of the weights and measurements of bones. In his search for an index of the skeletal weight of carcasses Palsson used cannon bone lengths and weights, both independently and incorporated in a weight:length ratio, which he subsequently utilised as a measure of cannon thickness. In equating the weight:length ratio to bone thickness Pálsson implies a constant bone density as he states that "the weight of a bone depends on its length, thickness and density." No evidence of constant bone density is presented in his work. Nevertheless, his proof that the major part of growth in bone thickness occurs at a later stage than growth in length is based solely on a comparison of rates of increase in bone weight and length.

Pálsson correlated the weight of bone in the carcasses of lambs and hoggets with the length and weight of the left metacarpus, the weight of all four cannon bones, and the weight x 100 : length ratio of the left metacarpus. In all cases, and particularly in the relationship incorporating his measure of thickness, the correlation coefficients were greater for the hoggets than for the lambs. His interpretation of these results is that in the older group thickness contributes relatively more to skeletal weight than at the younger age. In the lambs cannon length has a greater influence on the weight of the skeleton than is the case in hoggets. Pálsson concluded that cannon weight afforded a more satisfactory index of skeletal weight than did cannon length, and that the weight of all four cannons was not in any way superior as an index to the weight of the left fore cannon. He also related the weight of the skeleton to the length of tibia + tarsus (T). This measurement proved to be superior to cannon length as an index of skeletal weight in the lamb group, but not in the hoggets.

Pálsson also attempted to use the cannon bone as an index of carcass quality, and to this end correlated length with the shape index of the eye muscle (100B/A). In all cases the correlation coefficients were negative, and significant only between breeds. Pálsson interpreted this as proof that short-boned animals have absolutely deeper eye muscles (measurement B) relative to eye muscle "length" (measurement A). Although the shape index is generally accepted as a satisfactory index of carcass quality Pálsson has shown that it is not significantly related to the amount of muscular tissue in the carcass, which is likewise considered to be a good index of carcass quality. In his studies on pig carcasses McMeekan (1941) also demonstrated a non-significant, but negative, correlation between the shape index and weight of carcass muscle. This apparent anomaly may be explained in terms of the distinction between quantitative and qualitative indices of carcass quality. As McMeekan pointed out, "...the loin is the most valuable part of the carcass, and it is the shape rather than the quantity of muscle in area which determines its suitability for high-quality and high-priced trade." It is thus apparent that although the shape index is frequently looked upon as being indicative of the degree of muscular development it is not possible from Pálsson's correlations of cannon length and shape index to infer anything regarding the relationship between cannon length and the weight or degree of development of carcass muscle.

Studies on the use of certain weights and measurements as indices of carcass quality in sheep have also been carried out by Walker and McMeekan (1944). Although these workers present a considerable amount of data relating to cannon lengths and weights, which they use to demonstrate the later-maturing growth in bone thickness (as measured by the weight:length ratio) compared to growth in length, they do not present any relationships between cannon length or weight and the weight of carcass muscle.

Pálsson and Vergés (1952) also investigated the differential length and thickness growth in the sheep skeleton, but made no attempt to relate bone weights or lengths to the weight of muscular tissue in the carcass. Their studies confirm the earlier findings of Hammond (1932), Pálsson (1939), McMeekan (1941), and Walker and McMeekan (1944) that growth in "thickness" occurs mostly at a later stage than growth in length. Pálsson and Vergés' study of the differential effects of a less than optimal plane of nutrition shows that bone shape is affected to a greater extent than bone weight, that thickness is affected to a greater degree than length, and that the later-maturing bones such as the femur and those of the pelvis are more affected than the earlier-maturing cannon bone.

The Council of the New Zealand Romney Marsh Sheep Breeders' Association (1959) believe that a strong relationship exists between bone and muscle in the sheep. This body states that "quality of bone is automatically an indication of the fleshing qualities (and character of the fleece)", and again that "good quality bone is the indication of good quality meat (and good manufacturing wool)." In this context quality of bone is judged by the external appearance and form of the cannon. The definition of what is deemed desirable in this connection is given in the following quotation:

> "BONE: The cannon bone should not be long, and at least adequate in size for the weight of the animal (and a little to spare is all to the good) provided always and above all that the bone is of the very best quality. Coarse round bone of any size is bad, and the more there is of it, the more harmful the animal will be; but a very diminutive spindly shank is equally undesirable and does not indicate a robust hardy sheep."

The Council attempts to define bone quality in the following:

> "QUALITY OF BONE: Just as inferior quality flesh can be detected to a large extent by its inferior and harsh outer covering of characterless wool, so can coarse bone be detected by its outward covering of harsh chalky-white hairs inclined to stick out prominently from the surface of the skin, whereas good quality bone may be discerned by its outer covering of hair lying smoothly. This applies to the hair covering the face as well as to the covering of the legs of the sheep."

It is doubtful, to say the least, whether such a subjective assessment made on the live animal bears any relation to the cannon bone _per se_. The extremely small amount of muscular tissue found in the vicinity of this bone would also suggest that there are better live-animal indices of the development of muscular tissue in the carcass. Rae (1946) has shown that the subjective assessment of bone quality bears no relation to cannon bone weight (r=0.07).

Thus, in spite of the considerable amount of data available from the work of Hammond (1932), Hirzel (1939), Pálsson (1939), Walker and McMeekan (1944), and Pálsson and Vergés (1952) on the weights and measurements of the cannon and other bones, and on the weight of muscular tissue in the sheep carcass, there remains a lack of information on the worth of bone weights and lengths as indices of carcass muscle.

A limited amount of information concerning the possibilities of predicting the weight of carcass muscular tissue from bone data comes from the study of bone-muscle relationships in species other than the sheep. In his studies on the growth and development of the pig McMeekan (1940, 1941) considered a number of carcass and bone measurements as possible indices of the weight of carcass muscle. One of the better indices noted in this work was the length of the fore-trotter, which showed a correlation coefficient of 0.80 with the weight of carcass muscle. Kropf (1959) found no evidence of any significant relationship between cannon length and the percentage of lean cuts in pig carcasses, and concluded that cannon characteristics in general were not closely associated with physical carcass measurements in this species.

Zimmerman (1956a, 1956b) also investigated bone-muscle relationships in the pig, and reported positive correlations between cannon circumference and the weight of the adjacent musculature, and between the length, circumference and weight of the femur, and the proportion of muscular tissue in the ham. None of the relationships was sufficiently high to be of predictive value. Zimmerman extended his studies to the transverse section of bones, and noted a positive relationship between the cross-sectional area of the femoral medullary cavity and the weight of muscle in the ham. He also reported a negative correlation between the thickness of the wall of the femur and the weight of muscle in the ham. There was no significant relationship between the weight of this muscular tissue and the surface area of the femur.

Orts (1959) studied the use of certain bone characteristics as indices of muscling in beef carcasses. Although many highly significant correlations were demonstrated between the weight, cross-sectional area, weight:length ratio, and specific gravity of the cannon bone, and the weights of wholesale cuts and ribeye area, Orts showed that these relationships generally lost their significance when the effects of carcass weight were eliminated. McMeekan (1956) has also discussed the question of bone-muscle relationships in beef cattle. In reviewing the work of Hammond at Cambridge and his own work in New Zealand he states that "...as regards the weight and shape (of bone), the shorter and thicker the bone the greater the depth or thickness of muscle lying over that bone." It is certainly true that there is evidence of a positive relationship between the weight of muscular tissue and bone thickness, as measured by the weight:length ratio, and although, to the best of the present writer's knowledge, no one has related the depth of muscular tissue overlying a long bone to the thickness of that bone, as might readily be done on the transverse section of, say, the leg, it is generally accepted that an increase in bone thickness is accompanied by an increase in the depth of the overlying musculature. However, there is no evidence known to the writer which would suggest that a decrease in bone length is associated with an increased weight or depth of muscle. Pálsson (1939) has shown that, in sheep, there is a highly significant positive correlation between cannon length and skeletal weight, which McMeekan (1956) considers to be closely related to the weight of carcass muscle. In support of his contention quoted above McMeekan claimed that "there is a strong positive correlation between the weight of bone in each meat animal and the weight of muscle tissue. In other words, it is not possible to get a carcass with a really great wealth of fleshing without having associated with that flesh a heavy weight of bone. The reason for that is obvious if you think about it from a biological point of view. The muscles are tied to the bone - they are there to operate the bone - so their size and shape must, for mechanical reasons, be associated with the size and shape of the bones." McMeekan's own work on pig carcasses supports the view that bone length is positively related to muscle weight (McMeekan, 1941).

Much of the confusion surrounding the nature of the relationship between bone length and muscle weight arises from the studies of Hammond (1932, 1952) and the reports of Pálsson (1955) concerning the domestication and improvement of meat animals. These workers have shown that the improved and earlier-maturing breeds of meat animals which possess a well-developed musculature have shorter and thicker bones than the more primitive breeds. However, there is no evidence to suggest that an increase in bone thickness is necessarily accompanied by a decrease in length; indeed, the evidence from the work of Zimmerman (1956a) and others suggests a positive relationship between these two dimensions.

In discussing the strong correlation between bone and muscle weights in beef carcasses McMeekan (1956) stated that "so strong is this relationship that the weight of muscle can be determined within 1 per cent. if the weights of the cannon bones are known." No evidence for this precision of estimation is quoted. McMeekan's claim has since been considered by American workers. Wythe (1958), and Wythe, Orts and King (1961) studied the relationship of bone to muscle in beef carcasses, using the weights of certain wholesale and "retail trimmed" cuts, and the area of ribeye as indicators of muscling, and equating the bone weight:length ratio to bone thickness. These workers found that the weights and lengths of the metacarpus, metatarsus, tibia, femur, and radius-ulna were significantly and positively correlated at the 1 per cent. level of probability to the above indices of muscle, as were the "thicknesses" of the metacarpus, metatarsus, and tibia. No relationships between the weight:length ratios of the femur or radius-ulna and the indices of muscle were presented. Bone "thickness" was more closely correlated (r=0.70) with some index of muscle than was either bone weight or length in only one of 12 possible instances, yet these workers place more emphasis on bone thickness than on either weight or length as a possible index of carcass muscle. They consider that "the strong positive correlations obtained indicate that bones of an animal develop proportionately in length and weight and suggest that a real association existed between bone thickness and muscling of the cattle studied." It is doubtful, however, whether any of the relationships reported by these workers could be considered to be of predictive value, and although no regression equations or standard errors of estimate of muscle are presented, there is certainly no evidence which would suggest that the weight of carcass muscle could be predicted to within 1 per cent. from the weight of the cannon or any other bone studied.

Similar studies on cattle were carried out by Orts and King (1959) who related cannon weight, length, the ratio of weight: length, and area to the weights of certain unspecified wholesale cuts, ribeye area and chilled carcass weight. Cannon weight and the weight:length ratio were more closely correlated with these measures of carcass muscle than were the cannon length and area variates, but although all the correlations were highly significant none except that between cannon weight and carcass weight (r=0.95) was high enough to be of predictive value. The relationships reported by Barton and Kirton (1958<u>a</u>) between carcass weight and the weight of carcass muscle in sheep would suggest that carcass weight is not a sufficiently good index of the weight of muscular tissue to allow prediction from cannon weight within the limits claimed by McMeekan (1956).

The usefulness of certain measurements of cannon bones and lumbar vertebrae as possible indices of muscle in beef carcasses has been intensively studied by Orme, Pearson, Bratzler, Magee and Wheeler (1959). These workers reported that live weight, chilled carcass weight, primal cut weight, and the weight of total carcass lean, as estimated from the separable lean in the 9-10-11 rib cut using the regression equation of Hankins and Howe (1946), were, in almost all cases, significantly and positively related to the weight, length, width, circumference and thickness measurements of the fore and hind cannon bones. The combined effects of live weight and each of the cannon measurements considered separately accounted for only 14 to 34 per cent. of the variation in ribeye area. Radiographic measurements of the lumbar vertebrae bore little if any relationship to the area of ribeye muscle, and in combination with live weight did not account for any more variation in this measurement than that supplied by live weight and the cannon variates. The conclusions drawn from this work were that measurements of the cannon bones and lumbar vertebrae are related to muscling, but that the relationships are not sufficiently high to be useful for predictive purposes.

Cole, Orme and Kincaid (1960) have reported a correlation of 0.75 between the weights of total carcass bone and separable carcass lean, but give no indication of the precision of estimation of the weight of carcass muscle from total bone afforded by their data.

French (1938) made use of the weights and linear dimensions of the cannon and other bones as a basis for the comparison of the degree of development attained by different breeds of sheep. This particular work was modelled on the more intensive studies of British sheep carried out by Hammond (1932) but no attempt was made to relate the considerable amount of data referring to bones to carcass components other than bone.

There is a suggestion from work on the human that certain bones might prove better indices of body composition than others. In a study of the weights and linear measurements of human skeletons Lowrance and Latimer (1957) noted that average skeletal weight was less variable than that of any of the individual bones. The most constant of the individual bones were the femur and os coxae; the sternum and hyoid were the most variable.

Lowrance and Latimer (1957) also presented evidence of bilateral asymmetry in the bones of particularly the upper extremities. Bilateral asymmetry in the weight and chemical composition of the long bones of chickens, pigs and dairy heifers has also been reported by Beakley and Dustman (1959). Studies by Graff (1960) of the early growth of the skeleton in mice have shown evidence of bilateral asymmetry in the growth patterns of the long bones, although there was no consistent bias in favour of one particular side. The magnitude of the bilateral variations found in the above studies suggests, however, that the reliability of linear measurements as indices of carcass composition would seldom be seriously affected.

2. THE RELATIONSHIPS OF CERTAIN JOINTS TO THE CARCASS AS A WHOLE

Investigations into the use of sample joints as indices of the physical composition of the carcass may be divided, perhaps somewhat arbitrarily, into two main categories, viz., the approach favoured by American workers, and that of the Cambridge School. The American workers have tended to concentrate their attentions on the three rib cut (i.e., the 9th, 10th, and 11th ribs) which is a particularly convenient sample joint for many of their studies involving a large number of beef carcasses. The early work of the Cambridge School was carried out on sheep and pig carcasses, and those concerned in these studies have favoured the use of the leg and the loin as sample joints for the estimation of carcass composition.

The requirements for a satisfactory sample joint have been discussed by Pálsson (1939) and McMeekan (1941). In the first place it is essential that the joint be as typical of the whole carcass in respect of composition as is possible. The second requirement is that the joint selected be capable of separation from the carcass with a high degree of accuracy, and that the points of jointing be well defined to ensure a satisfactory degree of replication by different workers, i.e., it should be liable to the minimum of cutting errors in the jointing. These two workers also consider it preferable that the sample joint be cut from a valuable part of the carcass, for, if such a joint fulfils the first two requirements indicated above, it will have the additional advantage of yielding specific and exact informations regarding a region or regions of economic importance.

Pálsson also states that a sample joint should be typical of the whole carcass as regards rate of development. This qualification would seem to be somewhat idealistic, and McMeekan (1941) is more realistic in his realisation that, because of the differential rates of development of the various regions and tissues of the body, no one region is capable of providing a perfect index of the whole carcass. For this reason McMeekan advocates the estimation of carcass composition from two sample joints, one of which attains "maturity" early in life, and one which is relatively late developing. It should be noted, however, that at least part of the greater accuracy of prediction afforded by the use of two such sample joints than can be provided by either alone may be attributed to the closer ratio of the part-whole relationship necessarily incurred in the use of sample joints.

(1) The Rib Cuts

The extensive use by American workers of rib cuts as indices of carcass composition stems from the early studies carried out at Missouri by Moulton, Trowbridge and Haigh (1921, 1922a, 1922b, 1923). Although these workers did not possess the necessary techniques to derive the statistical relationships between the composition of sample joints and that of the carcass, they recognised the possibility of utilising certain cuts as indices of the whole, and in a communication to Lush, Moulton expressed the opinion that "the wholesale rib cut rather adequately represented the carcass" (Lush, 1926). Lush (1926) subsequently demonstrated a very close relationship ($r=0.93$) between the percentage of fat in the wholesale rib cut (9 ribs) and that in the entire live animal. He reported this index to be more reliable than any other single indicator or combination of indicators, and that it was little influenced by sex, breed or slaughter technique. In the same study Lush also noted that the percentages of fat in the live animal and in the carcass were almost perfectly correlated, suggesting that the percentage fat in the wholesale rib cut would prove an equally satisfactory index of the percentage fat in the carcass.

In an investigation of the usefulness of the bone:muscle ratio as an index of carcass merit in beef cattle, Hankins, Knapp and Phillips (1943) used the 9-10-11 rib cut to obtain an estimate of the composition of the entire dressed carcass, on the strength of previously determined, but hitherto unpublished, relationships. The correlation between the percentages of dissectible fatty tissue in the 9-10-11 rib cut and in the dressed carcass (r=0.93) was certainly high, but not as high as might have been anticipated from Lush's earlier work. The correlations between the percentages of separable muscular tissue and between the percentages of bone in the three rib cut and in the carcass were 0.90 and 0.80 respectively. Although these correlations suggest the presence of relationships sufficiently high to be of some predictive worth, it is debatable whether these relationships would be good enough to be used as indices of carcass composition in a study designed to evaluate the worth of another index of carcass merit - in this case the bone:muscle ratio.

Hopper (1944) statistically analysed data collected in studies at Missouri (Trowbridge, Moulton and Haigh, 1915, 1918; Moulton, Trowbridge and Haigh, 1921, 1922<u>a</u>, 1922<u>b</u>, 1923) and added to them some unpublished data from North Dakota, in a study of the different methods of estimating the physical and chemical composition of cattle. Hopper considered the use of the wholesale rib cut, the 9-10-11 rib cut, and the edible portions of these cuts, as possible indices of the composition of the empty body, the carcass, and the edible portions of the carcass. The edible portion of the 9-10-11 rib cut was selected as the most satisfactory index of the physical composition of the edible portion of the carcass (separable lean, r=0.94; separable fat, r=0.98). From this the physical composition of the carcass could be estimated, taking the percentage of bone in the 9-10-11 rib cut as an index of the percentage of bone in the carcass (r=0.94), and calculating the percentages of lean and fat from those estimated for the edible portion of the carcass.

The widespread use, by American workers, of the rib cuts as sample joints may also be attributed to Hankins and Howe (1946). These latter workers have presented correlations and regression equations relating the components of the 9-10-11 rib cut to those of the dressed carcass, working again on a percentage basis. This study, carried out on 120 cattle, yielded overall correlations of 0.93 for the fatty tissue, 0.85 for the separable lean, and 0.83 for bone. There were, however, some noteworthy sex differences, e.g., the correlation coefficient of 0.90 between the percentage lean in the three rib cut and that in the carcass of steers was very much higher than the corresponding relationship derived for heifers (r=0.72). The relationships presented by these workers are, in general, less satisfactory than those of Hopper (1944).

In a more recent study of the use of various indices of muscular tissue in beef carcasses Cole, Orme and Kincaid (1960) found the 9-10-11 rib cut to be the least satisfactory of seven sample joints analysed. These workers used absolute weights rather than percentages as employed by the majority of others in this field.

Hankins (1947) has reported on the use of the wholesale rib cut as an index of the physical composition of lamb carcasses. The relationships reported in this work (fat, r=0.98; muscle, r=0.92; bone, r=0.97) are comparable to those presented for cattle by Hopper (1944).

It would thus appear that, in general, the wholesale and 9-10-11 rib cuts are capable of providing reasonably satisfactory estimates of the physical components of the carcass, and in particular of the proportion of fatty tissue.

(2) The Leg and The Loin

Pálsson (1939) and McMeekan (1941) both consider that the sample joints which best fulfil the requirements they specify are the leg and the loin. Pálsson has expressed the opinion that the leg is the best single joint for predicting the dissectible components of the sheep carcass, although he adds the qualification that, because of its relatively early development and small amount of fat, this joint may slightly underestimate the total amount of carcass fat in early maturing, over-fat individuals. The loin, on the other hand, is a late-developing joint in which a considerable amount of fat may be laid down in later life, and, because of this, Pálsson considers that the combination of one leg + loin gives more satisfactory results than the use of either joint alone. As already indicated, however, the greater accuracy afforded by the use of two such sample joints may be attributed not only to the combination of early- and late-maturing parts, but also to the comparison of a greater proportion of the carcass with the whole carcass.

One disadvantage which Pálsson found in using the loin as a sample joint was the variable number of vertebrae contained in this part. Sisson (1930) gives the number of lumbar vertebrae in the sheep as seven, although he states that frequently only six may be found, and very occasionally, five. Pálsson adopted six as the standard number, and found that correction to this standard improved the prediction of carcass bone. Similar corrections for muscular and fatty tissues, however, resulted in lower correlation coefficients. It is of interest to note here that Pálsson (1940) has discussed variations in the number of vertebrae in the different anatomical regions as they affect the value of an animal for meat production.

In spite of this disadvantage associated with the use of the loin Pálsson's results show that the physical components of both the leg and the loin are closely related to the total amounts of the respective tissues in lamb and hogget carcasses, and that in all cases the combination of one leg + loin provides an even more reliable estimate of carcass composition than that supplied by either joint alone.

Later reports by Kirton (1957), and Barton and Kirton (1958b, 1960) who studied the use of the leg and the loin, separately and in combination, as sample joints in a large number of lamb and mutton carcasses, have substantiated Pálsson's finding. Barton and Kirton (1958b) have also shown that there is no predictive advantage to be gained by treating the leg and the loin as separate independent variates of a multiple regression equation. The standard errors of estimate provided by this approach were very similar to those supplied by the linear regressions on the sum of leg and loin.

McMeekan (1941) has also found the use of leg + loin to be of higher predictive worth than either joint considered on its own, in the estimation of the physical components of pig carcasses. Aunan and Winters (1949), also working on the pig, related the percentages of lean and fat in the wholesale loin cut to the percentages of these tissues in the carcass. The correlations reported by these workers are somewhat lower than those quoted by McMeekan for the loin alone, but, as Harrington (1958) has pointed out, because one set of results was expressed in absolute weights and the other in percentages, and because there is no evidence that the two samples of pigs were equally variable, it is not possible to conclude that the use of a wholesale cut rather than an anatomical joint reduces the predictive value of the sample joint.

It is worthwhile to note here that Barton and Kirton (1958b),

1960) have emphasised the need for caution in the use of sample joints in evaluating the results of certain types of experimental work. They quote examples from the work of Preston and Gee (1957) and Kirton and Barton (1958a, 1958b) in which implantations of hexoestrol and thyroxine evoked differential and opposite responses in the leg and loin joints of sheep. In such cases reliance on sample joints as indices of carcass composition could lead to serious errors and misinterpretation of the true nature of an experimental treatment.

(3) Other Sample Joints

The use of sample joints other than those already discussed above has been considered at various times. Barton and Kirton (1958b) have demonstrated the existence of some very close relationships between the physical components of the neck, thorax, shoulder, and pelvis, and the total amounts of the same components in the carcasses of ewes and wether lambs. The results presented by these workers suggest that the thorax provides a prediction of carcass composition equivalent or superior to that provided by the leg + loin - a conclusion which is not surprising in view of the fact that this joint comprises approximately one quarter of the total carcass weight. They add, however, that the practical considerations of the difficulty of separating the thorax from the carcass, and the considerable time required for dissection, make this joint unsuitable for predictive purposes. Pálsson (1939) and McMeekan (1941) have also criticised the use of the thorax as a sample joint on account of its relatively low commercial value.

Pálsson considers that, from the point of view of composition, the shoulder is probably superior to any other sample joint, but both he and McMeekan classify the shoulder as unsuitable because of its liability to jointing errors. Pálsson has put forward the same criticism against the use of the pelvis because it has three cut surfaces, but Barton and Kirton consider this joint preferable to the neck and shoulder as regards ease of dissection and jointing.

