A STUDY OF GROWTH AND CONFORMATION IN EARLY AND LATE
MATURING BREEDS OF SHEEP.

by

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Submitted to the University of Edinburgh as a
Thesis in fulfilment of the requirements for
the degree of Doctor of Philosophy.

Institute of Animal Genetics
University of Edinburgh.

October 1950.
A STUDY OF GROWTH AND CONFORMATION IN EARLY AND LATE MATURING BREEDS OF SHEEP.

VOLUME I - TEXT.
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INTRODUCTION.

Hammond's classical work on the growth and development of British breeds of sheep has demonstrated the striking changes in conformation which selection for mutton qualities has brought about. His studies involved the dissection and weighing of the amount of bone, muscle and fat in the different joints and sections of the body from samples of many breeds at different stages of growth. As a supplement to these studies, which were inevitably limited to very small numbers of animals, it was suggested that measurements should be taken on live animals at successive stages of growth in a series of breeds representative of different types, in order to discover how far body measurements on live animals can indicate the known differences in conformation and their development during ontogeny.

Measurements made after dissection are more accurate than those taken on live animals. However, skeletal measurements on live animals can be made with a fair degree of accuracy. They have the advantage that they can be taken without killing the animal and the same animal can be measured repeatedly at successive stages of growth. Thus, the progressive development during growth of the conformational differences between breeds can be studied, and also the accuracy of different measurements can be estimated by comparing the repeated measurements made by different persons. Such an
investigation should also throw light on the value of
different body measurements as an aid in selection of meat
quality, or for the determination of the rate of advance
caus ed by selection for conformation on experimental farms.

Ideally, this kind of work should be done on
samples of different breeds reared under the same conditions,
but facilities for this purpose were not available, and
measurements had to be made on animals reared under the normal
commercial conditions, so that genetic and environmental
effects could not be separated.

It was planned to measure at regular intervals,
from birth to 21 weeks of age (marketing age), samples