The use of American wholesale cuts, as opposed to the anatomical joints employed by British workers, in the prediction of physical carcass composition, has also received attention at various times, belying the adequacy of the generalisation regarding the use of the three rib cut by American workers. Recent investigations of the relationships of wholesale cuts and certain carcass measurements to the weight of the muscular tissue in beef carcasses, by Cole, Orme and Kincaid (1960) have demonstrated the possibility of using the round and the chuck as sample cuts for the prediction of carcass muscle. These cuts, and particularly the round, were found to be more descriptive of carcass muscling than any other wholesale cuts, linear carcass measurements, area of loin eye, or carcass weight. The wholesale round is approximately equivalent to the anatomical leg used by British workers, and the correlation supplied by this cut was of the same order as those reported by Barton and Kirton (1958b) for the leg joint of mutton and lamb carcasses, but was inferior to those noted from the use of leg + loin. Cole, Orme and Kincaid did not consider the prediction of carcass fatty tissue or bone from wholesale cuts.

* * *

The comparatively small amount of work which has been undertaken on the use of sample joints in the prediction of the physical composition of the carcass indicates that the 9-10-11 rib cut has a place in this field, particularly in studies involving a large number of cattle. It would appear, however, that in sheep the combination of one leg + loin best satisfies the requirements demanded of sample joints, and is capable of providing the most satisfactory description of the carcass as a whole.

3. CONCERNING SOME ASPECTS OF BONE MEASUREMENT AND COMPOSITION

In his now classic studies of the growth and development of sheep, Hammond (1932) assessed bone thickness from the quotient of bone weight/bone length. Bone weight is determined by the external dimensions of the bone, the internal dimensions of the medullary cavity, and the densities of the bony material and of the marrow contents of the medullary cavity. Thus, any comparison, such as that employed by Hammond, of bone dimensions which are derived from the ratios of weight to some other dimension must also take into account the composite densities of the bones compared. (The term "composite density" is used here to denote the density of a bone as a whole, and will have a value which lies between the density of the bony material and that of the marrow substance. Henceforth the term "density" will, for convenience, be used to indicate composite density.

Hammond quoted differences noted by Hofmeister (1873) and Sanson (1910) in the specific gravities of various bones as evidence for his hypothesis of differential skeletal growth, but made no reference to the possibility of differences in bone specific gravity or density in his use of the weight:length ratio as a measure of bone thickness. Pálsson (1939) also made extensive use of bone weight/length as a measure of thickness, although he was aware that in employing the quotient for this purpose he necessarily invoked the assumption of constant bone density (cf.p. 32). Indeed, the whole concept of the later maturity of bone thickness relative to length, as noted in an earlier section, is based on this weight:length which still finds favour with certain workers (cf. Wythe, Orts and King (1961) p. 39).

In the past the skeleton was regarded as an inert supporting structure somewhat akin to the steel frame of a building. The early work of Hales (1727) and Duhamel (1742) demonstrated, however, that bone is not a static tissue, and there is now a considerable body of evidence to show that, what Pritchard (1956) has termed "a unique tissue", is in a dynamic state, and is constantly undergoing rapid reconstruction and remodelling to meet changing mechanical and biochemical demands. Sissons (1953, 1956), Ottaway (1955), Bell (1956), Bourne (1956), McCance and Widdowson (1956), and Romer (1958) have all taken pains to dispel the concept of bone as an inert tissue, and have continually stressed the living and dynamic nature of bone.

Since it was first appreciated that the skeleton, like the other components of the body, was a living tissue there has been a considerable amount of research into the physiological and biochemical properties of bone. From the findings which have emerged from this work it has become apparent that there are considerable fluctuations in the various physical and chemical factors determining bone density.

Burnett (1908) was one of the first to demonstrate that the effects of certain nutritional treatments are manifested on the internal aspects of the bone. This early finding has since been substantiated by Bell, Cuthbertson and Orr (1941) who found that although neither the external dimensions nor quality of the bony material of rat femurs were affected by a calcium deficiency, the strength of the bone as a whole was diminished by a thinning of the metaphyseal wall due to increased absorption of the walls of the medullary cavity. It would appear that in an attempt to maintain normal growth expansion in the absence of a sufficient calcium intake the bone is compelled to draw on its own calcium from the inner surfaces in order to re-deposit it on the outer surface. Clark (1958) reported that a similar situation has been postulated in humans suffering from only moderate calcium deficiencies. In studies on the sheep skeleton Benzie, Boyne, Dalgarno, Duckworth, Hill and Walker (1955, 1956, 1960), and Benzie, Boyne, Dalgarno, Duckworth and Hill (1959) found evidence of bone resorption under conditions of both calcium and phosphorus deficiencies. These workers noted that the severity of resorption varied between bones within sheep, and between regions within bones.

Certain vitamins are also capable of influencing the pattern of growth and the conformation of bones. Mellanby (1944, 1947), and Barnicot (1950) have investigated the effects of vitamin A on bone growth. A deficiency of this essential factor slows bone growth and leads to abnormalities in shape through its retarding effects on the maturation, vascularisation, and proliferation of the epiphyseal plate. The general effect is to cause the bones to become thickened and coarse in appearance. Fell and Mellanby (1950) have demonstrated that vitamin A exerts a direct local action on bone and that excessive amounts lead to skeletal rarefaction and resorption. Bourne (1956) has shown vitamin C to be an important factor in the calcification of the bone matrix, and has suggested that deficiencies of this vitamin also affect the trabecular pattern in the metaphyses and slow the proliferation of cartilage in the epiphyseal plate. The importance of vitamin D in the metabolism and mobilisation of calcium and phosphorus is now well known. Wolbach and Bessey (1942) have shown that vitamin D deficiencies cause retardation and suppression of normal growth sequences in epiphyseal cartilage and also failure in the calcification of bone and cartilage matrices. Apparently the failure of mature cartilage cells to degenerate and of matrices to calcify both result from a deficiency of calcium and/or phosphorus ions in the blood. Hypervitaminosis D causes the withdrawal of calcium and phosphorus from all available sources, including the bones.

Although this review of some of the effects of minerals and vitamins on the growth and gross anatomy of bones is necessarily perfunctory and incomplete, sufficient evidence has been presented to show that nutritional factors are capable of affecting the internal and external dimensions and the composition of bone, and thus influencing bone density.

There is abundant evidence in the literature to show that the endocrinological factors governing bone growth could have an appreciable effect on bone density. Asling and Evans (1956) have reviewed the role of the anterior pituitary in the regulation of skeletal development, and have shown that the endocrine secretions of the anterior hypophysis are largely responsible for the maturation of the skeleton, as judged from the pattern of epiphyseal ossification. Silberberg and Silberberg (1956) have likewise appraised the knowledge regarding the relationships of the steroid hormones to bone growth. More recently the section of this field dealing with the use of synthetic steroids in animal production has been reviewed and contributed to by Gassner, Reifenstein, Algeo and Mattox (1958), Casida, Andrews, Bogart, Clegg and Nalbandov (1959), Burgess, Kennedy and Ingram (1960), Burgess and Lamming (1960), and Preston, Greenhalgh and MacLeod (1960). One of the many important findings which have emerged is that certain steroid hormones can cause the persistence of bony tissue which would normally have been resorbed. This contributes primarily to the excess bone found in animals treated with synthetic oestrogens, while the actual accretion of bone plays a secondary role. One of the effects of such an inhibition of bone resorption would be to alter the proportions of the bony tissue and the medullary cavity. This would certainly affect bone density.

Pyle and Sontag (1943), Reynolds (1943), and Sontag and Lipford (1943) studied certain aspects of skeletal growth in the human. These workers have demonstrated that in addition to the nutritional and endocrine factors mentioned above, there is an hereditary factor operating upon both the time and order of appearance of the skeletal epiphyses and upon the pattern of ossification. Thus, there is also evidence to indicate that genetical factors can also exert a degree of influence over the composition and conformation of bone, and are consequently of importance in the determination of density.

The effects of growth rate on skeletal development have been studied by Dickerson and Widdowson (1960), and Widdowson and McCance (1960). These workers found that rats which had grown more rapidly than the average had skeletons which were in all respects more mature at any age than those of their litter-mates which had grown more slowly. However, the rate of maturity of the skeleton was not increased sufficiently to keep pace with the rapid growth in body weight, so that rapidly growing animals of the same body weight as more slowly grown and older individuals, had femora which were shorter, contained less calcium, and had less well developed epiphyses. It may be reasonable to conclude in view of these results that differences in growth rate would also produce differences in bone density.

The trabecular pattern of a bone may have some influence on bone weight, and, through weight, on bone density. The relationship of the bone weight:length ratio to bone thickness will vary with the shape of the transverse section. Bell (1956) considers it probable that both the trabecular pattern and shape of cross-section are developed in direct response to mechanical stimuli, although the precise nature of the response is not understood. Evidence of the direct adaptive response to functional requirement is shown by the fact that the lamellar architecture in the bones of the lower limb of man acquires its final arrangement only when the child begins to walk. It has also been suggested by Clark (1958) that the refinements and details of contour of bones are conditioned by similar extrinsic factors, e.g., the accurate adaptation of joint surfaces is related to movement, and the less conspicuous ridges and depressions to the tensions and pressures of the adjacent musculature and associated ligaments. This view is supported by the work of Murray (1957).

The literature also contains a certain amount of more direct evidence to show that bone density is not constant. Such proof comes from the work of Mack, Brown and Trapp (1949) who employed roentgenograms for the quantitative evaluation of bone density, and from that of Kraybill, Hankins and Farnworth (1954) who used hydrostatically determined bone densities as an index of the percentage of bone in cattle. Kraybill <u>et al</u>. noted that bone density increased up to maturity in a typical growth curve relationship. These results show, however, that even in mature animals there may be wide variations in bone density. The means and standard deviations of metacarpal density of one group of 13 bulls and another of 34 cows were 1.377±0.156 and 1.632±0.042 respectively. (These workers do not quote the units of measurement of density, and it is probable that the figures referred to are in fact relative densities or specific gravities.) Kropf (1959), in his studies on the pig, noted differences of more than 0.3 in within-bone specific gravities.

Changes in the composition of bone with age have also been noted by Ellenberger, Newlander and Jones (1950) who showed that in dairy cattle the percentage of dry matter in the skeleton approximately doubled from the time of birth until maturity. Kraybill et al. consider that such changes in the chemical composition of bone are reflected by changes in bone density. Shorland, Barton and Rae (1961) have shown that there is considerable variation in the chemical composition of the bones of mature ewes, particularly as regards the percentage and iodine value of the fat. These workers noted a difference of more than 15 per cent. in the mean fat percentages of the metacarpus and the femur. A difference of almost 35 in the mean iodine values of these bones showed that this component was subject to large qualitative, as well as quantitative, variations. Riney (1955) has attempted to use the quantitative variations in the fat content of bone marrow as a means of evaluating the condition of red deer (Cervus elaphus) in New Zealand. In his search for a suitable index of condition he noted that the bone marrow was the first fat depot to respond to any favourable metabolic change.

Those workers who have employed the ratio of bone weight to length as a measure of thickness have no doubt appreciated that, because no bone is a perfect cylinder, this derived dimension is, in fact, under conditions of constant density, a function of the square of a purely hypothetical radius. The evidence reviewed in this section would suggest, however, that it is unlikely that bone density is sufficiently constant to warrant any great degree of reliance being placed on this so-called bone "thickness". This is not to say that the weight:length ratio has no value, but rather that it be regarded as measuring bone weight per unit length, which may well have some indicatory value, and not as a measure of bone thickness per se, as has frequently been implied in the past.

CHAPTER III

MATERIALS AND METHODS

1. SOURCES OF DATA

Investigations and experiments carried out by the Sheep Husbandry Department, Massey Agricultural College, have provided the two sources of data used in this study.

(1) 120 Series

In response to a request from the British Ministry of Food work was undertaken in New Zealand in 1942 to provide information on the composition of mutton and lamb carcasses and joints in terms of the three main anatomical tissues, viz., bone, muscle, and fat; on the chemical composition of the edible tissues of the carcass; and on the calorific and protein yields of the principal grades of New Zealand export mutton and lamb carcasses. This information was required for the effective organisation of food rationing and the determination of food import policies under the conditions prevailing in Great Britain during World War II (Clarke and McMeekan, 1952a).

The major part of this work was carried out at Massey Agricultural College where 120 lamb, ewe, and wether carcasses, obtained from the Co-operative Wholesale Society Limited's Longburn Freezing Works, were examined. Samples of

TABLE 1

Grades of Lamb and Mutton Carcasses - 120 Series

Description	Grade Mark	Weight Range (lb)	Carcasses Selected	Mean Frozen Wt. ex Store (lb)
Prime Down Cross Lambs	2	Up to 36	10	32.2
	8	37-42	10	39.6
	4	43-50	10	46.2
Prime Crossbred Lambs	2	Up to 36	10	32.1
	8	37-42	10	39.5
	4	43-50	10	46.1
Second Quality Lambs	Y	Up to 36	10	30.5
Ewes	1	Up to 48	5	44.7
	7	49-56	5	52.6
	3	57-64	5	60.4
	9	65-72	5	68.6
	5	73-80	5	76.5
Wethers	7	49-56	5	53.3
	3	57-64	5	61.0
	9	65-72	5	69.5
	5	73 and over	5	76.9
Second Quality Wethers	X	Up to 56	5	46.5

lamb, ewe, and wether carcasses of each grade were selected from commercially graded lots in such a manner as to ensure that the weight range within each grade was adequately covered. Details of grades and mean carcass weights within grades are given in Table 1.

The carcasses used in the original study were chosen to represent a typical cross-section of the North Island mutton and lamb industry of New Zealand, i.e., the ewes and wethers were from Romney, or more correctly "Romney Crossbred" flocks, while the lambs included both Romney and Southdown-Romney crosses. All carcasses were telescoped to facilitate export under war time conditions of restricted shipping space.

Further details of the materials and methods used in this work, and reports of the results, have been given by McMeekan and Clarke (1942), Shorland, de la Mare, Sorrell and Barnicoat (1947), Barnicoat and Shorland (1952), and Clarke and McMeekan (1952a, 1952b). The grading system referred to in Table 1 has been discussed by Barton (1947), and Smith-Pilling (1959), and a statistical analysis of the differences, in terms of bone, muscle, and fat, between the various grades, based on the above data, has recently been given by Barton (1960).

In 1950 a series of measurements was made on the bones which had been labelled and stored at the time of dissection. During and subsequent to the original dissection work a number of bones were unavoidably broken, and thus only those carcasses for which the skeletal records were complete were used in the present study. The amended numbers of carcasses within each grade and sex are presented in Table 2.

The information extracted from the original data sheets and the subsequent bone measurement investigation is presented in Table 3. The division into dependent and independent variates, and the symbols used throughout this work are also given in the table.

(2) Ryegrass Strain Trial

The second source of data has been provided by trials carried out on the Massey Agricultural College sheep farm from May 1957 until December 1958 to determine the effect of short-rotation and perennial ryegrass, with and without white clover, on the iodine status of sheep. Details of this work have been given by Flux, Butler, Rae and Brougham (1960).

Ulyatt (1960) carried out carcass analyses on 39 Romney ewes used in the Ryegrass Strain Trial (R.S.T.). His material was made available for the present study. The information in Table 4, relating to the muscular tissue and the weights of certain bones, was extraced from Ulyatt's raw data. The bone measurements were subsequently made by the writer.

2. DETERMINATION OF WEIGHT OF MUSCULAR TISSUE

(1) 120 Series

All carcasses used in this investigation were divided into neck, thorax, loin, pelvis, two shoulder, and two leg joints, the

TABLE 3

Variates Considered - 120 Series

	Units	Symbol
A. **Dependent Variates**		
Weight of Muscular Tissue in Carcass	kg.	Y_1
Weight of Muscular Tissue in Shoulder	kg.	Y_2
Weight of Muscular Tissue in Leg	kg.	Y_3
B. **Independent Variates**		
Frozen Carcass Weight	kg.	X
Length of Radius-ulna	cm.	Rl
Weight of Radius-ulna	g.	Rw
Length of Humerus	cm.	Hl
Weight of Humerus	g.	Hw
Weight of Humerus per cm. length	g.	Ht
Length of Tibia	cm.	Tl
Weight of Tibia	g.	Tw
Length of Femur	cm.	Fl
Weight of Femur	g.	Fw

TABLE 4

Variates Considered - Ryegrass Strain Trial Series

	Units	Symbol
A. **Dependent Variates**		
Weight of Muscular Tissue in Carcass	kg.	Y_1
Weight of Muscular Tissue in Shoulder	kg.	Y_2
B. **Independent Variates**		
Frozen Carcass Weight	kg.	X
Length of Metacarpus	cm.	Cl
Weight of Metacarpus	g.	Cw
Width of Metacarpus	cm.	Cd
Weight of Metacarpus per cm. length	g.	Ct
Length of Humerus	cm.	Hl
Weight of Humerus	g.	Hw
Weight of Humerus per cm. length	g.	Ht

loin being separated from the thorax in such a manner as to include the last thoracic vertebra in the loin joint. Right shoulders and legs only were dissected in all but a few cases. All joints were dissected in a defrosted or semi-defrosted condition into bone, muscle, fat, and tendon and waste.

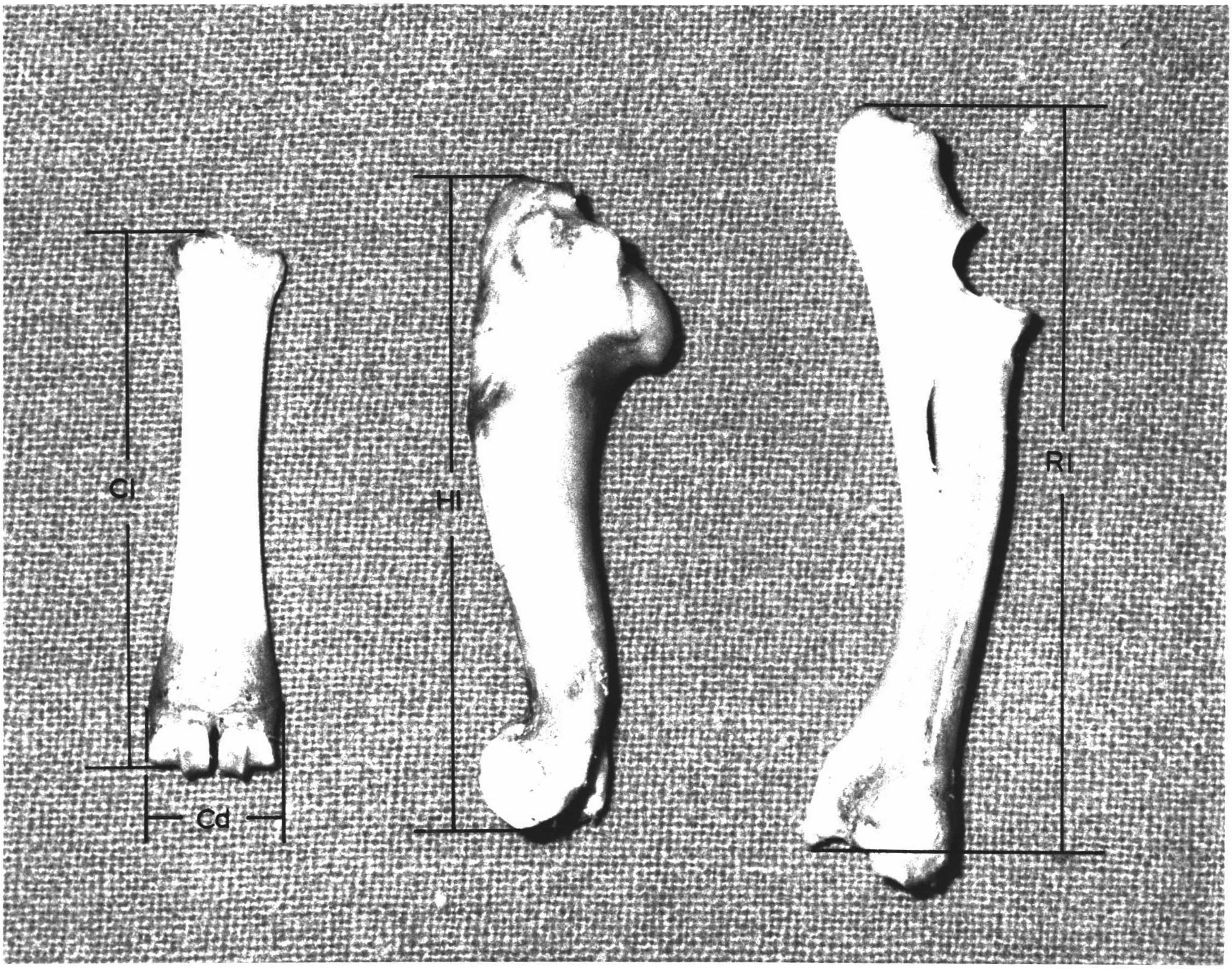
The weights of muscular tissue in the shoulder and leg were obtained by doubling the weights of muscle dissected from the right shoulder and leg, respectively. Thus, the weight of the total muscular tissue in the carcass was taken as the sum of the weights of muscular tissue in the neck, thorax, loin, and pelvis, plus twice the weight of the muscular tissue in the right shoulder and leg joints.

(2) Ryegrass Strain Trial

In the Ryegrass Strain Trial investigation only the left side of each carcass was dissected into its component tissues, the right side being used for chemical analysis. The frozen carcasses were split down the mid-line with a meat bandsaw. The left side was then divided by the bandsaw into four joints, viz., leg, loin, 9-10-11 rib cut, and "rest". These joints were later subdivided to give seven smaller joints, similar in definition to the anatomical joints described by Pálsson (1939). The bandsawed "leg" was divided into the anatomical leg and pelvis, and the "rest" divided into neck, thorax, and shoulder, again following the procedure outlined by Pálsson (1939). Thus, the weight of the carcass muscular tissue is

PLATE I

Bones Of The Thoracic Limb



Metacarpus Humerus Radius-Ulna

Cl = Metacarpus length

Cd = Metacarpus width

Hl = Humerus length

Rl = Radius-ulna length

the sum of the separate weights of muscular tissue dissected out from the leg, pelvis, loin, 9-10-11 rib cut, thorax, shoulder, and neck, multiplied by a factor of approximately two (the ratio of carcass weight to weight of left side) to convert the figure to a whole carcass basis. This conversion factor ranged from 1.95 to 2.08. The inequality of the weights of the two sides is considered to be due more to the difficulties involved in bandsawing than to any inherent bilateral asymmetry, and thus the weight of muscular tissue in the shoulder, which is not affected by the bandsaw cut, was calculated as exactly twice the weight of muscular tissue dissected from the left shoulder. This was done to give data comparable to that available in the 120 Series.

3. DEFINITION OF REFERENCE POINTS IN BONE MEASUREMENTS

(1) 120 Series

Details of the measurements of the bones listed in Table 3 are given below. In all but a few instances the measurements refer to bones from the right side of the carcass.

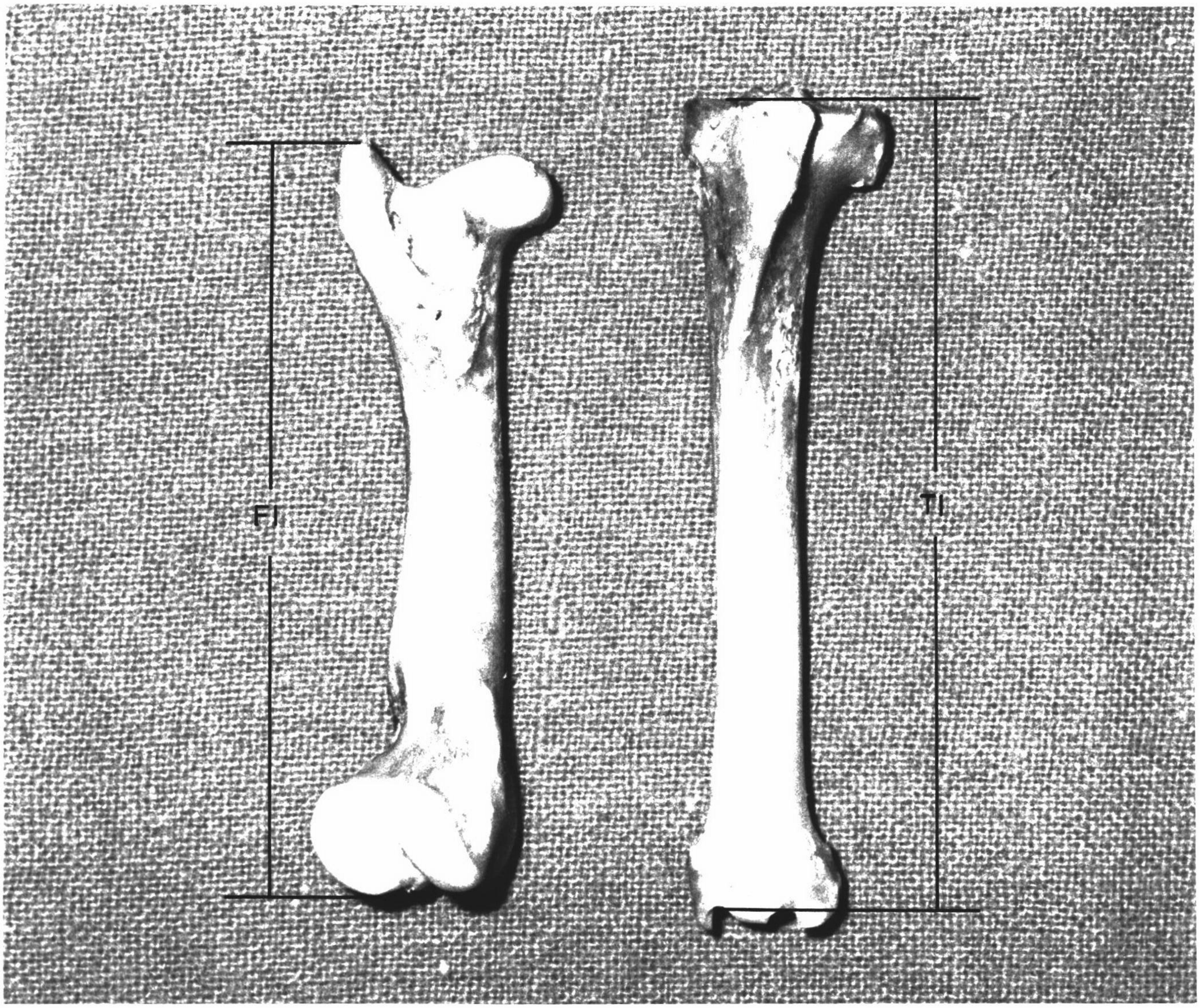
Radius-ulna Length (Rl) - from the tip of the olecranon process of the ulna to the tip of the styloid process of the radius (Plate 1).

Humerus Length (Hl) - from the highest point of the superior border of the lateral tuberosity to the most inferior and lateral point of the lateral epicondyle (Plate 1).

Tibia Length (Tl) - from the interspinous notch on top of the head of the tibia to the anterior median notch

PLATE 2

Bones Of The Pelvic Limb



Femur Tibia

Fl = Femur Length

Tl = Tibia Length

on the distal extremity (Plate 2).

Femur Length (Fl) - from the upper limit of the great trochanter to the lower limit of the lateral condyle (Plate 2).

(2) Ryegrass Strain Trial

The bone measurements detailed below were made by the writer using Gneupel anthropometric calipers (Plate 3). In this case only those bones from the left side of the carcass were available for measurement, the entire right side having been bandsawn and ground for chemical analysis.

Metacarpus (Cannon) Length (Cl) - from the highest point of the medial tuberosity to the most inferior point of the medial condyle (Plate 1).

Metacarpus (Cannon) Width (Cd) - the maximum width at the distal extremity, measured between the most distal foramen and the saggital notch (Plate 1).

Humerus Length (Hl) - from the highest point of the superior border of the lateral tuberosity to the most inferior and lateral point of the lateral epicondyle (Plate 1).

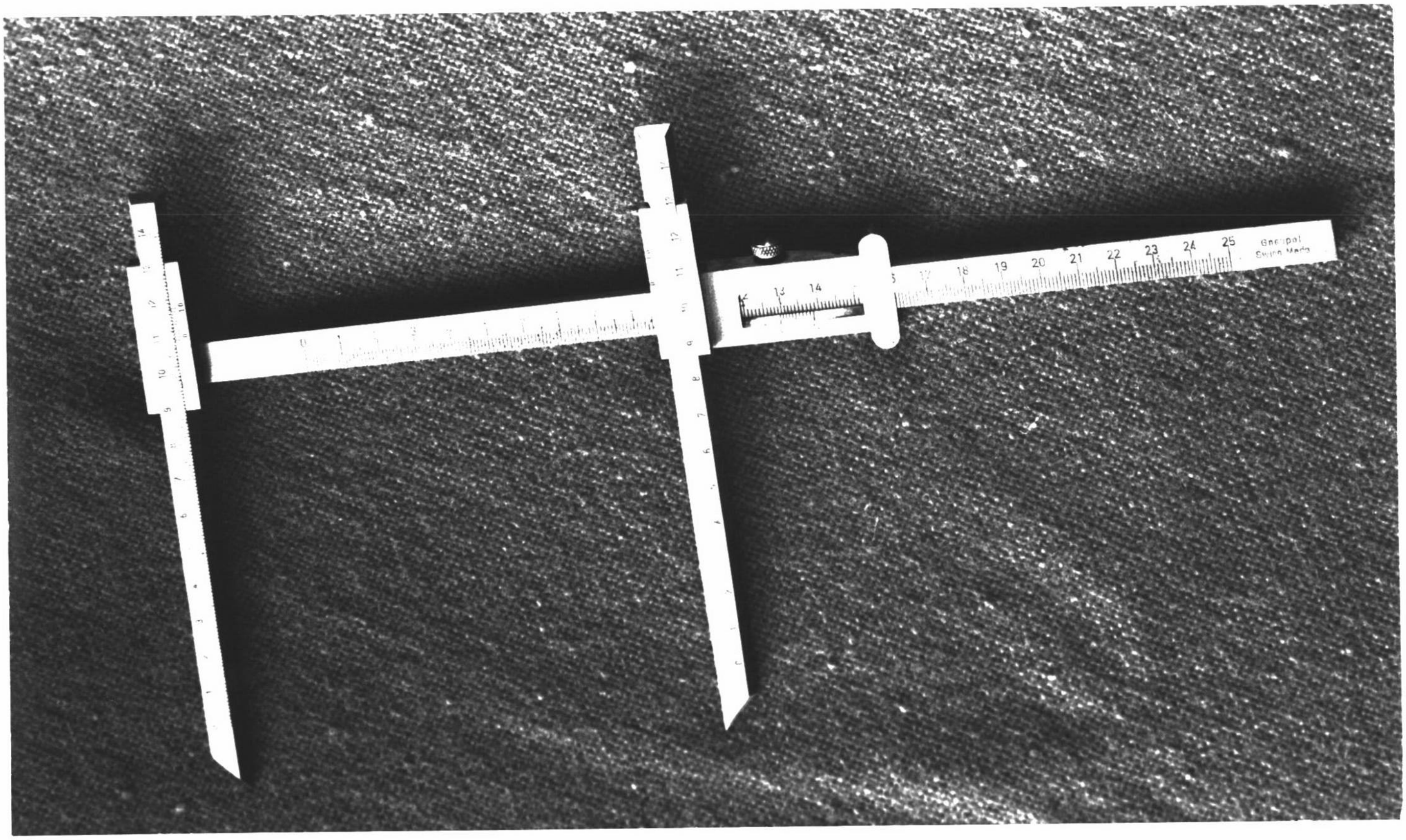
4. STATISTICAL METHODS

The analysis of covariance, as described by Snedecor (1957), was used to test the significance of differences between population regressions, and to assess the homogeneity of variance.

Tests of zero order correlation coefficients were made using

PLATE 3

Gneupel Anthropometric Calipers



Fisher's z transformation (Fisher and Yates, 1943). Fisher's transformation was also used to obtain weighted values of z in combining the sample correlation coefficients of groups of unequal size, where tests of regression and correlation coefficients showed that these groups could be considered as having been drawn from the one population.

Multiple regression equations and multiple correlation coefficients were computed from standard partial regression coefficients derived from zero order correlations. The computation of partial regression coefficients also involves the use of corrected sums of squares. Thus, in combining carcass classes or groups which can be considered as different samples of the one population, the zero order correlation coefficients used in calculating the standard partial regression coefficients of the combined groups were also derived from pooled sums of squares and crossproducts, and not from weighted values of z. However, the small differences, in most cases apparent only in the third decimal place, between the two estimates of correlation show that the lack of a suitable statistical technique for overcoming the asymmetrical distribution of r in this case is relatively unimportant.

The significance of the information contributed by each of the independent variates in the multiple regression equations was tested by the method described by Snedecor (1957). The general case is set out as follows:

Test of Each Independent Variate after the Effects of the Others have been Removed

Source of Variation	d.f.	Sum of Squares	M.S.	F
X_1 and X_2	n	$\Sigma\hat{y}_{12}^2$		
X_1 alone	n-1	$\Sigma\hat{y}_1^2$		
X_2 after X_1	n-(n-1)	$\Sigma\hat{y}_{12}^2 - \Sigma\hat{y}_1^2$	P	P/E
X_1 and X_2	n	$\Sigma\hat{y}_{12}^2$		
X_2 alone	n-1	$\Sigma\hat{y}_2^2$		
X_1 after X_2	n-(n-1)	$\Sigma\hat{y}_{12}^2 - \Sigma\hat{y}_2^2$	Q	Q/E
Error	N-(n+1)	$\Sigma d_{y.12}^2$	E	

Where,

X_1 and X_2 = independent variates

n = number of independent variates

N = total number in sample

Σy_{12}^2 = sum of squares due to regression of Y on both X_1 and X_2

= $b_{y1.2}\Sigma x_1 y + b_{y2.1}\Sigma x_2 y$

Σy_1^2 = sum of squares due to regression of Y on X_1 = $b_{y1}\Sigma x_1 y$

Σy_2^2 = sum of squares due to regression of Y on X_2 = $b_{y2}\Sigma x_2 y$

$d_{y.12}^2$ = sum of squares due to deviations from regression = $\Sigma y^2 - \Sigma\hat{y}_{12}^2$

The data relating to the Ryegrass Strain Trial carcasses were arranged according to a two-way classification (pasture type and birthrank), with unequal subclass numbers. The statistical procedure used by Ulyatt (1960) and most appropriate to this classification was the method of fitting constants by least squares. The model chosen was:

$$y_{ijk} = \mu + p_i + b_j + (pb)_{ij} + e_{ijk}$$

where,

$i = 1,2,\ldots\ldots,r$

$j = 1,2,\ldots\ldots,s$

$k = 0,1,2,\ldots\ldots,n_{ij}$

y_{ijk} is the observation on the k^{th} animal of the j^{th} birthrank on the i^{th} pasture type.

μ is an effect common to all ewes in the population and is, in effect, a population mean.

The constant p_i is an effect common to all ewes on the i^{th} pasture type.

The four pasture types were:

p_1 = perennial ryegrass,

p_2 = short-rotation ryegrass,

p_3 = perennial ryegrass plus white clover

p_4 = short-rotation ryegrass plus white clover

The constant b_j is an effect common to all ewes in the j^{th} classification of birthrank.

The four birthranks were:

b_1 = ewes rearing single lambs,

b_2 = ewes rearing twin lambs,

b_3 = ewes which bore a lamb but did not rear it,

b_4 = dry ewes.

The interaction contributed to the individuals in the $(ij)^{th}$ cell is measured by the constant $(pb)_{ij}$.

The constant e_{ijk} is a deviation or error. In testing the significance of differences between the classifications the deviations are assumed to be normally and independently distributed around a mean of zero with variance σ_e^2.

A formal presentation of the procedure used in estimating the unknown parameters in this particular model has been given by Kempthorne (1952). Details of the matrix used, and of its inversion, together with the computation of the reduction in sums of squares due to fitting constants and the analysis of variance used in testing for interaction have been set out by Ulyatt (1960).

The procedure outlined above was applied to the variates listed in Table 4. Where interactions were found to be non-significant further tests were applied to determine the significance of the pasture and birthrank effects. The effect of the significant "treatment" was then eliminated by summing the corrected sums of squares and crossproducts computed within each treatment group. Where a significant interaction was found the tests of significance of the pasture and birthrank effects were no longer applicable.

CHAPTER IV

RESULTS

It is necessary to define the terms used in referring to the subdivision of the data. The first breakdown is into two main "series" - the 120 Series and Ryegrass Strain Trial Series, which have already been encountered in the previous chapter. The 120 Series is further subdivided into four "classes", viz., ewes, wethers, ewe lambs and wether lambs. The corresponding categories in the Ryegrass Strain Trial Series are the four treatment or pasture "groups". These terms are used throughout this work.

1. 120 SERIES

The means, standard deviations, and ranges of the 120 Series variates are given in Tables 5 and 6. In all cases the males have higher means than the females of a comparable degree of maturity, e.g., the wethers have a greater weight of muscular tissue in the carcass and in the shoulder and leg joints, a higher carcass weight, and heavier and longer bones than the ewes. The same pattern is seen in a comparison of means in the two lamb groups. No such consistent effect in favour of one sex is apparent in either the standard deviations or ranges.

TABLE 5

Dependent Variates - 120 Series

Means, Standard Deviations and Ranges

Class	Mean	S.D.	Range
	Muscular Tissue in Carcass (kg.)		
Ewes	13.41	2.03	9.14 - 17.11
Wethers	13.93	1.89	9.60 - 17.36
Ewe Lambs	8.56	1.36	6.63 - 11.70
Wether Lambs	9.11	1.34	6.76 - 11.47
	Muscular Tissue in Shoulder (kg.)		
Ewes	2.62	0.41	1.77 - 3.29
Wethers	2.67	0.33	1.87 - 3.32
Ewe Lambs	1.60	0.25	1.25 - 2.20
Wether Lambs	1.71	0.28	1.16 - 2.30
	Muscular Tissue in Leg (kg.)		
Ewes	3.27	0.48	2.30 - 4.23
Wethers	3.65	0.49	2.58 - 4.47
Ewe Lambs	2.31	0.39	1.80 - 3.27
Wether Lambs	2.45	0.38	1.78 - 3.10

120 Series Class Numbers:
Ewes = 23
Wethers = 24
Ewe Lambs = 24
Wether Lambs = 36

TABLE 6

Independent Variates - 120 Series

Means, Standard Deviations and Ranges

Class	Mean	S.D.	Range
	Carcass Weight (kg.)		
Ewes	27.37	5.58	17.19 - 36.65
Wethers	28.00	5.43	17.58 - 36.06
Ewe Lambs	17.22	2.79	12.93 - 23.00
Wether Lambs	17.46	2.94	11.75 - 21.82
	Radius-ulna Length (cm.)		
Ewes	18.93	0.90	16.9 - 20.5
Wethers	20.28	0.84	18.5 - 21.8
Ewe Lambs	15.98	0.79	14.5 - 17.5
Wether Lambs	16.94	1.20	15.0 - 19.5
	Radius-ulna Weight (g.)		
Ewes	76.43	9.94	62 - 97
Wethers	94.33	10.93	77 - 119
Ewe Lambs	57.45	8.09	44 - 71
Wether Lambs	66.28	9.81	49 - 86
	Humerus Length (cm.)		
Ewes	14.50	0.67	12.9 - 15.6
Wethers	15.13	0.53	13.7 - 16.1
Ewe Lambs	12.43	0.51	11.5 - 13.5
Wether Lambs	12.96	0.78	11.5 - 14.5
	Humerus Weight (g.)		
Ewes	103.43	13.05	80 - 123
Wethers	123.41	12.73	100 - 148
Ewe Lambs	74.50	10.73	56 - 93
Wether Lambs	86.28	13.74	51 - 110

(Continued)

TABLE 6 (Continued)

Class	Mean	S.D.	Range
	Humerus Weight per cm. (g.)		
Ewes	7.11	0.64	5.67 - 8.11
Wethers	8.15	0.69	6.90 - 9.21
Ewe Lambs	5.97	0.70	4.67 - 7.36
Wether Lambs	6.63	0.80	3.92 - 7.59
	Tibia Length (cm.)		
Ewes	19.72	0.86	17.8 - 21.4
Wethers	20.71	0.86	19.0 - 22.2
Ewe Lambs	16.82	0.72	15.0 - 18.0
Wether Lambs	17.67	1.17	15.0 - 20.0
	Tibia Weight (g.)		
Ewes	104.30	13.44	84 - 131
Wethers	125.92	14.70	99 - 153
Ewe Lambs	78.63	10.27	60 - 97
Wether Lambs	89.78	12.25	66 - 120
	Femur Length (cm.)		
Ewes	17.46	0.86	15.5 - 19.2
Wethers	18.17	0.78	16.0 - 19.5
Ewe Lambs	15.02	1.71	13.5 - 16.5
Wether Lambs	15.60	0.99	14.0 - 19.0
	Femur Weight (g.)		
Ewes	131.13	20.67	92 - 170
Wethers	158.83	17.56	130 - 196
Ewe Lambs	95.42	14.18	69 - 120
Wether Lambs	113.17	18.84	78 - 162

Linear regressions of weight of muscular tissue in the carcass on carcass weight, on bone lengths and on bone weights, with associated standard errors of estimate in absolute and percentage units, are given for the four separate carcass classes in Table 7, together with the corresponding zero order correlation coefficients. In all four classes carcass weight is more closely correlated with the weight of muscular tissue in the carcass than is any other independent variate, and provides the most accurate prediction of total carcass muscle. In general, bone weights are more closely related to and give better predictions of the weight of carcass muscular tissue than do the corresponding bone lengths. Except in one instance, the correlations between the weight of carcass muscle and the independent variates are higher in the two lamb classes than in the two classes of mature sheep. These differences are greater in the relationships with bone length than in those with bone weight.

Length measurements of the radius-ulna and tibia are not significantly related to carcass muscle in either class of mature sheep. The correlation between carcass muscle and humerus length does not reach the level required for significance in the wethers, and is significant at only the 5 per cent. level of probability in the ewes. The correlation between carcass muscle and femur length is likewise significant at only the 5 per cent. level in the ewe class. In such cases the corresponding regression equations are of little predictive

TABLE 7

Relationships Between Weight of Muscular Tissue In Carcass and Other Variates - 120 Series

Dependent Variate = Weight of Muscular Tissue in Carcass (kg.) (Y_1).

Class	Correlation Coefficient(r)	Regression Equation	$S_{y.x}$(kg.)	$S_{y.x}$ as % $\bar{y}$
X = Carcass Weight (kg.)				
Ewes	0.86^{**}	$Y_1=0.31X + 4.87$	1.06	7.90
Wethers	0.84^{**}	$Y_1=0.29X + 5.74$	1.04	7.47
Ewe Lambs	0.89^{**}	$Y_1=0.43X + 1.15$	0.64	7.48
Wether Lambs	0.93^{**}	$Y_1=0.43X + 1.67$	0.49	5.38
Rl = Radius-ulna Length (cm.)				
Ewes	0.38^{ns}	$Y_1=0.85Rl - 2.65$	1.92	14.32
Wethers	0.36^{ns}	$Y_1=0.81Rl - 2.53$	1.80	12.92
Ewe Lambs	0.75^{**}	$Y_1=1.30Rl - 12.17$	0.91	10.63
Wether Lambs	0.75^{**}	$Y_1=0.84Rl - 5.10$	0.90	9.88
Rw = Radius-ulna Weight (g.)				
Ewes	0.76^{**}	$Y_1=0.16Rw + 1.50$	1.34	10.00
Wethers	0.68^{**}	$Y_1=0.12Rw + 2.78$	1.41	10.12
Ewe Lambs	0.86^{**}	$Y_1=0.14Rw + 0.28$	0.71	8.29
Wether Lambs	0.80^{**}	$Y_1=0.11Rw + 1.89$	0.82	9.00
Hl = Humerus Length (cm.)				
Ewes	0.46^{*}	$Y_1=1.40Hl - 6.88$	1.84	13.72
Wethers	0.29^{ns}	$Y_1=1.02Hl - 1.46$	1.85	13.28
Ewe Lambs	0.74^{**}	$Y_1=1.98Hl - 16.11$	0.93	10.86
Wether Lambs	0.59^{**}	$Y_1=1.01Hl - 3.98$	1.10	12.07
Hw = Humerus Weight (g.)				
Ewes	0.73^{**}	$Y_1=0.11Hw + 1.67$	1.41	10.51
Wethers	0.68^{**}	$Y_1=0.10Hw + 1.44$	1.41	10.12
Ewe Lambs	0.84^{**}	$Y_1=0.11Hw + 0.61$	0.74	8.64
Wether Lambs	0.73^{**}	$Y_1=0.07Hw + 2.94$	0.93	10.21

(Continued)

TABLE 7 (Continued)

Class	Correlation Coefficient(r)	Regression Equation	$S_{y.x}$(kg.)	$S_{y.x}$ as % $\bar{y}$
Ht = Humerus Weight per cm. (g.)				
Ewes	0.77^{**}	$Y_1 = 2.43Ht - 3.88$	1.31	9.77
Wethers	0.71^{**}	$Y_1 = 1.92Ht - 1.72$	1.36	9.76
Ewe Lambs	0.77^{**}	$Y_1 = 1.50Ht - 0.37$	0.88	10.28
Wether Lambs	0.69^{**}	$Y_1 = 1.16Ht + 1.41$	0.98	10.76
Tl = Tibia Length (cm.)				
Ewes	0.33^{ns}	$Y_1 = 0.76Tl - 1.66$	1.96	14.62
Wethers	0.32^{ns}	$Y_1 = 0.69Tl - 0.40$	1.83	13.14
Ewe Lambs	0.55^{**}	$Y_1 = 1.05Tl - 9.09$	1.15	13.43
Wether Lambs	0.65^{**}	$Y_1 = 0.74Tl - 4.04$	1.03	11.31
Tw = Tibia Weight (g.)				
Ewes	0.73^{**}	$Y_1 = 0.11Tw + 1.98$	1.42	10.59
Wethers	0.62^{**}	$Y_1 = 0.08Tw + 3.84$	1.51	10.84
Ewe Lambs	0.88^{**}	$Y_1 = 0.12Tw - 0.55$	0.67	7.83
Wether Lambs	0.78^{**}	$Y_1 = 0.09Tw + 1.44$	0.85	9.33
Fl = Femur Length (cm.)				
Ewes	0.43^{*}	$Y_1 = 1.02Fl - 4.40$	1.87	13.94
Wethers	0.56^{**}	$Y_1 = 1.36Fl - 10.78$	1.60	11.49
Ewe Lambs	0.67^{**}	$Y_1 = 1.27Fl - 10.48$	1.03	12.03
Wether Lambs	0.71^{**}	$Y_1 = 0.96Fl - 5.83$	0.96	10.54
Fw = Femur Weight (g.)				
Ewes	0.73^{**}	$Y_1 = 0.07Fw + 4.10$	1.43	10.66
Wethers	0.56^{**}	$Y_1 = 0.06Fw + 4.32$	1.59	11.41
Ewe Lambs	0.84^{**}	$Y_1 = 0.08Fw + 0.91$	0.76	8.88
Wether Lambs	0.78^{**}	$Y_1 = 0.06Fw + 2.82$	0.85	9.33

ns = Not significant at the 5% level of probability
* = Significant at the 5% level of probability
** = Significant at the 1% level of probability

This nomenclature will be used throughout this work to denote levels of significance.

value and have been included solely for the sake of completeness.

The standard errors of estimate expressed as a percentage of the mean of the dependent variate also show the superiority of the relationships between carcass muscle and bone weight, as opposed to length, and the closer limits of prediction of the regression equations pertaining to the lamb classes, particularly when the comparisons with mature sheep are made within sexes.

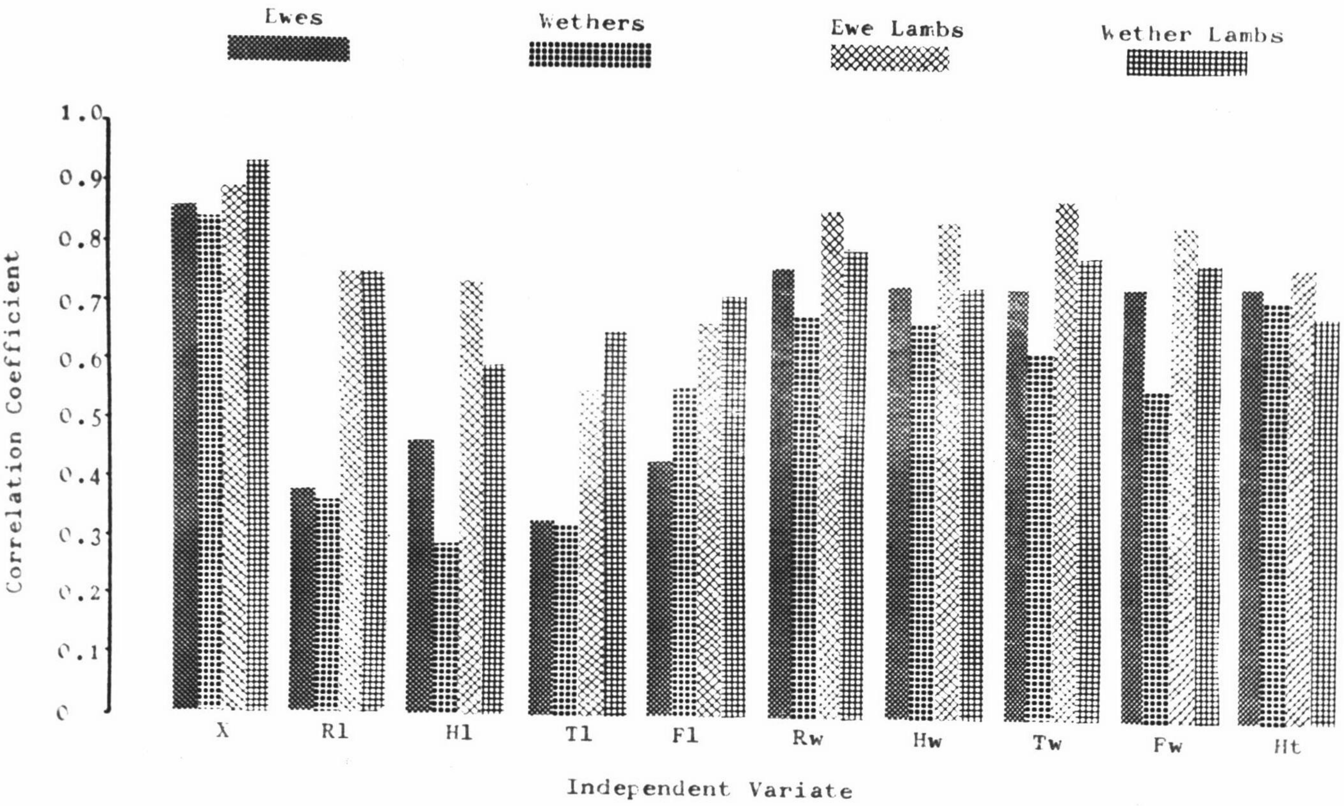
The exception to the above generalisations is found in the relationships between total muscle and humerus weight per cm. Although there is little difference between the four correlation coefficients ($r=0.69$ to 0.77), the ranking order, together with that of the percentage standard errors of estimate, is changed. In both the ewe and wether classes humerus weight per cm. is more closely correlated with the weight of muscular tissue in the carcass than is absolute bone weight. The percentage standard errors of estimate likewise show that bone weight per unit length gives more accurate prediction of the dependent variate in these classes. In the lamb classes, however, total humerus weight is more closely related to and gives better predictions of carcass muscle than is the case with bone weight per cm. In all four classes humerus length is less satisfactory for predictive purposes than either of the variates involving bone weight.

Carcass weight provides better estimates of the weight

FIG. 1

Diagrammatic Presentation Of Correlation Coefficients In Table 7

Dependent Variate = Weight Of Muscular Tissue In Carcass (Y_1)



of muscular tissue in the carcass than does any bone measurement.

Among the four bones studied there are no clear-cut differences in predictive value in favour of any one. As the humerus is the only bone common to this data and that of the Ryegrass Strain Trial it has been selected for the computation of weight per unit length, with a view to providing a comparison and possible combination of these two main series.

The correlation coefficients contained in Table 7 are presented graphically in Fig. 1. This presentation contains no new information but allows the reader to make comparisons within and between groups more readily than does any tabulation of figures.

In Table 8 the weight of muscular tissue in the shoulder is related to carcass weight and to the lengths and weights of the radius-ulna and humerus, the principal bones of that joint. Similar relationships between the weight of muscle in the leg and measurements of the tibia and femur are presented in Table 9. A study of the correlation coefficients in these tables reveals the same patterns as noted in the relationships with total carcass muscle, viz.:

(i) correlations with carcass weight are consistently higher than those with bone lengths or weights,

(ii) bone weight is more closely correlated with the weight of muscular tissue than is bone length,

(iii) correlation coefficients are higher for the two classes of lambs than for the mature sheep,

FIG. 2

Diagrammatic Presentation Of Correlation Coefficients In Table 8

Dependent Variate = Weight Of Muscular Tissue In Shoulder (Y_2)

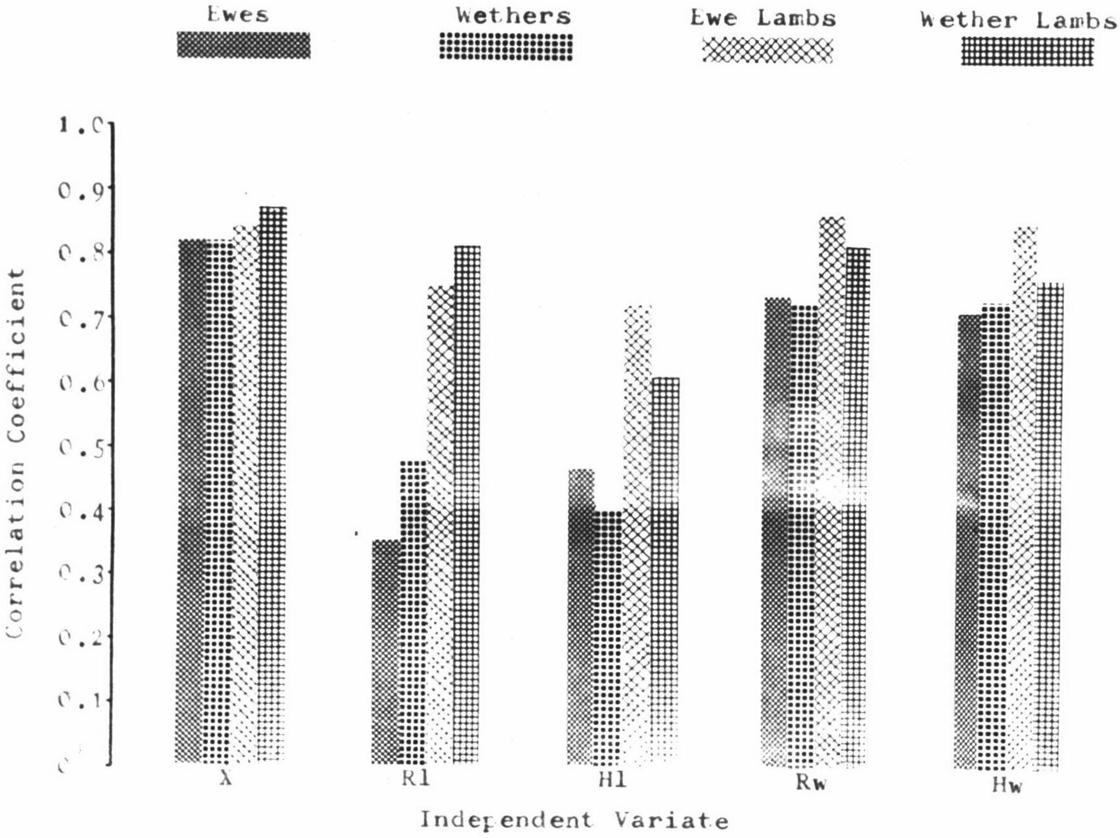


TABLE 8

Relationships Between Weight of Muscular Tissue in Shoulder and Other Variates - 120 Series

Dependent Variate = Weight of Muscular Tissue in Shoulder (kg.) (Y_2)

Class	Correlation Coefficient(r)	Regression Equation	$S_{y.x}$(kg.)	$S_{y.x}$ as % $\bar{y}$
		X = Carcass Weight (kg.)		
Ewes	0.82^{**}	$Y_2=0.06X + 0.98$	0.24	9.20
Wethers	0.82^{**}	$Y_2=0.05X + 1.26$	0.19	7.12
Ewe Lambs	0.84^{**}	$Y_2=0.08X + 0.30$	0.14	8.75
Wether Lambs	0.87^{**}	$Y_2=0.08X + 0.27$	0.14	8.19
		Rl = Radius-ulna Length (cm.)		
Ewes	0.35^{ns}	$Y_2=0.16Rl - 0.41$	0.39	14.94
Wethers	0.47^{*}	$Y_2=0.18Rl - 1.05$	0.30	11.24
Ewe Lambs	0.75^{**}	$Y_2=0.24Rl - 2.25$	0.17	10.63
Wether Lambs	0.81^{**}	$Y_2=0.19Rl - 1.48$	0.17	9.94
		Rw = Radius-ulna Weight (g.)		
Ewes	0.74^{**}	$Y_2=0.04Rw - 0.07$	0.28	10.73
Wethers	0.73^{**}	$Y_2=0.02Rw + 0.79$	0.23	8.61
Ewe Lambs	0.86^{**}	$Y_2=0.03Rw + 0.06$	0.13	8.13
Wether Lambs	0.81^{**}	$Y_2=0.02Rw + 0.19$	0.17	9.94
		Hl = Humerus Length (cm.)		
Ewes	0.46^{*}	$Y_2=0.28Hl - 1.43$	0.37	14.17
Wethers	0.40^{*}	$Y_2=0.25Hl - 1.14$	0.31	11.61
Ewe Lambs	0.72^{**}	$Y_2=0.36Hl - 2.85$	0.18	11.25
Wether Lambs	0.61^{**}	$Y_2=0.22Hl - 1.13$	0.22	12.87
		Hw = Humerus Weight (g.)		
Ewes	0.71^{**}	$Y_2=0.02Hw + 0.31$	0.29	11.11
Wethers	0.73^{**}	$Y_2=0.02Hw + 0.34$	0.23	8.61
Ewe Lambs	0.85^{**}	$Y_2=0.02Hw + 0.12$	0.14	8.75
Wether Lambs	0.76^{**}	$Y_2=0.02Hw + 0.38$	0.18	10.53

FIG. 3

Diagrammatic Presentation Of Correlation Coefficients In Table 9

Dependent Variate = Weight Of Muscular Tissue In Leg (Y_3)

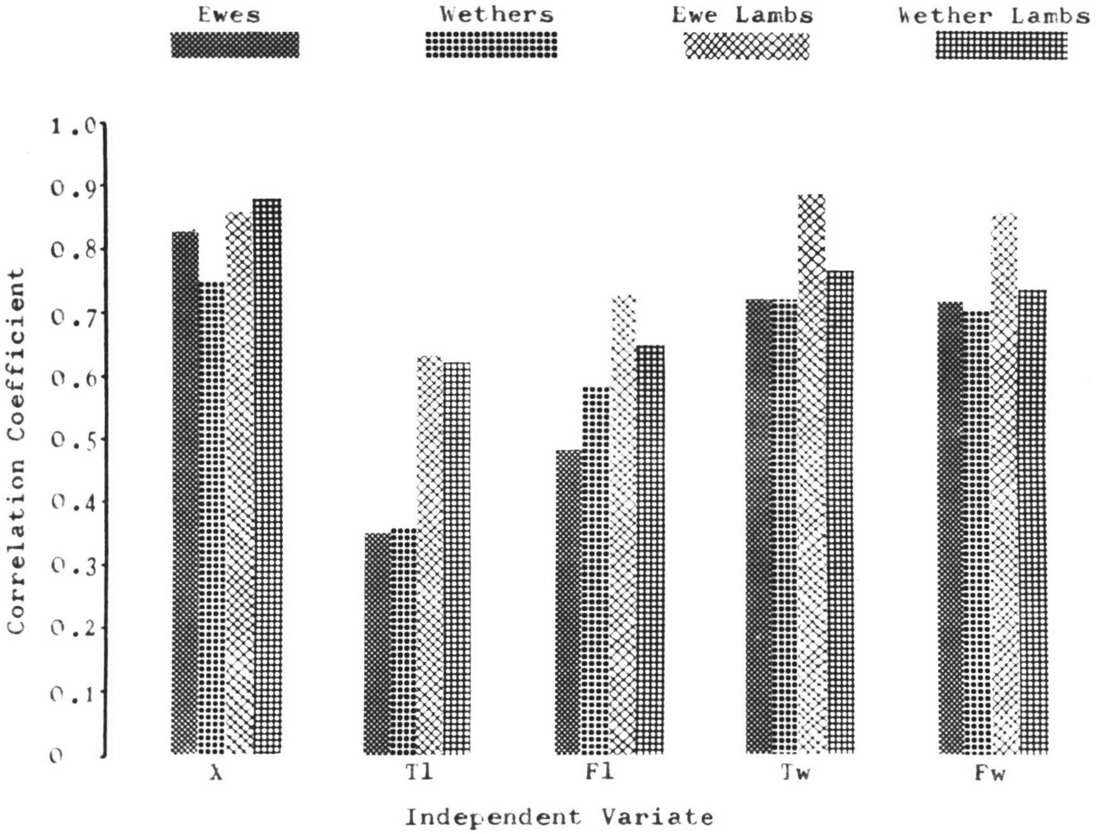


TABLE 9

Relationships Between Weight of Muscular Tissue in Leg and Other Variates - 120 Series

Dependent Variate = Weight of Muscular Tissue in Leg (kg.) (Y_3)

Class	Correlation Coefficient (r)	Regression Equation	$S_{y.x}$(kg.)	$S_{y.x}$ as % $\bar{y}$
X = Carcass Weight (kg.)				
Ewes	0.82^{**}	$Y_3=0.07X + 1.34$	0.28	8.56
Wethers	0.75^{**}	$Y_3=0.07X + 1.76$	0.33	9.04
Ewe Lambs	0.86^{**}	$Y_3=0.12X + 0.25$	0.20	8.66
Wether Lambs	0.88^{**}	$Y_3=0.11X + 0.45$	0.19	7.76
Tl = Tibia Length (cm.)				
Ewes	0.35^{ns}	$Y_3=0.20Tl - 0.63$	0.46	14.07
Wethers	0.36^{ns}	$Y_3=0.20Tl - 0.56$	0.47	12.88
Ewe Lambs	0.63^{**}	$Y_3=0.34Tl - 3.44$	0.31	13.42
Wether Lambs	0.62^{**}	$Y_3=0.20Tl - 1.12$	0.31	12.65
Tw = Tibia Weight (g.)				
Ewes	0.72^{**}	$Y_3=0.03Tw + 0.57$	0.34	10.40
Wethers	0.72^{**}	$Y_3=0.02Tw + 0.63$	0.34	9.32
Ewe Lambs	0.89^{**}	$Y_3=0.03Tw - 0.34$	0.18	7.79
Wether Lambs	0.77^{**}	$Y_3=0.02Tw + 0.29$	0.25	10.20
Fl = Femur Length (cm.)				
Ewes	0.48^{*}	$Y_3=0.27Fl - 1.45$	0.43	13.15
Wethers	0.58^{**}	$Y_3=0.36Fl - 2.96$	0.41	11.23
Ewe Lambs	0.73^{**}	$Y_3=0.40Fl - 3.64$	0.27	11.69
Wether Lambs	0.65^{**}	$Y_3=0.25Fl - 1.51$	0.30	12.24
Fw = Femur Weight (g.)				
Ewes	0.72^{**}	$Y_3=0.02Fw + 1.08$	0.34	10.40
Wethers	0.71^{**}	$Y_3=0.02Fw + 0.54$	0.35	9.59
Ewe Lambs	0.86^{**}	$Y_3=0.02Fw + 0.06$	0.20	8.66
Wether Lambs	0.74^{**}	$Y_3=0.02Fw + 0.73$	0.26	10.61

and (iv) the differences noted in (iii) are greater in those relationships involving bone length.

The relationships computed on a carcass muscle basis (Table 7) may be compared with those incorporating shoulder muscle (Table 8) and leg muscle (Table 9). Although the radius-ulna and humerus variates provide better estimates of carcass muscle than of shoulder muscle in the ewes, ewe lambs, and wether lambs, the standard errors of estimate expressed as a percentage of mean muscle weight are consistently lower for shoulder muscle in the wether class. A similar comparison of the predictive ability of the tibia and femur variates shows that in the ewe, wether, and ewe lamb classes these variates give better estimates of leg muscle than of carcass muscle, while in the wether lambs the percentage standard errors of estimate of carcass muscle are consistently smaller. These differences will be considered at a later stage, but it is pertinent to note at this point that the differences, although consistent, are small in relation to the size of the standard errors of estimate. Comparisons of the standard errors in Table 7 with those in Tables 8 and 9 also reveal small, but inconsistent, changes in ranking order.

Comparisons of the corresponding correlation coefficients in Table 7, and Tables 8 and 9 show a high degree of similarity between the relationships of each independent variate to the two, or in the case of carcass weight, three dependent variates. This is also readily seen in a comparison of Fig. 1 with Figs. 2 and 3. The significance of the differences between analagous

TABLE 10

Multiple Relationships Between Weight of Muscular Tissue in Carcass and Other Variates - 120 Series

Dependent Variate = Weight of Muscular Tissue in Carcass (kg.) (Y_1)

Class	Correlation Coefficient (R)	Regression Equation	$S_{y.x}$ (kg.)	$S_{y.x}$ as % $\bar{y}$
X = Carcass Weight (kg.) Hl = Humerus Length (cm.)				
Ewes	0.87^{**}	$Y_1=0.29X^{**} + 0.43Hl^{ns} - 0.84$	1.04	7.76
Wethers	0.84^{**}	$Y_1=0.29X^{**} + 0.03Hl^{ns} + 5.36$	1.20	8.62
Ewe Lambs	0.90^{**}	$Y_1=0.36X^{**} + 0.56Hl^{ns} - 4.52$	0.62	7.24
Wether Lambs	0.95^{**}	$Y_1=0.39X^{**} + 0.29Hl^{*} - 1.48$	0.45	4.94
X = Carcass Weight (kg.) Hl = Humerus Weight (g.)				
Ewes	0.91^{**}	$Y_1=0.24X^{**} + 0.06Hw^{**} + 0.94$	0.86	6.41
Wethers	0.87^{**}	$Y_1=0.24X^{**} + 0.04Hw^{ns} + 2.43$	0.98	7.04
Ewe Lambs	0.95^{**}	$Y_1=0.28X^{**} + 0.06Hw^{**} - 0.69$	0.42	4.91
Wether Lambs	0.95^{**}	$Y_1=0.36X^{**} + 0.02Hw^{**} + 0.95$	0.44	4.83
Hl = Humerus Length (cm.) Hw = Humerus Weight (g.)				
Ewes	0.79^{**}	$Y_1=-1.71Hl^{*} + 0.19Hw^{**} + 18.79$	1.03	7.68
Wethers	0.71^{**}	$Y_1=-0.95Hl^{ns} + 0.13Hw^{**} + 12.63$	1.05	7.54
Ewe Lambs	0.86^{**}	$Y_1= 0.69Hl^{ns} + 0.08Hw^{**} - 6.14$	0.72	8.41
Wether Lambs	0.73^{**}	$Y_1= 0.09Hl^{ns} + 0.07Hw^{**} + 2.10$	0.94	10.32
X = Carcass Weight (kg.) Hl = Humerus Length (cm.) Hw = Humerus Weight (g.)				
Ewes	0.94^{**}	$Y_1=0.22X^{**} - 1.25Hl^{*} + 0.12Hw^{**}$ 13.60	0.75	5.59
Wethers	0.88^{**}	$Y_1=0.23X^{**} - 0.69Hl^{ns} + 0.06Hw^{*} + 10.57$	0.96	6.89
Ewe Lambs	0.96^{**}	$Y_1=0.30X^{**} - 0.20Hl^{ns} + 0.06Hw^{**} + 1.17$	0.44	5.14
Wether Lambs	0.95^{**}	$Y_1=0.36X^{**} + 0.13Hl^{ns} + 0.02Hw^{ns} - 0.26$	0.44	4.83
X = Carcass Weight (kg.) Ht = Humerus Weight per cm. (g.)				
Ewes	0.93^{**}	$Y_1=0.23X^{**} + 1.35Ht^{**} - 2.39$	0.77	5.74
Wethers	0.88^{**}	$Y_1=0.23X^{**} + 0.84Ht^{*} + 0.70$	0.95	6.82
Ewe Lambs	0.95^{**}	$Y_1=0.32X^{**} + 0.81Ht^{**} - 1.79$	0.42	4.91
Wether Lambs	0.94^{**}	$Y_1=0.38X^{**} + 0.28Ht^{*} + 0.64$	0.46	5.05

relationships (e.g. humerus length and carcass muscle, and humerus length and shoulder muscle) was tested using Fisher's z transformation. In all of the 36 possible comparisons the differences proved to be non-significant.

There is thus no evidence to suggest that the bone measurements used in this study are more closely related to the weight of muscular tissue in the anatomical joints containing these bones than to the weight of the total carcass muscle, or vice versa; nor is there evidence that these measurements give a better prediction of the weight of muscular tissue in the joint than of that in the carcass, or vice versa. As the carcass is generally of greater bilogical interest and economic importance than either the shoulder or the leg the prediction of the weight of muscular tissue in the carcass has been selected as the objective in the development of the above bone-muscle relationships.

Multiple correlation coefficients and regression equations relating weight of carcass muscle to carcass weight and humerus measurements within the four carcass classes are presented in Table 10. The correlation coefficients and percentage standard errors of estimate show the same general pattern as was noted in Table 7 and Fig. 1. The differences in the relationships of bone weight and bone length to carcass muscle, although still apparent, are of lesser magnitude due to the effect of the relatively high correlations between carcass weight and muscle weight.

Age differences are again apparent in the correlations,

TABLE 11

Correlation Between Independent Variates

120 Series

Class	Correlation Coefficient (r)
Carcass Weight : Humerus Length	
Ewes	0.40^{ns}
Wethers	0.33^{ns}
Ewe Lambs	0.73^{**}
Wether Lambs	0.49^{**}
Carcass Weight : Humerus Weight	
Ewes	0.55^{**}
Wethers	0.61^{**}
Ewe Lambs	0.65^{**}
Wether Lambs	0.65^{**}
Carcass Weight : Humerus Weight per cm.	
Ewes	0.55^{**}
Wethers	0.61^{**}
Ewe Lambs	0.54^{**}
Wethor Lambs	0.63^{**}
Humerus Weight : Humerus Length	
Ewes	0.85^{**}
Wethers	0.65^{**}
Ewe Lambs	0.74^{**}
Wether Lambs	0.77^{**}

TABLE 12

Standard Partial Regression Coefficients

120 Series

Carcass Muscle on (a); (b) and (c) held constant

Independent Variates			Classes			
a	b	c	Ewes	Wethers	Ewe Lambs	Wether Lambs
Carcass Weight	Humerus Length		0.80	0.84	0.73	0.85
Carcass Weight	Humerus Weight		0.66	0.68	0.58	0.79
Carcass Weight	Humerus Length	Humerus Weight	0.62	0.66	0.62	0.69
Carcass Weight	Humerus Weight per cm.		0.62	0.65	0.66	0.83
Humerus Length	Carcass Weight		0.14	0.01	0.21	0.17
Humerus Length	Humerus Weight		-0.56	-0.27	0.26	0.05
Humerus Length	Carcass Weight	Humerus Weight	-0.41	-0.19	-0.07	0.08
Humerus Weight	Carcass Weight		0.37	0.27	0.46	0.22
Humerus Weight	Humerus Length		1.21	0.85	0.65	0.69
Humerus Weight	Carcass Weight	Humerus Length	0.74	0.41	0.50	0.16
Humerus Weight per cm.	Carcass Weight		0.43	0.31	0.42	0.17

the lambs having higher coefficients than the mature sheep, particularly when the comparisons are made within sexes. These differences are likewise reduced by the incorporation of carcass weight as an independent variate. As was noted in the consideration of Table 7 the relationships including humerus weight per unit length prove to be exceptions to these generalisations.

A comparison of the standard errors of estimate, both in absolute and percentage terms, in Tables 7 and 10 shows that the multiple regression equations give better predictions of the weight of carcass muscle than do the linear regressions. The multiple regressions also provide additional information regarding the predictive worth of the separate independent variates. A knowledge of the correlations between these independent variates and of the standard partial regression coefficients allows of a better assessment of predictive values than can be arrived at solely from an examination of the significance of the information contributed by any single variate. This information is given in Tables 11 and 12.

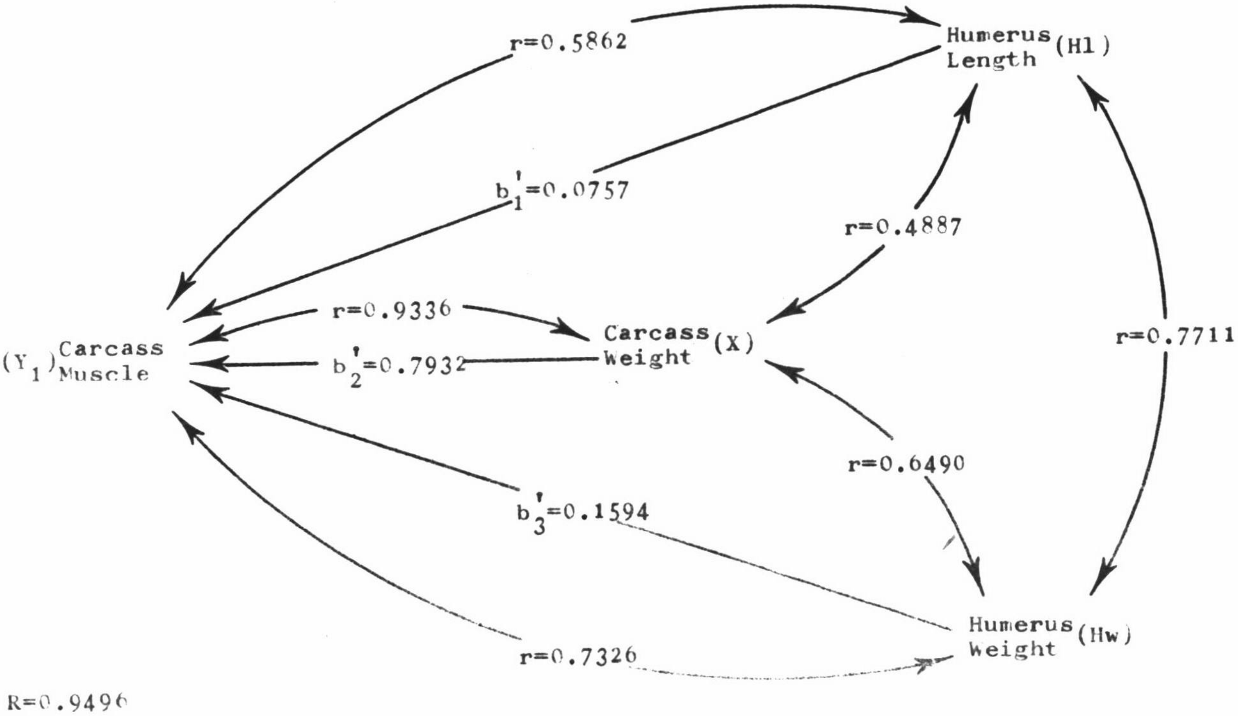
Path coefficient diagrams, as devised by Wright (1934), and which give a schematic representation of the relationships between the three or more variates, are also of value in the interpretation of the results given in Table 10. An example of this type of presentation is given in Fig. 4, where the straight lines represent standard partial regression coefficients and the curved lines indicate correlations. b'_1 is the path from Hl to Y_1 and measures the direct effect of humerus length on carcass

FIG. 4

Schematic Presentation Of Multiple Regression Equation

$$Y_1 = 0.36X + 0.13Hl + 0.02Hw - 0.26$$

From Table 10 (Wether Lambs)



R=0.9496

muscle. Alternative paths from Hl to Y_1 act through carcass weight (X) and humerus weight (Hw). The value of an alternative or indirect path is defined as the product of the correlation between the two independent variates in question and the standard partial regression coefficient of Y_1 on the second independent variate. The correlation between Y_1 and any independent variate is the sum of all the paths from that variate to Y_1.

Thus, in Fig. 4 the correlation between carcass muscle (Y_1) and humerus length (Hl) may be broken down as follows:

Direct effect of Hl on Y_1 $= b_1'$ $= 0.0757$

Indirect effect acting through X $= r_{HlX} \cdot b_2'$ $= 0.3876$

Indirect effect acting through Hw $= r_{HlHw} \cdot b_3'$ $= 0.1229$

$r_{Y_1 Hl}$ $= 0.5862$

Similarly,

Direct effect of Hw on Y_1 $= b_3'$ $= 0.1594$

Indirect effect acting through X $= r_{HwX} \cdot b_2'$ $= 0.5148$

Indirect effect acting through Hl $= r_{HwHl} \cdot b_1'$ $= 0.0584$

$r_{Y_1 Hw}$ $= 0.7326$

and,

Direct effect of X on Y_1 $= b_2'$ $= 0.7932$

Indirect effect acting through Hw $= r_{HwX} \cdot b_3'$ $= 0.1034$

Indirect effect acting through Hl $= r_{HlX} \cdot b_1'$ $= 0.0370$

$r_{Y_1 X}$ $= 0.9336$

The above is given as an example of the use of path coefficients in the interpretation of the multiple relationships in Table 10. Although some 50 such diagrams have been constructed in the course of this work it is both impracticable and unnecessary to include all of them. The relevant information for the construction of such schematic representations is contained in the tables of results.

Four of the five sets of multiple regression equations in Table 10 contain carcass weight as an independent variate. In each case this variate makes a highly significant contribution to the predictive power of the regression equation, as tested by the method outlined on page 72. The predictive worth of this variate can also be judged from the magnitude of the changes in the coefficient of regression when other independent variates are incorporated in the equation. Taking the ewe class as an example, the regression coefficient of weight of carcass muscle on carcass weight alone is 0.31 (Table 7). The inclusion of humerus length, which makes a non-significant contribution, reduces this by 0.07. Humerus length and humerus weight, as separate independent variates, are responsible for the largest reduction of 0.09, while the combination of these bone measurements in the weight per unit length variate decreases the coefficient by 0.08.

The corresponding regression coefficients for the wether class follow those of the ewes very closely. In Table 7 where carcass weight is the sole independent variate there is a difference of 0.02 between the coefficients of the two classes. In the multiple regression equations (Table 10) the partial regression coefficients are the same for both carcass classes in three of the four relationships incorporating carcass weight. In the fourth case (carcass muscle on carcass weight, humerus length, and humerus weight) there is a difference of only 0.01 between the carcass weight partial coefficients of these two classes. The above pattern is also evident in the standard partial regression coefficients (Table 12).

There is also a marked, although less striking, similarity between the carcass weight partial regression coefficients of the two lamb classes. In all cases these coefficients are higher in the lamb classes than in the mature sheep.

The incorporation of humerus length with carcass weight and/or humerus weight adds little to the predictive powers of those other variates. Of the 12 multiple regressions in which this variate appears, its contribution to the prediction of carcass muscle weight is significant in only three instances, and then at only the 5 per cent. level of probability. In the ewe and wether classes this is due primarily to the poor relationships between this variate and carcass muscle (Table 7). The correlation coefficients in Table 11 and standard partial regression coefficients in Table 12 show that the highly significant correlations between carcass muscle and humerus length in the lamb classes are largely a result of the close relationships of the latter to humerus weight and, through humerus weight, to carcass weight. This is well exemplified in Fig. 4, where, in spite of the highly significant correlation between carcass muscle and humerus length ($r=0.59$) the standard partial regression coefficient showing the direct effect of humerus length on carcass muscle is very small ($b_1' = 0.08$).

The changes in the partial and standard partial regression coefficients of humerus length are less in the two equations containing humerus weight than in those which include carcass weight. This may be taken as further evidence of the dependency of humerus length on the weight of that bone for its predictive powers.

The negative sign of the humerus length partial regression coefficient seen in five of the 12 equations containing this variate is a result of the poor relationship of humerus length to carcass muscle, and arises whenever the product of the correlation between the two independent variates and the standard partial regression coefficient of the second independent variate is greater than the correlation between humerus length and the dependent variate.

The inclusion of humerus length in a multiple regression equation with humerus weight and/or carcass weight reduces the standard errors of estimate of carcass muscle, although not to any appreciable extent. Exceptions to this generalisation are found in the regression of carcass muscle on carcass weight and humerus length in the wethers, the regression of carcass muscle on humerus length and humerus weight in the wether lambs, and the regression of carcass muscle on carcass weight, humerus length and humerus weight in the ewe lambs. In these instances the standard errors of estimate are increased by the inclusion of humerus length. Such small increases are certainly non-significant, and are at least partly attributable to the loss of the degree of freedom associated with this additional variate.

Humerus weight, in combination with carcass weight, contributes highly significant information regarding the weight of carcass muscle in all carcass classes except the wethers. In all classes, including the wethers, the correlations with carcass muscle are increased, and the standard errors of estimate decreased, by the inclusion of the humerus weight variate. In combination with humerus length, humerus weight carries almost all the predictive power of the relationships, as may be seen from the standard partial regression coefficients in Table 12, and as might be anticipated from the correlation coefficients in Tables 7 and 11. In the multiple regressions on all three variates the significance of the additional information contributed by humerus weight is lessened, although its inclusion is still effective in reducing the standard errors of estimate, particularly in the mature sheep and ewe lamb classes.

The partial and standard partial regression coefficients of humerus weight in the equations containing all three independent variates bear a closer similarity to those in the regressions incorporating carcass weight and humerus weight than to those in the regressions which exclude carcass weight, i.e., the addition of humerus length to humerus weight does not have as great an effect on the predictive power of that variate as does the addition of carcass weight.

In multiple regressions with carcass weight, humerus weight per cm. makes significant contributions to the prediction of the weight of muscular tissue in the carcass. The additional information supplied by the weight per unit length variate is significant at the 5 per cent. level of probability in the male classes, and at the 1 per cent. level in the females. The combination of carcass weight and humerus weight per cm. affords better prediction of the dependent variate than does carcass weight with humerus length, particularly in the two classes of mature sheep. Prediction in these classes, but not in the lambs, is improved to a lesser extent by the substitution of humerus weight per cm. for the absolute bone weight variate in the multiple regressions with carcass weight.

The multiple correlation coefficients and standard errors of estimate associated with the combination of carcass weight and humerus weight per unit length show marked similarities to those provided by the combination of carcass weight, humerus length and humerus weight. Although the single humerus weight per unit length variate can replace both the length and weight variates in the multiple relationships without any appreciable loss in the efficiency of prediction of carcass muscle, a comparison of the linear regressions on humerus weight per cm. (Table 7) and the multiple regressions on humerus length and humerus weight (Table 10) shows that, in the absence of the carcass weight variate, the combination of the two absolute variates is more closely related to an provides better predictions of the dependent variate than is the case when both measurements are incorporated in the one variate.

Of the multiple relationships presented in Table 10 the combinations of humerus length and humerus weight, and of carcass weight and humerus length, provide the least satisfactory estimates of carcass muscle. There is little difference in the efficiencies of estimation afforded by the other combinations of independent variates.

2. RYEGRASS STRAIN TRIAL

The model used in analysing the Ryegrass Strain Trial data has been outlined in Captor III. The analyses of variance employed in testing the interaction between, and the significance of, the birthrank and pasture effects in certain variates are given in Appendix I. These tests were not applied to the two weight per unit length variates, as these quantities are derived from the absolute length and weight measurements of the respective bones. Evidence of a significant interaction between birthrank and pasture effects was found only in the cannon width variate. As the tests of significance of treatment effects are no longer applicable for this variate, cannon width has not been included in the ensuing analyses. In none of the variates tested was birthrank found to have any significant effect. Pasture type, on the other hand, produced an effect significant at the 1 per cent. level of probability on the weight of muscular tissue in the carcass, on carcass weight, and on both humerus measurements. In the two cannon variates tested the effect of pasture type was significant at the 5 per cent. level.

Pasture type is thus responsible for significant differences in all the Ryegrass Strain Trial variates. The tests summarised in Appendices II and III are designed to show whether this particular treatment effected any alteration in the relationships among these variates. Appendix II deals with the within pasture-type regressions of carcass muscle on each of the seven independent variate. These tests reveal no significant differences between the four sample regression coefficients in six of the seven families of regressions, and a difference, significant at the 5 per cent. level, between the slopes of the four regressions on cannon weight. Thus, with the exception of the last-mentioned relationship, the four regression coefficients of any one family can be considered as referring to different samples drawn from the one population.

Possible causes of the difference in the slopes of the sample regressions of carcass muscle on cannon weight will be considered in Chapter V. However, any biological explanation

TABLE 13

Dependent and Independent Variates - Ryegrass Strain Trial Series
Means, Standard Deviations and Ranges

Variate	Mean	S.D.	Range
Muscular Tissue in Carcass (kg.)	11.85	1.46	6.76 - 16.42
Muscular Tissue in Shoulder(kg.)	2.19	0.26	1.28 - 3.10
Carcass Weight (kg.)	28.24	5.03	11.71 - 41.77
Cannon Length (cm.)	10.61	0.37	9.7 - 11.8
Cannon Weight (g.)	35.01	3.91	26.2 - 45.2
Cannon Width (cm.)	2.83	0.15	2.5 - 3.2
Cannon Weight per cm. (g.)	3.30	0.28	2.70 - 4.04
Humerus Length (cm.)	13.14	0.48	12.1 - 14.7
Humerus Weight (g.)	96.46	10.15	74 - 128
Humerus Weight per cm. (g.)	7.32	0.58	6.02 - 8.76

of this difference does nothing to make the difference less real. While fully appreciating the opening to criticism created by the further use of the cannon weight variate, this measurement has been retained and will be used in the subsequent analyses because of the importance of its role in any study of bone-muscle relationships. Its inclusion is also supported by the relatively low level of probability at which the difference in the sample regression coefficients attains significance, and further, by the lack of any such difference in the tests among independent variates (Appendix III).

Further evidence is presented in Appendix III to show that, although the different pasture types produce significant differences in the various carcass and bone measurements, the relationships among these variables do not differ between treatment groups.

The significant pasture type effect is eliminated in the summation of corrected sums of squares and crossproducts computed within pasture types and used in the derivation of the cannon regression coefficients in Appendices II and III.

The means, standard deviations, and ranges of the Ryegrass Strain Trial variates are presented in Table 13. Comparisons with Tables 5 and 6 show that the Ryegrass Strain Trial carcasses have higher mean carcass weights and higher mean humerus weights per cm. length than the 120 Series ewe carcasses. The dependent variates and humerus length and weight variates of the Ryegrass Strain Trial carcasses have

TABLE 14

Relationships Between Weight of Muscular Tissue in Carcass and Other Variates - Ryegrass Strain Trial Series

Dependent Variate = Weight of Muscular Tissue in Carcass (kg.) (Y_1)

Independent Variate	Correlation Coefficient(r)	Regression Equation	$S_{y.x}$ (kg.)	$S_{y.x}$ as % $\bar{y}$
Carcass Weight	0.83^{**}	$Y_1 = 0.24X + 5.03$	0.82	6.92
Cannon Length (cm.)	0.32^{*}	$Y_1 = 1.27Cl - 1.64$	1.40	11.81
Cannon Weight (g.)	0.69^{**}	$Y_1 = 0.26Cw + 2.89$	1.08	9.11
Cannon Weight per cm. (g.)	0.75^{**}	$Y_1 = 3.90Ct - 1.03$	0.97	8.19
Humerus Length (cm.)	0.60^{**}	$Y_1 = 1.80Hl - 11.85$	1.18	9.96
Humerus Weight (g.)	0.76^{**}	$Y_1 = 0.11Hw + 1.24$	0.96	8.10
Humerus Weight per cm. (g.)	0.73^{**}	$Y_1 = 1.82Ht - 1.48$	1.01	8.52

lower mean values than the ewes of the 120 Series. Although the ranges of all variates, except humerus length, are greater in the Ryegrass Strain Trial carcasses than in those of the 120 Series ewes, the standard deviations of all Ryegrass Strain Trial variates are lower than those of the ewes in the 120 Series.

The zero order correlation coefficients and linear regression equations relating the weight of carcass muscle to carcass weight and to the cannon and humerus variates are presented in Table 14. The best prediction of the dependent variate is again given by carcass weight.

The ranking order of the correlations with the three cannon variates follows that of the humerus variates in the 120 Series ewes. Cannon weight per unit length is most closely related to and provides the most satisfactory estimate of carcass muscle. This is followed by the absolute weight variate, and in third place, by cannon length which is significantly related to carcass muscle at only the 5 per cent. level of probability.

The ranking order of the three humerus variates does not follow that of the cannon measurements or of the 120 Series ewes' humerus measurements. In this case the relative positions of humerus weight and humerus weight per cm. are reversed, although the difference between them is not large. This change may be due, in part at least, to the difference in the correlations between the components of the weight per cm. variates. The lower correlation between cannon length and

TABLE 15

Relationships Between Weight of Muscular Tissue in Shoulder and Other Variates - Ryegrass Strain Trial Series

Dependent Variate = Weight of Muscular Tissue in Shoulder (kg.) (Y_2)

Independent Variate	Correlation Coefficient(r)	Regression Equation	$S_{y.x}$(kg.)	$S_{y.x}$ as % $\bar{y}$
Carcass Weight (kg.)	0.74^{**}	$Y_2=0.04X + 1.10$	0.18	8.22
Cannon Length (cm.)	0.34^{**}	$Y_2=0.24Cl - 0.39$	0.25	11.42
Cannon Weight (g.)	0.64^{**}	$Y_2=0.04Cw + 0.69$	0.21	9.59
Humerus Length (cm.)	0.62^{**}	$Y_2=0.34Hl - 2.24$	0.21	9.59
Humerus Weight (g.)	0.74^{**}	$Y_2=0.02Hw + 0.34$	0.18	8.22

weight ($r = 0.54$) than between humerus length and weight ($r = 0.76$) gives more power to the derived weight per cm. variate in the case of the cannon (Table 17). The length variate again affords the least satisfactory prediction of carcass muscle. The standard errors of estimate associated with the three humerus variates are consistently lower in the Ryegrass Strain Trial ewes than in the 120 Series ewes, although the correlation coefficients of the weight and weight per cm. variates are very similar in both instances. This could be attributed to the greater number of observation in the Ryegrass Strain Trial data.

A comparison of the efficiencies of prediction afforded by the cannon and humerus variates shows that there is little difference between the standard errors of estimate of the regressions on humerus weight and cannon weight per cm. Humerus weight per cm. provides an only slightly less satisfactory estimate than either of the above variates. The ranking order thereafter is cannon weight, humerus length, and cannon length.

The relationships to and predictions of the weight of muscular tissue in the shoulder (Table 15) are of interest, even if not of as great import as the corresponding carcass muscle relationships. The major differences to be noted here are, firstly, that humerus weight provides as good an estimate of the weight of muscular tissue in the shoulder as does carcass weight, and secondly, that the efficiency of prediction of humerus length is equal to that of cannon weight. Cannon length maintains its consistently poor position as an index of muscular tissue.

TABLE 16

Multiple Relationships Between Weight of Muscular Tissue in Carcass and Other Variates - Ryegrass Strain Trial Series

Dependent Variate = Weight of Muscular Tissue in Carcass (kg.) (Y_1)

Independent Variate	Correlation Coefficient(R)	Regression Equation	$S_{y.x}$(kg.)	$S_{y.x}$ as % $\bar{y}$
Carcass Weight (kg.) Cannon Length (cm.)	0.89^{**}	$Y_1 = 0.24X^{**} + 1.24Cl^{**} - 8.15$	0.69	5.82
Carcass Weight (kg.) Cannon Weight (g.)	0.89^{**}	$Y_1 = 0.19X^{**} + 0.14Cw^{**} + 1.67$	0.68	5.74
Cannon Length (cm.) Cannon Weight (g.)	0.69^{**}	$Y_1 = -0.28Cl^{ns} + 0.27Cw^{**} + 5.35$	1.09	9.20
Carcass Weight (kg.) Cannon Length (cm.) Cannon Weight (g.)	0.91^{**}	$Y_1 = 0.21X^{**} + 0.73Cl^{*} + 0.09Cw^{*} - 4.90$	0.65	5.48
Carcass Weight (kg.) Cannon Weight per cm. (g.)	0.89^{**}	$Y_1 = 0.17X^{**} + 2.01Ct^{**} + 0.36$	0.69	5.82
Carcass Weight(kg.) Humerus Length(cm.)	0.92^{**}	$Y_1 = 0.21X^{**} + 1.24Hl^{**} - 10.43$	0.58	4.89
Carcass Weight(kg.) Humerus Weight(g.)	0.91^{**}	$Y_1 = 0.17X^{**} + 0.06Hw^{**} + 0.96$	0.62	5.23
Humerus Length(cm.) Humerus Weight(g.)	0.76^{**}	$Y_1 = 0.10Hl^{ns} + 0.11Hw^{**} + 0.29$	0.97	8.19
Carcass Weight(kg.) Humerus Length(cm.) Humerus Weight (g.)	0.93^{**}	$Y_1 = 0.19X^{**} + 0.91Hl^{**} + 0.02Hw^{ns} - 7.85$	0.57	4.81
Carcass Weight(kg.) Humerus Weight per cm. (g.)	0.88^{**}	$Y_1 = 0.18X^{**} + 0.88Ht^{**} + 0.37$	0.72	6.08

The differences between the analgous relationships in Tables 14 and 15 were tested using Fisher's z transformation. In none of the five cases was the difference large enough to be significant. Thus, the length and weight measurements of the cannon and humerus are no more closely related to the weight of muscular tissue in the shoulder than to the total weight of muscle in the carcass. As in the 120 Series, the aim of the further studies using the above bone measurements will be the prediction of the weight of the carcass muscle. The estimation of shoulder muscular tissue will not be considered further.

The multiple correlation coefficients and regression equations relating carcass muscle to carcass weight and to cannon and humerus measurements are given in Table 16. Of the five equations containing cannon variates the best prediction of the weight of carcass muscle is given by the combination of carcass weight, cannon length and cannon weight. Carcass weight with cannon length, with cannon weight, and with cannon weight per unit length are all of a similar efficiency of estimation which is only slightly less satisfactory than that furnished by the three-independent-variate regression. The standard error of estimate of carcass muscle provided by the combination of cannon length and cannon weight is considerably greater than that of any regression incorporating carcass weight.

In all the equations containing carcass weight this variate carries most of the predictive value of the regression, as may be judged from the level of significance of the carcass weight partial regression coefficients, from the magnitude of the changes in these

TABLE 17

Correlations Between Independent Variates - Ryegrass Strain Trial Series

Variates	Correlation Coefficient(r)
Carcass Weight : Cannon Length	0.01^{ns}
Carcass Weight : Cannon Weight	0.48^{**}
Carcass Weight : Cannon Weight per cm.	0.62^{**}
Carcass Weight : Humerus Length	0.26^{ns}
Carcass Weight : Humerus Weight	0.56^{**}
Carcass Weight : Humerus Weight per cm.	0.61^{**}
Cannon Length : Cannon Weight	0.54^{**}
Humerus Length : Humerus Weight	0.76^{**}
Cannon Length : Humerus Length	0.60^{**}
Cannon Weight : Humerus Weight	0.85^{**}

coefficients between regressions, and from an examination of the standard partial regression coefficients in Table 18.

Cannon length and cannon weight both contribute highly significant predictive information regarding the weight of carcass muscle when either is separately considered with carcass weight. However, taken together, and excluding carcass weight, cannon length does not add any significant information to that already supplied by cannon weight. A path coefficient diagram constructed from the correlation coefficients in Tables 14 and 17, and standard partial regression coefficients in Table 18 shows that the non-significance of this contribution arises from the fact that the influence of cannon length is expressed almost wholly through cannon weight.

When carcass weight is included as a third independent variate with cannon length and cannon weight the contributions of the bone measurements are significant at only the 5 per cent. level. This change in the predictive value of these variates is due to the fact that cannon weight is relatively closely related to carcass weight ($r = 0.48$) while cannon length and carcass weight are virtually unrelated ($r = 0.01$). Thus, the effect of cannon length on carcass muscle, although small ($r = 0.32$, significant at the 5 per cent. level), acts either directly or through cannon weight, but not through carcass weight, whereas approximately half of the effect of cannon weight on carcass muscle acts through carcass weight. Although cannon weight always gives more information regarding the dependent variate than does cannon

TABLE 18

Standard Partial Regression Coefficients - Ryegrass Strain Trial Series

Carcass Muscle on (a); (b) and (c) held constant

Independent Variates			Coefficient
a	b	c	
Carcass Weight	Cannon Length		0.83
Carcass Weight	Cannon Weight		0.65
Carcass Weight	Cannon Length	Cannon Weight	0.71
Carcass Weight	Cannon Weight per cm.		0.59
Carcass Weight	Humerus Length		0.73
Carcass Weight	Humerus Weight		0.44
Carcass Weight	Humerus Length	Humerus Weight	0.66
Carcass Weight	Humerus Weight per cm.		0.62
Cannon Length	Carcass Weight		0.31
Cannon Length	Cannon Weight		-0.07
Cannon Length	Carcass Weight	Cannon Weight	0.18
Cannon Weight	Carcass Weight		0.37
Cannon Weight	Cannon Length		0.72
Cannon Weight	Carcass Weight	Cannon Length	0.24
Cannon Weight per cm.	Carcass Weight		0.39
Humerus Length	Carcass Weight		0.41
Humerus Length	Humerus Weight		0.03
Humerus Length	Carcass Weight	Humerus Weight	0.30
Humerus Weight	Carcass Weight		0.59
Humerus Weight	Humerus Length		0.74
Humerus Weight	Carcass Weight	Humerus Length	0.17
Humerus Weight per cm.	Carcass Weight		0.35

length, it fails to provide any additional information when carcass weight is included as an independent variate; hence the changes in the predictive values of the partial regression coefficients.

The multiple regression equations incorporating humerus length and humerus weight provide smaller standard errors of estimate than the corresponding cannon bone regressions. Although humerus weight is more closely correlated to the dependent variate than is humerus length, the multiple regression on carcass weight and humerus length provides a slightly better estimate of carcass muscle than does that on carcass weight and humerus weight. Path coefficient diagrams are again helpful in interpretation. Humerus length is relatively closely related to carcass muscle (r = 0.60), but not to carcass weight (r = 0.26). Humerus weight, on the other hand, is more closely correlated with both carcass muscle (r = 0.76) and carcass weight (r = 0.56). In the regression on carcass weight and humerus weight much of the predictive information contributed by humerus weight is also supplied by carcass weight, whereas in the regression on carcass weight and humerus length a large proportion of the information furnished by humerus length is unique to that variate.

The relatively close correlation between the two humerus variates (r = 0.76) suggests that much of the predictive power of each is common to the other. The higher correlation of carcass muscle to humerus weight allows practically all of the influence of humerus length to act through humerus weight (0.57 of a total of 0.60), as was the case in the cannon relationships.

The above pattern of relationships is also responsible for the transference of highly significant predictive value from humerus weight to humerus length when carcass weight is included as a third independent variate. Humerus weight, which on its own gives a relatively good estimation of carcass muscle, supplies little information beyond that given by carcass weight, while only a small proportion of the predictive value of humerus length acts through this variate.

In the combination of carcass weight and humerus weight per cm. both independent variates provide highly significant information regarding the dependent variate. However, the multiple correlation coefficient fails to reach those of the other relationships incorporating carcass weight; the standard error of estimate furnished by carcass weight and humerus weight per cm. is correspondingly larger than those provided by these other regressions containing carcass weight, but is more satisfactory than that afforded by the combination of humerus length and humerus weight.

A comparison of the predictive powers of the cannon and humerus multiple regressions shows that, with the exception of the weight per cm. equations, the regressions on humerus variates furnish closer estimates of carcass muscle than do the corresponding regressions on cannon variates. The superiority of the cannon weight per cm. variate over the analagous humerus variate is again apparent in the multiple relationships. This advantage is too slight to detract from the superiority of the humerus as an index of the weight of muscular tissue in the carcass.

3. INTEGRATION OF 120 SERIES AND RYEGRASS STRAIN TRIAL DATA

It is the aim of this section to bring together the data from the 120 Series and the Ryegrass Strain Trial Series and to examine the possibilities of combining the separate classes and groups of those two series in the minimum number of biologically and biometrically homogeneous groupings. It has already been shown in the previous section that, after appropriate statistical techniques have been applied, the carcasses from the four pasture groups of the Ryegrass Strain Trial may be considered as one such comparable or homogeneous combination. The four classes of carcasses in the 120 Series and the single Ryegrass Strain Trial grouping offer several possibilities for such integration. Within the 120 Series the four classes may be combined by sex and by degree of maturity. There is also the possibility that all four classes can be fairly combined in one large grouping which might be extended to incorporate the Ryegrass Strain Trial Series. Should this prove unsound it may be admissible to combine the Ryegrass Strain Trial data with that of the 120 Series ewes, with that of the two female classes of the 120 Series, or with that of the two classes of 120 Series mature sheep.

Tests of heterogeneity of regression have again been used as the main criterion in judging whether two or more classes, groups, or series can be fairly combined. In cases where any dubiety existed after such tests the differences in correlation coefficients were tested, using Fisher's z transformation.

The homogeneity of the four 120 Series carcass classes may be determined by testing the significance of the differences in slope of the separate regressions. The application of this test to the 10 families of linear regressions in Table 7 is set out in Appendix IV. The appearance of differences significant at the 5 per cent. level in the regressions on carcass weight and on humerus weight per cm. fails to uphold the hypothesis that the four carcass classes can be considered as samples of the one population. The tests in Appendix IV also show that the differences between the coefficients of regression on the weight of the bones considered are greater (i.e., have higher variance ratios) than the differences between the regressions on the length of the same bone. The hypothesis that the four sample correlation coefficients in each family of relationships were drawn from a common population was also tested. This test which measures the strength, as opposed to the nature, of the relationship between two variables likewise showed that the four 120 Series classes could not be satisfactorily combined in one homogeneous grouping. The tests of correlation coefficients emphasised the greater differences between the correlations incorporating bone length than between those with bone weight, as was noted above in considering the results in Table 7.

As the 120 Series carcass classes cannot be justifiably considered as four samples of the one population it is unnecessary to test the possibility of combining the 120 Series and Ryegrass Strain Trial carcasses in one composite grouping. Two possibilities remain for reducing the number of classes in the 120 Series, viz., integration by sex and by degree of maturity. Examination of the correlation coefficients in Table 7 and Fig. 1 suggests that combination by degree of maturity, i.e., into mature sheep and lambs, is the more sound of the two possibilities. This means of division and integration is supported by biological considerations and by the tests of heterogeneity of regression in Appendices V and VI. Making due allowance for the difference in degrees of freedom between these two classes, the variance ratios indicate smaller differences between the two classes of mature sheep than between the two classes of lambs, although in both cases these differences are non-significant.

Thus, the number of carcass classes in the 120 Series has been halved, leaving three categories in all, viz., 120 Series mature sheep, 120 Series lambs, and the Ryegrass Strain Trial Series. The last mentioned series has more in common with the 120 Series mature sheep than with the lambs, and the next step must be an examination of the possibilities of combining these two groupings of mature sheep. Carcass weight, humerus length, humerus weight, and humerus weight per unit length are the only independent variates common to the 120 Series and Ryegrass Strain Trial data. In examining the bases for pooling the available data pertaining to mature sheep the ewes and wethers of the 120 Series have been considered separately and not as a combination, there being no biological or biometrical reasons to assume a greater degree of similarity between these two classes than between either class and the Ryegrass Strain Trial Series. Tests of the coefficients of regression of carcass muscle on the four independent variates common to the three groupings fail to reveal any significant differences between the groupings (Appendix VII). Tests of correlation coefficients likewise fail to demonstrate any disparity, and further strengthen the hypothesis that the three groupings may be considered as separate samples drawn from the same population, thus allowing them to be statistically treated as one composite sample of that population.

It thus appears that the most satisfactory manner of combining the original eight carcass classes and groups in the minimum number of composite groupings is in respect to degree of maturity. The tests of heterogeneity of regression outlined in Appendices II and VII and supported by similar tests of the corresponding correlation coefficients, allow the six classes and groups of mature sheep (i.e. those from the four pasture types of the Ryegrass Strain Trial together with the ewes and wethers of the 120 Series to be fairly considered as samples of one population. These same tests also show that the two classes of lambs may be regarded as samples of a different population.

4. 120 SERIES MATURE SHEEP

The aim of the preceding section was defined as the integration of all available data to form the minimum number of biologically and biometrically comparable carcass groupings. However, it is worthwhile going back one stage to consider the results afforded by the combined ewe and wether classes of the 120 Series, before these are incorporated with the Ryegrass Strain Trial carcasses in the composite mature sheep grouping. The results relating to the Ryegrass Strain Trial data presented in Section 2 of this chapter are complete in themselves, and it is desirable to treat the 120 Series mature sheep and lambs similarly, as a complement to the published results of the original investigation. Apart from the direct comparison of the two stages of maturity contained within the one series, this treatment also allows a comparison of lambs and mature sheep to be made over a larger number of variates than is possible when the Ryegrass Strain Trial carcasses are included in the mature sheep grouping.

The linear regression equations and zero order correlation coefficients relating carcass muscle in the 120 Series mature sheep to carcass weight and to radius-ulna, humerus, tibia and femur measurements are summarised in Table 19. The zero order

TABLE 19

Relationships Between Weight of Muscular Tissue in Carcass and Other Variates - 120 Series Mature Sheep

Dependentent Variate = Weight of Muscular Tissue in Carcass (kg.)(Y_1)

Independent Variate	Correlation Coefficient(r)	Regression Equation	$S_{y.x}$(kg.)	$S_{y.x}$ as % $\bar{y}$
Carcass Weight (kg.)	0.85**	$Y_1=0.30X + 5.30$	1.03	7.53
Radius-ulna Length (cm.)	0.37*	$Y_1=0.83Rl - 2.63$	1.82	13.31
Radius-ulna Weight (g.)	0.73**	$Y_1=0.13Rw + 2.14$	1.36	9.95
Humerus Length (cm.)	0.38**	$Y_1=1.25Hl - 4.82$	1.81	13.24
Humerus Weight (g.)	0.71**	$Y_1=0.11Hw + 1.47$	1.38	10.10
Humerus Weight per cm. (g.)	0.74**	$Y_1=2.15Ht - 2.77$	1.32	9.66
Tibia Length (cm.)	0.32*	$Y_1=0.73Tl - 1.04$	1.85	13.53
Tibia Weight (g.)	0.68**	$Y_1=0.09Tw + 2.92$	1.45	10.61
Femur Length (cm.)	0.50**	$Y_1=1.18Fl - 7.30$	1.70	12.44
Femur Weight (g.)	0.65**	$Y_1=0.07Fw + 4.01$	1.48	10.83

Number of Observations = 47

correlation coefficients presented in Table 19 and in the subsequent tables of results referring to the combined grouping have been derived from weighted z values. The computation of multiple correlation coefficients and partial regression coefficients has been based on values of r calculated from pooled sums of squares and crossproducts. The justification for this procedure, and the degree of similarity between the two values of r have been considered under the heading of "Statistical Methods" in Chapter III.

The combination of the ewe and wether classes (Table 19) does little to alter the relationships given for the separate classes in Table 7. The correlation coefficients, regression coefficients and standard errors of estimate supplied by the combined grouping are all intermediate in respect to the two original classes. The sole exception to this is the standard error of estimate provided by humerus weight ($S_{y.x}$ = 1.38 kg.) which is lower than that furnished by either the ewe or wether classes ($S_{y.x}$ = 1.41 kg. in both instances.) However, the greater number of degrees of freedom afforded by the combination of these classes has the effect of changing the level of probability at which the correlation coefficients attain significance. Thus, although the correlations between carcass muscle and radius-ulna length in the ewe and wether classes (0.36 and 0.38, respectively, Table 7) are non-significant, the combined class correlation coefficient of 0.37 (Table 19) just fails to attain significance at the 1 per cent. level.

Thus, the general picture supplied by the 120 Series mature sheep is that the most satisfactory prediction of carcass muscle is given by carcass weight; bone weights provide better estimates than do the lengths of the same bones; and the single bone weight per unit length variate is slightly superior in predictive worth to the absolute weight variate. There is a close similarity between the two sets of correlation coefficients and standard errors of estimate furnished by the weight variates of the radius-ulna and humerus, and also between those provided by the tibia and femur weights. The advantage in efficiency of prediction enjoyed by the weights of bones of the anterior limb is too small to be categorically classified as real. No such difference is apparent in the relationships with the length variates in the mature sheep, or with either the weight or length variates in the lamb classes.

As stated above, the ewe and wether grouping of the 120 Series is not regarded as a final entity; the ultimate consideration of mature sheep must include those from the Ryegrass Strain Trial. For this reason, and because of the lack of additional information obtained from combining these two 120 Series classes, the multiple correlations and regression equations relating to this intermediate grouping are not included in the tables of results.

5. 120 SERIES LAMBS

The zero order correlation coefficients and linear regression equations relating to the combined grouping of 120 Series ewe and

TABLE 20

Relationships Between Weight of Muscular Tissue in Carcass and Other Variates - 120 Series Lambs

Dependent Variate = Weight of Muscular Tissue in Carcass (kg.)(Y_1)

Independent Variate	Correlation Coefficient(r)	Regression Equation	$S_{y.x}$(kg.)	$S_{y.x}$ as % $\bar{y}$
Carcass Weight (kg.)	0.92^{**}	$Y_1=0.43X + 1.46$	0.54	6.07
Radius-ulna Length (cm.)	0.75^{**}	$Y_1=0.94Rl - 6.67$	0.91	10.24
Radius-ulna Weight (g.)	0.82^{**}	$Y_1=0.12Rw + 1.37$	0.78	8.77
Humerus Length (cm.)	0.65^{**}	$Y_1=1.22Hl - 6.72$	1.05	11.81
Humerus Weight (g.)	0.78^{**}	$Y_1=0.08Hw + 2.23$	0.87	9.79
Humerus Weight per cm. (g.)	0.72^{**}	$Y_1=1.27Ht + 0.78$	0.94	10.57
Tibia Length (cm.)	0.61^{**}	$Y_1=0.80Tl - 5.05$	1.07	12.04
Tibia Weight (g.)	0.82^{**}	$Y_1=0.10Tw + 0.78$	0.79	8.89
Femur Length (cm.)	0.69^{**}	$Y_1=1.04Fl - 7.04$	0.98	11.02
Femur Weight (g.)	0.81^{**}	$Y_1=0.06Fw + 2.28$	0.82	9.22

Number of Observations = 60

wether lambs are given in Table 20. As with the results from the 120 Series mature sheep in Table 19 this pooling of classes fails to provide any closer estimation of carcass muscle than that already given by the better of the two original classes. All correlation coefficients, regression coefficients and standard errors of estimate supplied by the combined grouping lie between those of the original ewe and wether lamb classes. In this instance there is no evidence from the ranking of the correlation coefficients or standard errors of estimate of any pattern of superiority in predictive ability of particular bones. There is nothing to suggest that the length or weight measurements of the bones of the anterior limbs are better or worse indices than those of the posterior limbs, nor is there any advantage of proximal bones over distal ones, or _vice versa_.

The combined lamb class multiple relationships in Table 21 provide little information that could not have been obtained from the same relationships calculated on an individual class basis (Table 10). The multiple correlation coefficients, partial regression coefficients and standard errors of estimate supplied by the pooled data are no more satisfactory than those given by the better of the two original classes. The reiteration of the merits and demerits of the different combinations of independent variates will serve little purpose at this stage. It is sufficient to point again to the predictive importance of the carcass weight variate. The partial and standard partial

TABLE 21

Multiple Relationships Between Weight of Muscular Tissue in Carcass and Other Variates - 120 Series Lambs

Dependent Variate = Weight of Muscular Tissue in Carcass (kg.) (Y_1)

Independent Variates	Correlation Coefficient(R)	Regression Equation	$S_{y.x}$(kg.)	$S_{y.x}$ as % $\overline{y}$
Carcass Weight(kg.) Humerus Length(cm.)	0.93^{**}	$Y_1=0.38X^{**}+0.33Hl^{**}-2.02$	0.51	5.74
Carcass Weight(kg.) Humerus Weight(g.)	0.94^{**}	$Y_1=0.34X^{**}+0.03Hw^{**}-0.43$	0.45	5.06
Humerus Length(cm.) Humerus Weight(g.)	0.77^{**}	$Y_1=0.18Hl^{ns}+0.07Hw^{**}+0.55$	0.87	9.79
Carcass Weight(kg.) Humerus Length(cm.) Humerus Weight(g.)	0.94^{**}	$Y_1=0.34X^{**}-0.01Hl^{ns}+0.03Hw^{**}+0.56$	0.46	5.17
Carcass Weight(kg.) Humerus Weight per cm.(g.)	0.94^{**}	$Y_1=0.35X^{**}+0.47Ht^{**}-0.26$	0.46	5.17

regression coefficients of this variate are little affected by the other variates which appear in the multiple regressions (Tables 21 and 23). The predictive worth of carcass weight is further emphasised by the appreciably lower correlation and higher standard error of estimate of the single relationship which does not include this variate.

It is noteworthy that the increased size of the combined grouping affects the level of significance of the contribution which certain independent variates make to the prediction of the weight of carcass muscle. In all cases carcass weight and humerus weight, both absolute and per unit length, make highly significant contributions to the predictive worth of the regressions in which they appear. In contrast to the multiple relationships given for the separate lamb classes in Table 10, humerus length, in conjunction with carcass weight, makes a highly significant contribution to the prediction of carcass muscle. However, where humerus length appears in the same regression as humerus weight, the variate with which it is most closely correlated, it fails to supply significant predictive information; the major part of the contribution of humerus length is already supplied by humerus weight which is more closely related to the dependent variate. The inclusion of humerus length with carcass weight and humerus weight does not increase the multiple correlation coefficient ($R = 0.94$), but does effect a small increase in the standard error of estimate as a consequence of the greater residual mean square which follows the removal of the degree of freedom associated with this additional variate.

TABLE 22

Correlations Between Independent Variates - 120 Series Lambs

Variates	Correlation Coefficient(r)
Carcass Weight : Humerus Length	0.55^{**}
Carcass Weight : Humerus Weight	0.65^{**}
Carcass Weight : Humerus Weight per cm.	0.60^{**}
Humerus Length : Humerus Weight	0.76^{**}

TABLE 23

Standard Partial Regression Coefficients - 120 Series Lambs

Carcass Muscle on (a); (b) and (c) held constant

Independent Variates			Coefficient
a	b	c	
Carcass Weight	Humerus Length		0.82
Carcass Weight	Humerus Weight		0.72
Carcass Weight	Humerus Length	Humerus Weight	0.72
Carcass Weight	Humerus Weight per cm.		0.75
Humerus Length	Carcass Weight		0.17
Humerus Length	Humerus Weight		0.09
Humerus Length	Carcass Weight	Humerus Weight	-0.01
Humerus Weight	Carcass Weight		0.30
Humerus Weight	Humerus Length		0.70
Humerus Weight	Carcass Weight	Humerus Length	0.30
Humerus Weight per cm.	Carcass Weight		0.27

6. MATURE SHEEP

The composite mature sheep classification incorporates data from the 120 Series ewe and wether carcass classes, and from the four Ryegrass Strain Trial pasture groups. The principal advantage arising from the integration of these data lies in the increased number of observations on which the correlations and prediction equations are based. This advantage is offset to a certain extent by the fact that there are only four independent variates common to the component classes and groups, viz., carcass weight and the three humerus variates. Where the relationships of carcass muscle to bones other than the humerus are of particular interest, as is the case with the cannon, reference must be made to the results presented for the original carcass classes and groups.

The linear relationships of carcass muscle to the four independent variates (Table 24) follow essentially the same pattern as seen in the component classes and groups. Carcass weight is the most closely correlated to carcass muscle and provides the lowest standard error of estimate. Humerus weight gives a more satisfactory prediction of the dependent variate than does the length of that bone. The predictive value of the weight per cm. variate is very similar to that of absolute weight, and it is doubtful whether the incorporation of length in the ratio is of any advantage.

The multiple relationships presented in Table 25 follow

TABLE 24

Relationships Between Weight of Muscular Tissue in Carcass and Other Variates - Mature Sheep

Dependent Variate = Weight of Muscular Tissue in Carcass (kg.) (Y_1)

Independent Variate	Correlation Coefficient(r)	Regression Equation	$S_{y.x}$(kg.)	$S_{y.x}$ as% $\bar{y}$
Carcass Weight (kg.)	0.84^{**}	Y_1=0.28X + 5.11	0.94	7.32
Humerus Length (cm.)	0.49^{**}	Y_1=1.44Hl - 7.45	1.55	12.06
Humerus Weight (g)	0.73^{**}	Y_1=0.11Hw + 1.39	1.19	9.26
Humerus Weight per cm. (g.)	0.74^{**}	Y_1=2.02Ht - 2.32	1.18	9.18

Number of Observations = 86

TABLE 25

Multiple Relationships Between Weight of Muscular Tissue in Carcass and Other Variates - Mature Sheep

Dependent Variate = Weight of Muscular Tissue in Carcass (kg.) (Y_1)

Independent Variates		Correlation Coefficient(R)	Regression Equation	$S_{y.x}$(kg.)	$S_{y.x}$ as % $\bar{y}$
Carcass Weight(kg.)	Humerus Length(cm.)	0.86^{**}	$Y_1 = 0.26X^{**} + 0.65Hl^{**} - 3.44$	0.88	6.85
Carcass Weight(kg.)	Humerus Weight(g.)	0.89^{**}	$Y_1 = 0.21X^{**} + 0.05Hw^{**} - 1.25$	0.79	6.15
Humerus Length(cm.)	Humerus Weight(g.)	0.74^{**}	$Y_1 = 0.70Hl^{ns} + 0.13Hw^{**} + 8.60$	1.17	9.11
Carcass Weight(kg.)	Humerus Length(cm.) Humerus Weight(g.)	0.89^{**}	$Y_1 = 0.21X^{**} - 0.20Hl^{ns} + 0.06Hw^{**} + 3.32$	0.79	6.15
Carcass Weight(kg.)	Humerus Weight per cm.(g.)	0.89^{**}	$Y_1 = 0.21X^{**} + 1.00Ht^{**} - 0.41$	0.80	6.23

TABLE 26

Correlations Between Independent Variates - Mature Sheep

Variates		Correlation Coefficient (r)
Carcass Weight :	Humerus Length	0.32^{**}
Carcass Weight :	Humerus Weight	0.57^{**}
Carcass Weight :	Humerus Weight per cm.	0.59^{**}
Humerus Length :	Humerus Weight	0.76^{**}

TABLE 27

Standard Partial Regression Coefficients - Mature Sheep

Carcass Muscle on (a), (b) and (c) held constant

Independent Variates			Coefficient
a	b	c	
Carcass Weight	Humerus Length		0.77
Carcass Weight	Humerus Weight		0.63
Carcass Weight	Humerus Length	Humerus Weight	0.62
Carcass Weight	Humerus Weight per cm.		0.63
Humerus Length	Carcass Weight		0.21
Humerus Length	Humerus Weight		-0.22
Humerus Length	Carcass Weight	Humerus Weight	10.06
Humerus Weight	Carcass Weight		0.37
Humerus Weight	Humerus Length		0.89
Humerus Weight	Carcass Weight	Humerus Length	0.42
Humerus Weight per cm.	Carcass Weight		0.36

the now well-established pattern. Carcass weight and humerus weight, considered separately, together, or in conjunction with a third variate, contribute highly significant predictive information regarding the weight of carcass muscle. Humerus length makes a highly significant contribution in the regression with carcass weight, but fails to supply any new knowledge when incorporated in relationships with humerus weight. The inclusion of humerus length as a third independent variate fails to increase the multiple correlation coefficient or to decrease the standard error of estimate. Path coefficient diagrams constructed from the zero order correlation coefficients in Tables 24 and 26, and from the standard partial regression coefficients in Table 27 show that an appreciably higher proportion of the relationship between humerus length and carcass muscle than of that between humerus weight and carcass muscle acts through carcass weight. The relatively high correlation between humerus weight and length ($r = 0.76$) infers that a high proportion of the predictive worth of one is common to the other. As humerus weight is more closely related to and gives a better estimate of the dependent variate than does humerus length it is the weight variate which absorbs the information offered by length. The weight per cm. length variate retains its relative predictive value in the multiple relationships. Although appreciably superior to bone length it fails by a small margin to attain the level of prediction furnished by bone weight.

CHAPTER V

DISCUSSION

The results presented in Chapter IV show that carcass weight affords a more satisfactory estimate of the weight of carcass muscular tissue than does any of the other variates examined. The consistently superior predictive powers of carcass weight are apparent in all stages of the foregoing analyses, from the individual classes of the 120 Series to the ultimate and larger classifications of lambs and mature sheep. The interpretation of this finding cannot be stated in definite terms, but, in seeking a reason for the greater predictive worth of carcass weight, the part-whole nature of the relationship between carcass muscle and carcass weight should not be overlooked.

The tests of heterogeneity of regression employed in examining the possibilities of combining different carcass groupings indicate the presence of a significant age difference in the relationships between the weight of carcass muscle and carcass weight. This age difference, noted throughout the results, is consistent with the hypothesis of differential growth rates between the carcass tissues, as outlined by Hammond (1932). Hammond's thesis would suggest a greater deposition of fatty tissue, and a lesser increase in the weight of muscular tissue, per unit increase in carcass weight, in mature sheep than in lambs. The larger regression coefficients noted in the individual lamb classes and the combined grouping, as compared with those of any category of mature sheep, demonstrate the more rapid growth of muscular tissue in the younger individuals. The closer correlations between carcass weight and the weight of carcass muscle, and the narrower limits of prediction of carcass muscle afforded by carcass weight in the lambs, as opposed to the older sheep, may be attributed to the differential development of the carcass components which results in the muscular tissue forming a greater proportion of carcass weight in the younger sheep. This closer part-whole relationship in the lamb carcasses would have the effect of increasing the correlation between these two variates, and would allow a more satisfactory prediction of the component in question (carcass muscle) from the weight of the whole (carcass weight).

The literature contains little information regarding the relationships between carcass weight and carcass muscle in sheep. The main contribution in this respect is that of Barton and Kirton (1958a), but, as their work was based largely on the 120 Series data used in the present study, only limited comparisons may be made between their results and those under discussion. The Ryegrass Strain Trial results presented in Chapter IV constitute a new contribution to the knowledge in this field. The similarity of the relationships derived from this source and those of the 120 Series, presented here and by Barton and

Kirton, substantiate the conclusions of these latter workers that, in certain circumstances, carcass weight is capable of providing a satisfactory estimate of the weight of carcass muscular tissue.

Shorland, de la Mare, Sorrell and Barnicoat (1947) have also commented on the use of carcass weight in the determination of carcass composition. The present results are at variance with the opinion expressed by these workers that the use of carcass weight in the estimation of carcass composition is limited to within-sex determinations. The tests employed in the combination of carcass classifications showed no evidence of sex differences in the regressions of carcass muscle on carcass weight. Although the data do not permit an assessment of the effect of breed differences, they support the contention of Shorland et al. regarding the inadequacy of this approach to overcome differences in growth rate, in as far as the classifications of lambs and mature sheep are characterised by such differences.

The correlations noted between carcass muscular tissue and carcass weight were, in all instances, higher than that reported for cattle by Cole, Orme and Kincaid (1960).

The results show that the weight of carcass muscular tissue is more closely correlated with bone weight than with bone length, regardless of age or sex. This finding bears out the contention of Lush (1928) regarding the greater descriptive powers of weights as opposed to linear measurements.

The closer relationship to and superior prediction of carcass muscle afforded by bone weights may be attributed to the more comprehensive nature of weight measurements in general. As previously indicated, the weight of a bone is the resultant of all internal and external dimensions and of the densities of the bony and marrow substances, and thus might be expected to furnish a description more typical of the whole than can be supplied by a single linear dimension.

The marked age differences in the correlations between carcass muscle and bone length are not easily interpreted. The poor, and frequently non-significant, relationships in the mature sheep, as compared with the highly significant relationships found in the lambs may be most readily interpreted in terms of the differential growth between and within the tissues of the carcass, as outlined on many occasions by members of the Hammond School. It may be reasoned that, at the time of cessation of growth in bone length following epiphyseal ossification, the muscular tissue in the carcass would still be actively increasing in weight. It might also be reasonable to expect that at this point the correlation between bone length and the amount of carcass muscular tissue would be at a maximum, and that, as the animal ages, the relationship between the now static bone length and the still growing muscular tissue would decrease. Thus, because the lambs are closer in time to that point where increase in bone length is halted than are the mature sheep, the bone length variate in those younger sheep is more closely related to and affords a better prediction of the weight of carcass muscle than is the case in the older individuals.

Age differences are also apparent, but to a less marked extent, in the relationships between bone weight and carcass muscle. Although the appropriate tests show that the differences in these relationships are not sufficiently large to be significant at the accepted levels of probability, their consistent appearance throughout the results does not allow them to be disregarded. The existence of these age differences may also be attributed to the earlier maturation of the skeleton than of muscular tissue, as hypothesised by the Hammond School. The lesser magnitude of the differences in the correlations with bone weight as compared to those discussed in connection with bone length may be due to the fact that skeletal maturation involves the cessation of growth in dimensions other than length, and consequently is not attained until some time after growth in length has ceased. If the correlation between the weight of a bone and the weight of the carcass musculature can be considered to be at a maximum at the time of the maturation of that bone, then the relationship between these variates in two ages of sheep will be greater in the age group which is nearer in time to the point at which this maturation occurs. This new hypothesis, then, is capable of providing an explanation of the predictive advantage of bone weight in the lambs, as compared with mature sheep, and of the lesser magnitude of this advantage relative to that noted for the relationships incorporating bone length.

The literature relating to the dynamics of bone would indicate, however, that the "maturation" of the skeleton or of a particular bone is not as clear-cut and well defined as may have been suggested in interpreting the relationships discussed above in terms of the long-established hypotheses of the Hammond School. The literature shows that nutritional and other factors may effect changes in certain bone dimensions and in bone density, in both immature and adult individuals, and it is thus evident that bone weight is not necessarily invariable subsequent to the attainment of this somewhat theoretical point of skeletal or bone maturity. These considerations do not, however, imply that the hypothesis postulated in the interpretation of the relationships between bone weight and carcass muscle is of no value, but rather that it may be inadequate to describe completely the relationship between these two variates and the effects of age upon this relationship.

The studies of Pálsson and Vergés (1952) on the differential effects between and within the tissues of the sheep carcass of a less than optimal plane of nutrition provide an interpretation of the significant difference noted in the Ryegrass Strain Trial pasture-group regressions of carcass muscle on cannon weight. The tests of the effects of pasture type on the variates studied reveal that the probability of significant differences between pasture groups is less for the cannon length and weight variates than for the corresponding humerus variates, the weight of carcass muscular tissue, and carcass weight. It can be reasoned that the differences caused by pasture type in the weight of carcass muscle, in carcass weight, and in humerus length and weight would be proportionate, and, because of this, that the relationships between these variates would remain unchanged. The results suggest that this is indeed the case. The results also indicate, in agreement with the findings of Pálsson and Vergés, that the variates of the earlier maturing cannon bones are affected to an appreciably lesser extent by pasture type than the variates of the other and later-maturing characters, and it would thus be expected that the relationships between the cannon variates and the weight of carcass muscle would also be affected. This line of reasoning might be used to interpret the appearance of the difference in the pasture-group regressions on cannon weight, but to be wholly acceptable a similar or greater difference would have to be demonstrable in the regressions of cannon length, as it is generally considered that bone length is an earlier-maturing character than bone weight. The results fail to show any evidence of a significant difference in the regressions on cannon length. Thus, it would appear that the differential effect of nutritional regime on early- and late-maturing characters is inadequate to explain the difference noted in the pasture-group regressions of carcass muscle on cannon weight.

The literature shows that the weight : length ratio of a bone has frequently been used as a measure of bone thickness.

However, there is also a considerable body of evidence which would indicate that bone density is subject to considerable variation, and for this reason the quotient of bone weight/bone length is considered here as measuring only the weight per unit length of a bone. Although this variate will undoubtedly be greatly influenced by the dimension of thickness, it is felt that any interpretation of the results obtained from the use of this quotient is inadequate without a consideration of the possible effects of bone density.

The results indicate that bone weight per cm. increases with age, and that this variate is greater in males than in females. This observation may be interpreted in terms of the findings of Hammond (1932) and many later workers that growth in thickness occurs mainly at a later stage than growth in length, and that males generally have thicker bones than females. A second complementary interpretation comes from the work of Kraybill, Hankins and Farnworth (1954) who demonstrated that, in cattle, bone density increases with age. Thus, the greater bone weight per cm. noted in the mature sheep may be attributed to the combined effects of increased thickness and increased density. The finding of Kraybill <u>et al.</u> that females tend to have bones of higher density than males is, however, at variance with the observation of the greater bone weight per cm. noted in the males in the present study, if the effects of sex on bone density are similar in cattle and sheep. The reconciliation of these findings requires the conclusion that the sex effects of bone thickness on the weight per cm. variate are greater than those of density.

A comparison of the indicatory or predictive values of the absolute weight and weight per cm. variates shows that in the lambs bone weight *per se* is somewhat more closely related to and gives a better prediction of the weight of carcass muscle than does the weight per cm. variate. In the mature sheep, however, the position is reversed, and bone weight per cm. is the more closely correlated with carcass muscle and enjoys a small predictive advantage over the absolute weight variate. In all cases bone length is inferior to the absolute and per cm. weight variates as an index of carcass muscle.

There is no unequivocal evidence of any age effects in the correlations incorporating bone weight per cm., but the results show a marked and significant age difference in the regressions of carcass muscle on this variate. The interpretation of the ranking of the coefficients of regression on bone weight per cm. requires a consideration of the differential rates of growth of bone and muscle. Because of the age changes in bone thickness and density, the weight per unit length of a bone increases with age up to what Hammond and others visualise as a point of skeletal maturity, where bone weight per unit length is assumed to become at least relatively constant. Thus, because of the continued growth of muscular tissue beyond this point of skeletal maturity, a lesser increment in bone weight per cm. is required to produce a certain stated increase in the weight of carcass muscle in a group of sheep which is close to that point at which the age changes in bone weight per cm. are least, than is the case in a younger group in which bone weight per cm. is still increasing.

The regressions on bone weight per cm. also suggest the presence of sex differences which might be interpreted in terms of the hypothesis outlined with regard to the age differences. On the basis of this hypothesis the larger regression coefficients observed in the wethers and wether lambs are attributable to the later skeletal maturity of males, as noted by Hammond (1932), and to the greater degree of development attained by males in their ultimate maturity. This is also exemplified in the data under discussion.

If Hammond's concept of the maturity of the carcass components were adequate to describe the quantitative relationships between bone and muscle, and if the hypothesis postulated regarding the decrease in correlation between these tissues following the maturation of the bone in question were acceptable, then it would be reasonable to expect that the later-maturing bones would provide more reliable information regarding the carcass musculature than would the earlier-maturing bones. However, the degrees of relationship between the bone variates studied and the weight of carcass muscle, and the efficiencies of prediction of carcass muscle afforded by these variates, fail to show a consistently superior indicatory value of any one bone. There is a suggestion from the Ryegrass Strain Trial analyses that the length and absolute weight variates of the later-maturing humerus provide a more satisfactory index of carcass muscle than do the corresponding variates of the earlier-maturing cannon, but this observation is not supported by the results obtained from the use of the weight per cm. variates. The general conclusion in this respect must be that there is no consistent pattern of superiority to be found in comparisons of the predictive worth of the more proximal bones with that of the more distal ones, nor are the bones of the hind limb consistently better or worse indices than those of the fore limb.

An examination of the coefficients of regression of carcass muscle on the lengths and weights of the different bones points to one reason why no single bone is of superior indicatory value as regards both the length and the weight variates. The coefficients of regression on humerus length, for example, are in all instances greater than those on radius-ulna length, but in the regressions on the weights of these bones the ranking order is reversed in every case. The same pattern is also evident in the corresponding comparisons of tibia and femur. The explanation of this consistent and, at first sight, surprising change in the relative sizes of these regression coefficients lies in the fact that, although the radius-ulna is a longer bone than the humerus, the latter is the heavier of the two. Similarly, the femur is heavier, and at the same time shorter, than the tibia. Thus, as might be anticipated, and as the regression coefficients show, one unit of increase in the length of the shorter of two bones is associated with a greater increment in carcass muscle than is a similar linear increase in the second and longer bone; an increase of one unit in the weight of that shorter bone, however, is not accompanied by as great an increment in carcass muscle as is a similar weight increase in the longer but less heavy bone.

It is not unreasonable to suppose that the bones studied might provide a more satisfactory prediction of the amount of muscular tissue in the anatomical joint in which they are contained than of the total weight of muscular tissue in the carcass. To this end the relationships between the different bone variates and the weights of muscular tissue in the appropriate joints were examined with a view to comparing the predictive powers of those variates on a carcass and a sample joint basis. The results indicate, however, that the bones of the fore limb are no more closely related to the weight of muscular tissue in the shoulder than to the weight of total carcass muscle, nor do they afford any closer predictions of the shoulder musculature than of that in the carcass. Similarly, the relationships between the bones of the hind limb and the weight of muscular tissue in the leg are little or no better than those derived on a carcass muscle basis. The similarities in the limits of prediction on a sample joint and carcass basis may be attributed to the very high correlations between the weights of muscular tissue in the shoulder and leg joints and that in the carcass, as demonstrated by Barton and Kirton (1958<u>b</u>).

It was noted in Chapter IV that the radius-ulna and humerus variates gave slightly better estimates of carcass muscle than of shoulder muscle in all carcass classes except the wethers, and that the tibia and femur variates provided closer predictions of leg muscle than of carcass muscle in all instances except the wether lambs. The differences in the standard errors of estimate are very small and it is unlikely that they are real. Nevertheless, the consistent pattern of these differences suggests the operation of some factor such as the later maturity of males and/or the more advanced stage of development attained by males in their maturity. Barton and Kirton (1958<u>b</u>) examined the relationships between the weights of leg muscle and carcass muscle in all four 120 Series carcass classes, and between the weights of shoulder muscle and carcass muscle in the ewe and the wether lamb classes, but their results offer no interpretation of the differences under discussion. It is felt that the data do not allow the postulation of any hypotheses regarding the cause of these differences, and that it is sufficient to note that there is a suggestion of possible sex differences in the efficiency with which bone measurements can estimate the amount of muscular tissue in a sample joint as compared with that in the carcass as a whole.

Although no significant differences were recorded in the correlations between carcass weight and the weights of muscular tissue in the shoulder and leg or in the carcass, the consistent pattern of superiority of the correlations and standard errors of estimate of muscle weight derived on a carcass basis does not permit these differences to be ignored. The close relationships between the weight of muscular tissue in the joints and the total weight of carcass muscle would suggest the narrower part:whole ratios involved in the relationships between carcass weight and carcass muscle as the major cause of their superiority.

The results indicate that the efficiency of estimation of the weight of muscular tissue in the carcass can be improved by the use of multiple regression equations incorporating independent variates which are not closely related to each other. The multiple relationships emphasise the predictive worth of carcass weight noted in the discussion of the linear regressions. These multiple relationships also show that, although bone weight is of inferior indicatory value to carcass weight, it supplies more information regarding the weight of carcass muscle than does bone length. The bone length variate occupies an unsatisfactory position in the multiple regressions, principally because of its close relationship to bone weight which incorporates much of the contribution offered by this variate. Despite the fact that the contribution of bone length to the prediction of carcass muscle is frequently non-significant, the inclusion of this variate is effective in reducing the standard error of estimate in many cases, although in certain instances where its contribution is virtually zero, the loss of the degree of freedom associated with bone length results in an increase in the limits of prediction. The contributions of the bone weight per cm. variate justify its inclusion in the multiple regressions with carcass weight. The results show, however, that the efficiency of prediction afforded by the ratio of weight to length is not as great as that supplied by the combination of the two absolute variates in a multiple regression equation.

It is apparent from the results that an increase in the number of observations beyond the size of the original classes and groups does little to improve the efficiency of estimation of carcass muscle. However, the larger groupings allow the assessment of the indicatory value of the more "marginal" variates to be made with greater confidence, and on the basis of the two final classifications, viz., mature sheep and 120 Series lambs, it would appear that there is no predictive advantage to be gained by the incorporation of bone length in a multiple regression which includes both carcass weight and bone weight as independent variates.

Although the multiple regressions provide more satisfactory estimates of the weight of carcass muscle than do the linear equations, they do not yield any information which is of value in the further interpretation of the relationships of bone to muscle in the sheep.

A consideration of the results in relation to the literature on bone-muscle relationships yields some points of interest. It has been noted in an earlier chapter that the cliché "the shorter and thicker the bone, the greater the amount of muscular tissue" arises from a misunderstanding of the studies of the effects of domestication and improvement of meat animals, and that although McMeekan (1956) has put forward this contention in regard to beef carcasses, his earlier work on the pig (McMeekan, 1940, 1941), together with that of Zimmerman (1956a) and others indicates that bone length is positively related to the amount of muscular tissue in the carcass. The results of this present study show that in lambs there is a highly significant positive correlation between bone length and the weight of carcass muscle. Although these variates are not as closely related in mature sheep as they are in lambs, and in spite of the negative but non-significant partial coefficients of regression of carcass muscle on bone length noted in a few instances, the results indicate that longer bones are associated with greater amounts of muscular tissue than are shorter bones. The highly significant positive correlations between bone weight per cm. and carcass muscle do support the view that bone thickness is indicative of the degree of development of the musculature, in as far as bone weight per cm. can be considered an index of bone thickness.

McMeekan (1956) has also claimed a strong positive correlation between the weight of a bone and the weight of carcass muscle. While the results under discussion show that bone weight is more closely related to the weight of carcass muscle than is any other bone variate studied, they also indicate that bone length is a major factor contributing to bone weight, and thus add support to the contention that bone length and muscle weight are positively related. With regard to the correlation between bone weight and muscle weight McMeekan (1956) considers this relationship so strong that the weight of carcass muscle can be estimated to within one per cent. of the actual weight from a knowledge of cannon bone weight. Studies by Wythe (1958), Orts (1959), Orts and King (1959), Orme, Pearson, Bratzler and Magee (1959), and Wythe, Orts and King (1961) have failed to demonstrate that cannon weight can supply a prediction of the weight of muscular tissue in beef carcasses within the limits claimed by McMeekan. The standard error of estimate of carcass muscle afforded by cannon weight in the Ryegrass Strain Trial Series ($S_{y.x}$ = 9.11 per cent.) indicates that McMeekan's claim is likewise ill-founded with respect to mutton carcasses. In the same Series the humerus weight variate gives a more satisfactory prediction ($S_{y.x}$ = 8.10 per cent.) than does cannon weight, but this is still substantially outside the limits quoted by McMeekan. It is possible, however, that the relationship of bone to muscle in sheep differs appreciably from that in cattle. The correlation between cannon weight and carcass weight ($r = 0.48$) noted in the present study, although highly significant, is appreciably lower than that demonstrated by Orts and King (1959) in beef cattle ($r = 0.95$). If this distinction between species is real, and if carcass weight carries a similar efficiency of prediction of carcass muscle in cattle to that noted in sheep, it is to be expected that cannon weight would afford a closer prediction of carcass muscle in beef carcasses. Studies to date have not shown this to be the case.

It is appropriate at this juncture to consider briefly the lines of further work which the findings of this present study would suggest as being the most profitable. In many instances the weight per unit length of a bone has been used, without adequate justification, as a measure of bone thickness, and in a few cases measurements of bone thicknesses and widths *per se* have been employed, but, to the best of this writer's knowledge, no attempt has been made to relate these derived and absolute measurements. It was originally envisaged that the present study would help to clarify this point, but unfortunately the interaction of factors affecting the sole width measurement prohibited a valid appraisal of this relationship. It is submitted, for reasons outlined in Chapter II, that the relationship between the measurements of bone thickness or width and bone weight per unit length should be examined before the latter is further used as a substitute for an actual measurement.

The superior indicatory powers of bone weights as opposed to pure linear measurements have been attributed to the more comprehensive nature of the weight variates which are resultants of all internal and external dimensions and of the densities of the bony and marrow substances. It is possible, however, for two bones of markedly different form to have identical weights, and it might well be that a consideration of the factors contributing to bone weight would yield further information to that supplied by a composite weight variate. In this connection the present knowledge on bone dynamics and certain theoretical considerations would suggest that the studies of Zimmerman (1956<u>a</u>, 1956<u>b</u>) on the cross-section of long bones could be extended with advantage, and that, incorporated in the type of approach adopted by Kraybill, Hankins and Busworth (1954), this might yield a useful index of carcass muscle. The photometric technique of measuring leaf area in plants, as described by Watson (1959), could be adapted to provide a relatively simple means of assessing the linear and area measurements of bones which Kraybill <u>et al.</u> determined by the use of roentgenograms. The projection of the shadow of a bone on a photosensitive screen could also be used to give an accurate and objective measurement of area in any one plane, and would permit linear measurements to be made with greater ease and accuracy than can be achieved on the bone itself.

Although the carcass weight and bone length, weight, and weight per unit length variates employed in this study provide indices of the weight of carcass muscular tissue which are unquestionably simple and objective, the prediction afforded by these variates cannot be considered as either precise or reliable. The possible lines of further study outlined above could well result in the achievement of an index of carcass muscle which simultaneously fulfils the requirements of precision, simplicity, objectivity, and reliability as laid down in the opening chapters.

CHAPTER VI

SUMMARY AND CONCLUSIONS

1. A study of some aspects of the bone-muscle relationships in 146 New Zealand lamb and mutton carcasses is presented. The literature relating to the use of linear measurements and sample joints in the estimation of carcass composition, and particularly of the weight of carcass muscular tissue, is reviewed. Reports from the literature of certain points pertinent to the use of bone measurements as indices of carcass composition are also considered. The sources of the data employed in the study, the determination of the weights of muscular tissue and of the weights and linear measurements of bones, and the statistical methods applied to these variates, are outlined.

2. The original carcass classifications and the means by which these are integrated to form the ultimate groupings of lambs and mature sheep are described.

3. The results show that, of the variates studied, carcass weight is the most closely related to and provides the most satisfactory estimates of the weight of carcass muscular tissue. The superior predictive powers of carcass weight in the lamb classification ($S_{y.x}$ = 6.07 per cent.) as

compared with the mature sheep ($S_{y.x}$ = 7.32 per cent.) is considered to be due, at least in part, to the greater proportion of muscular tissue in the carcasses of the younger sheep.

4. Of the three bone variates studied, viz., total or absolute weight, weight per cm., and length, absolute weight is the most closely correlated with and affords the best predictions of the weight of carcass muscle. The younger sheep show evidence of an advantage over the older individuals with respect to the level of prediction supplied by bone weight. This is attributed to the younger sheep being nearer in time to that point at which skeletal maturation, as envisaged by Hammond, occurs.

5. The bone length variates studied are the most poorly related to and supply the least satisfactory estimates of the weight of carcass muscle of all the variates studied. The very marked predictive superiority of bone length in lambs as compared with mature sheep is interpreted in terms of the differential rates of growth of bone and muscle.

6. The relationships of bone weight per cm. length to the weight of carcass muscle, and the predictions of

carcass muscle afforded by the derived variate are very similar to those noted in connection with the absolute bone weight variate, being slightly superior to bone weight *per se* in the mature sheep and somewhat inferior in the lambs.

Differences noted in the regressions on bone weight per cm. are intelligible in terms of the later maturity of males, and of the greater degree of development attained by males in their maturity.

7. There is no evidence of a consistently superior indicatory value of any one bone. Comparisons of the predictive worth of the more proximal bones with that of the more distal ones fail to show any pattern of superiority; nor are the bones of the hind limb consistently better or worse indices of muscular tissue than those of the fore limb.

8. The most satisfactory levels of prediction of carcass muscle afforded by the linear regressions on the variates studied (cf. paragraph 3 above) leave much to be desired. The efficiency of estimation is improved by the use of multiple regression equations incorporating independent variates which are not closely related to each other. The combination of carcass weight and bone weight provides the lowest

standard error of estimate in both the lambs ($S_{y.x}$ = 5.06 per cent.) and the mature sheep ($S_{y.x}$ = 6.15 per cent.) Such levels of estimation can scarcely be considered as satisfactory in spite of the large variations noted in the weights of carcass muscle.

9. The results show that the length and weight variates of a bone are relatively closely related, and that, in a multiple regression incorporating bone weight, the length variate fails to contribute sufficient unique information regarding the weight of carcass muscle to justify its inclusion in the relationship.

10. The contributions of bone weight per cm. in multiple regressions with carcass weight are highly significant in all cases, but the levels of prediction afforded by this combination of variates fail to reach those of carcass weight with absolute bone weight.

11. The conclusions drawn from this study support certain of the early findings of Hammond and his co-workers in as far as their findings offer credible biological interpretations of the statistical results. In particular the results of the present study suggest:
(1) that wethers have longer and heavier bones than ewes,
(2) that wethers mature more slowly than ewes, but attain a more advanced stage of development in their

ultimate maturity,

(3) that the increase in the weight, and in the weight per unit length of a bone continues after growth in length has ceased,

(4) that there is a greater increase in the weight of muscular tissue per unit increase in carcass weight in lambs than in mature sheep, and

(5) that the increase in the weight of carcass muscular tissue continues after bone growth has ceased.

12. It is submitted that further studies in this field might, with advantage, consider the use of certain internal bone measurements and of estimates of density in addition to the variates more commonly employed in the search for a precise, simple, objective and reliable index of the weight of carcass muscular tissue. Some possible techniques for increasing the ease and accuracy with which bone measurements may be obtained are suggested. It is advocated that the relationship between bone thickness and weight per unit length be investigated before the latter is further used as a substitute for an actual measurement.

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APPENDICES

The data used in this thesis has been lodged with the Sheep Husbandry Department, Massey Agricultural College.

APPENDIX I

Tests of Interaction Between and Significance of Birthrank and Pasture Effects - Ryegrass Strain Trial Series

Source	d.f.	S.S.	M.S.	F	Sig.
		Weight of Muscular Tissue in Carcass (kg.)			
Interaction	8	43.38	5.42	1.00	N.S.
Birthrank	3	4.94	1.65	0.30	N.S.
Pasture	3	139.52	46.51	8.55	**
Error	24	130.59	5.44		
Total	38	318.43			
		Frozen Carcass Weight (kg.)			
Interaction	8	756.51	94.56	1.97	N.S.
Birthrank	3	228.79	76.26	1.59	N.S.
Pasture	3	1139.73	379.91	7.92	**
Error	24	1150.66	47.94		
Total	38	3275.69			
		Cannon Length (cm.)			
Interaction	8	0.70	0.09	0.57	N.S.
Birthrank	3	0.72	0.24	1.55	N.S.
Pasture	3	1.55	0.52	3.34	*
Error	24	3.73	0.16		
Total	38	6.70			
		Cannon Weight (g.)			
Interaction	8	110.11	13.76	0.91	N.S.
Birthrank	3	10.02	3.34	0.22	N.S.
Pasture	3	161.37	53.79	3.57	*
Error	24	361.71	15.07		
Total	38	643.21			

(Continued)

APPENDIX I (Continued)

Source	d.f.	S.S.	M.S.	F	Sig.
		Cannon Width (cm.)			
Interaction	8	0.42	0.05	5.00	**
Error	24	0.35	0.01		
Total	32	0.77			
		Humerus Length (cm.)			
Interaction	8	1.95	0.24	1.06	N.S.
Birthrank	3	1.43	0.48	2.07	N.S.
Pasture	3	4.82	1.61	7.00	**
Error	24	5.52	0.23		
Total	38	13.72			
		Humerus Weight (g.)			
Interaction	8	1151.47	193.93	1.99	N.S.
Birthrank	3	22.88	7.63	0.08	N.S.
Pasture	3	1462.33	487.44	5.00	**
Error	24	2338.98	97.46		
Total	38	5375.66			

N.S. = Not significant at the 5% level of probability

* = Significant at the 5% level of probability

** = Significant at the 1% level of probability

This nomenclature will be used throughout the appendices to denote levels of significance.

APPENDIX II

Tests of Heterogeneity of Ryegrass Strain Trial Pasture Group Regressions : I

Pasture Group	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
		Carcass Muscle on Carcass Weight				
P_1	0.25	10	5.87			
P_2	0.23	9	11.37			
P_3	0.20	7	3.08			
P_4	0.29	5	3.95			
Within Groups		31	24.27	0.78		
Regression Coeff.		3	0.69	0.23	0.29	N.S.
Common	0.24	34	24.96			
		Carcass Muscle on Cannon Length				
P_1	1.68	10	22.91			
P_2	1.22	9	29.73			
P_3	1.53	7	4.83			
P_4	0.80	5	14.96			
Within Groups		31	72.43	2.34		
Regression Coeff.		3	0.42	0.13	0.06	N.S.
Common	1.27	34	72.85			
		Carcass Muscle on Cannon Weight				
P_1	0.30	10	14.94			
P_2	0.48	9	3.22			
P_3	0.09	7	5.59			
P_4	0.23	5	7.30			
Within Groups		31	31.05	1.00		
Regression Coeff.		3	12.02	4.00	4.00	*
Common	0.26	34	43.07			

(Continued)

APPENDIX II (Continued)

Pasture Group	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F.	Sig.
		Carcass Muscle on Cannon Weight per cm.				
P_1	4.26	10	13.39			
P_2	4.97	9	9.38			
P_3	2.59	7	4.00			
P_4	3.21	5	5.79			
Within Groups		31	32.56	1.05		
Regression Coeff.		3	2.43	0.81	0.77	N.S.
Common	3.90	34	34.99			
		Carcass Muscle on Humerus Length				
P_1	1.64	10	18.67			
P_2	2.37	9	18.77			
P_3	1.10	7	5.79			
P_4	1.69	5	7.55			
Within Groups		31	50.78	1.64		
Regression Coeff.		3	1.46	0.49	0.30	N.S.
Common	1.80	34	52.24			
		Carcass Muscle on Humerus Weight				
P_1	0.12	10	14.23			
P_2	0.15	9	3.74			
P_3	0.07	7	3.53			
P_4	0.08	5	8.18			
Within Groups		31	29.68	0.96		
Regression Coeff.		3	4.15	1.38	1.44	N.S.
Common	0.11	34	33.83			
		Carcass Muscle on Humerus Weight per cm.				
P_1	1.59	10	17.07			
P_2	2.43	9	6.29			
P_3	1.17	7	3.41			
P_4	1.71	5	8.28			
Within Groups		31	35.05	1.13		
Regression Coeff.		3	3.03	1.01	0.89	N.S.
Common	1.82	34	38.08			

APPENDIX III

Tests of Heterogeneity of Ryegrass Stain Trial Pasture Group Regressions : II

Pasture Group	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
		Carcass Weight on Cannon Length				
P_1	-0.19	10	301.76			
P_2	-0.18	9	425.09			
P_3	-0.56	7	101.16			
P_4	1.78	5	132.40			
Within Groups		31	960.41	30.98		
Regression Coeff.		3	2.78	0.93	0.03	N.S.
Common	0.11	34	963.19			
		Carcass Weight on Cannon Weight				
P_1	0.73	10	240.53			
P_2	1.39	9	175.28			
P_3	0.13	7	98.17			
P_4	0.47	5	101.63			
Within Groups		31	615.61	19.86		
Regression Coeff		3	125.17	41.72	2.10	N.S.
Common	0.62	34	740.78			

(Continued)

APPENDIX III (Continued)

Pasture Group	b	Deviations from Regressions				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
			Carcass Weight on Humerus Length			
P_1	2.57	10	285.73			
P_2	3.49	9	393.62			
P_3	-0.75	7	100.86			
P_4	3.26	5	105.59			
Within Groups		31	885.80	28.57		
Regression Coeff.		3	15.17	5.06	0.18	N.S.
Common	2.66	34	900.97			
			Carcass Weight on Humerus Weight			
P_1	0.30	10	230.25			
P_2	0.45	9	194.92			
P_3	0.14	7	87.97			
P_4	0.14	5	112.34			
Within Groups		31	625.48	20.18		
Regression Coeff.		3	41.20	13.73	0.68	N.S.
Common	0.28	34	666.68			

APPENDIX IV

Tests of Heterogeneity of 120 Series Carcass Class Regressions

Class	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
		Carcass Muscle on Carcass Weight				
Ewes	0.31	21	23.41			
Wethers	0.29	22	23.95			
Ewe Lambs	0.43	22	9.07			
Wether Lambs	0.43	34	8.08			
Within Classes		99	64.51	0.65		
Regression Coeff.		3	5.71	1.90	2.92	*
Common	0.34	102	70.22			
		Carcass Muscle on Radius-ulna Length				
Ewes	0.85	21	77.46			
Wethers	0.81	22	71.18			
Ewe Lambs	1.30	22	18.38			
Wether Lambs	0.84	34	27.49			
Within Classes		99	194.51	1.96		
Regression Coeff.		3	2.61	0.87	0.44	N.S.
Common	0.90	102	197.12			
		Carcass Muscle on Radius-ulna Weight				
Ewes	0.16	21	37.50			
Wethers	0.12	22	43.55			
Ewe Lambs	0.14	22	11.06			
Wether Lambs	0.11	34	22.90			
Within Classes		99	115.01	1.16		
Regression Coeff.		3	3.50	1.17	1.01	N.S.
Common	0.13	102	118.51			

(Continued)

APPENDIX IV (Continued)

Class	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
			Carcass Muscle on Humerus Length			
Ewes	1.40	21	70.98			
Wethers	1.02	22	75.22			
Ewe Lambs	1.98	22	18.98			
Wether Lambs	1.01	34	41.30			
Within Classes		99	206.48	2.09		
Regression Coeff.		3	4.94	1.65	0.79	N.S.
Common	1.23	102	211.42			
			Carcass Muscle on Humerus Weight			
Ewes	0.11	21	41.92			
Wethers	0.10	22	43.77			
Ewe Lambs	0.11	22	12.17			
Wether Lambs	0.07	34	29.16			
Within Classes		99	127.02	1.28		
Regression Coeff.		3	5.38	1.79	1.40	N.S.
Common	0.09	102	132.40			
			Carcass Muscle on Humerus Weight per cm.			
Ewes	2.43	21	36.11			
Wethers	1.92	22	41.00			
Ewe Lambs	1.50	22	17.01			
Wether Lambs	1.16	34	49.98			
Within Classes		99	127.09	1.28		
Regression Coeff.		3	11.34	3.78	2.95	*
Common	1.60	102	138.43			

(Continued)

APPENDIX IV (Continued)

Class	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
		Carcass Muscle on Tibia Length				
Ewes	0.76	21	80.64			
Wethers	0.69	22	73.76			
Ewe Lambs	1.05	22	29.32			
Wether Lambs	0.74	34	36.36			
Within Classes		99	220.08	2.22		
Regression Coeff.		3	1.06	0.35	0.16	N.S.
Common	0.78	102	221.14			
		Carcass Muscle on Tibia Weight				
Ewes	0.11	21	42.48			
Wethers	0.08	22	50.01			
Ewe Lambs	0.12	22	9.84			
Wether Lambs	0.09	34	24.64			
Within Classes		99	126.97	1.28		
Regression Coeff.		2	3.52	1.17	0.91	N.S.
Common	0.09	102	130.49			
		Carcass Muscle on Femur Length				
Ewes	1.02	21	73.36			
Wethers	1.36	22	56.18			
Ewe Lambs	1.27	22	23.48			
Wether Lambs	0.96	34	31.38			
Within Classes		99	184.40	1.96		
Regression Coeff.		2	2.07	0.69	0.37	N.S.
Common	1.09	102	186.47			
		Carcass Muscle on Femur Weight				
Ewes	0.07	21	42.80			
Wethers	0.06	22	55.94			
Ewe Lambs	0.08	22	12.56			
Wether Lambs	0.06	34	24.51			
Within Classes		99	135.81	1.37		
Regression Coeff.		2	2.52	0.84	0.61	N.S.
Common	0.06	102	138.33			

APPENDIX V

Tests of Heterogeneity of 120 Series Mature Sheep Regressions

Class	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
		Carcass Muscle on Carcass Weight				
Ewes	0.31	21	23.41			
Wethers	0.29	22	23.95			
Within Classes		43	47.36	1.10		
Regression Coeff.		1	0.13	0.13	0.12	N.S.
Common	0.30	44	47.49			
		Carcass Muscle on Radius-ulna Length				
Ewes	0.85	21	77.46			
Wethers	0.81	22	71.18			
Within Classes		43	148.64	3.46		
Regression Coeff.		1	0.02	0.02	0.01	N.S.
Common	0.83	44	148.66			
		Carcass Muscle on Radius-ulna Weight				
Ewes	0.16	21	37.50			
Wethers	0.12	22	43.55			
Within Classes		43	81.05	1.88		
Regression Coeff.		1	1.71	1.71	0.91	N.S.
Common	0.13	44	82.76			

(Continued)

APPENDIX V (Continued)

Class	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
		Carcass Muscle on Humerus Length				
Ewes	1.40	21	70.98			
Wethers	1.02	22	75.22			
Within Classes		43	146.20	3.40		
Regression Coeff.		1	0.57	0.57	0.17	N.S.
Common	1.25	44	146.77			
		Carcass Muscle on Humerus Weight				
Ewes	0.11	21	41.92			
Wethers	0.10	22	43.77			
Within Classes		43	85.69	1.99		
Regression Coeff.		1	0.26	0.26	0.13	N.S.
Common	0.11	44	85.95			
		Carcass Muscle on Humerus Weight per cm.				
Ewes	2.43	21	36.11			
Wethers	1.92	22	41.00			
Within Classes		43	77.11	1.79		
Regression Coeff.		1	1.30	1.30	0.73	N.S.
Common	2.15	44	78.41			

(Continued)

APPENDIX V (Continued)

Class	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
		Carcass Muscle on Tibia Length				
Ewes	0.76	21	80.64			
Wethers	0.69	22	73.76			
Within Classes		43	154.40	3.59		
Regression Coeff.		1	0.04	0.04	0.01	N.S.
Common	0.73	44	154.44			
		Carcass Muscle on Tibia Weight				
Ewes	0.11	21	42.48			
Wethers	0.02	22	50.01			
Within Classes		43	92.49	2.15		
Regression Coeff.		1	1.92	1.92	0.89	N.S.
Common	0.09	44	94.41			
		Carcass Muscle on Femur Length				
Ewes	1.02	21	73.36			
Wethers	1.36	22	56.18			
Within Classes		43	129.54	3.01		
Regression Coeff.		1	0.87	0.87	0.29	N.S.
Common	1.18	44	130.41			
		Carcass Muscle on Femur Weight				
Ewes	0.07	21	42.80			
Wethers	0.06	22	55.94			
Within Classes		43	98.74	2.30		
Regression Coeff.		1	0.42	0.42	0.18	N.S.
Common	0.07	44	99.16			

APPENDIX VI

Tests of Heterogeneity of 120 Series Lamb Regressions

Class	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
		Carcass Muscle on Carcass Weight				
Ewe Lambs	0.43	22	9.07			
Wether Lambs	0.43	34	8.07			
Within Classes		56	17.14	0.31		
Regression Coeff.		1	0.01	0.01	0.03	N.S.
Common	0.43	57	17.15			
		Carcass Muscle on Radius-ulna Length				
Ewe Lambs	1.30	22	18.38			
Wether Lambs	0.84	34	27.49			
Within Classes		56	45.87	0.82		
Regression Coeff.		1	2.33	2.33	2.84	N.S.
Common	0.94	57	48.20			
		Carcass Muscle on Radius-ulna Weight				
Ewe Lambs	0.14	22	11.06			
Wether Lambs	0.11	34	22.90			
Within Classes		56	33.96	0.61		
Regression Coeff.		1	1.33	1.33	2.18	N.S.
Common	0.12	57	35.29			

(Continued)

APPENDIX VI (Continued)

Class	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
		Carcass Muscle on Humerus Length				
Ewe Lambs	1.98	22	18.98			
Wether Lambs	1.01	34	41.30			
Within Classes		56	60.28	1.08		
Regression Coeff.		1	4.30	4.30	3.98	N.S.
Common	1.22	57	64.58			
		Carcass Muscle on Humerus Weight				
Ewe Lambs	0.11	22	12.17			
Wether Lambs	0.07	34	29.16			
Within Classes		56	41.33	0.74		
Regression Coeff.		1	2.33	2.33	3.15	N.S.
Common	0.08	57	43.66			
		Carcass Muscle on Humerus Weight per cm.				
Ewe Lambs	1.50	22	17.01			
Wether Lambs	1.16	34	32.97			
Within Classes		56	49.98	0.89		
Regression Coeff.		1	0.84	0.84	0.94	N.S.
Common	1.27	57	50.82			

(Continued)

APPENDIX VI (Continued)

Class	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
		Carcass Muscle on Tibia Length				
Ewe Lambs	1.05	22	29.32			
Wether Lambs	0.74	34	36.36			
Within Classes		56	65.68	1.17		
Regression Coeff.		1	0.89	0.89	0.76	N.S.
Common	0.80	57	66.57			
		Carcass Muscle on Tibia Weight				
Ewe Lambs	0.12	22	9.84			
Wether Lambs	0.09	34	24.64			
Within Classes		56	34.48	0.62		
Regression Coeff.		1	1.53	1.53	2.47	N.S.
Common	0.10	57	36.01			
		Carcass Muscle on Femur Length				
Ewe Lambs	1.27	22	23.48			
Wether Lambs	0.96	34	31.38			
Within Classes		56	54.86	0.98		
Regression Coeff.		1	0.84	0.84	0.86	N.S.
Common	1.04	57	55.70			
		Carcass Muscle on Femur Weight				
Ewe Lambs	0.08	22	12.56			
Wether Lambs	0.06	34	24.51			
Within Classes		56	37.07	0.66		
Regression Coeff.		1	2.02	2.02	3.06	N.S.
Common	0.06	57	39.09			

APPENDIX VII

Tests of Heterogeneity of 120 Series Mature Sheep and Ryegrass Strain Trial Regressions

Grouping		b	Deviations from Regression				
			d.f.	$d_{y.x}^2$	M.S.	F	Sig.
			Carcass Muscle on Carcass Weight				
120 S.	Ewes	0.31	21	23.41			
	Wethers	0.29	22	23.95			
R.S.T.	Ewes	0.24	37	24.96			
Within Groupings			80	72.32	0.90		
Regression Coeff.			2	2.20	1.10	1.22	N.S.
Common		0.28	82	74.52			
			Carcass Muscle on Humerus Length				
120 S.	Ewes	1.40	21	70.98			
	Wethers	1.02	22	75.22			
R.S.T.	Ewes	1.80	37	52.24			
Within Groupings			80	198.44	2.48		
Regression Coeff.			2	2.45	1.23	0.50	N.S.
Common		1.44	82	200.89			

(Continued)

APPENDIX VII (Continued)

Grouping	b	Deviations from Regression				
		d.f.	$d_{y.x}^2$	M.S.	F	Sig.
		Carcass Muscle on Humerus Weight				
120 S. Ewes	0.11	21	41.92			
Wethers	0.10	22	43.77			
R.S.T. Ewes	0.11	37	33.83			
Within Groupings		80	119.52	1.49		
Regression Coeff.		2	0.26	0.13	0.09	N.S.
Common	0.11	82	119.78			
		Carcass Muscle on Humerus Weight per cm.				
120 S. Ewes	2.43	21	36.11			
Wethers	1.92	22	41.00			
R.S.T. Ewes	1.82	37	38.08			
Within Groupings		80	115.19	1.44		
Regression Coeff.		2	2.17	1.09	0.76	N.S.
Common	2.02	82	117.36			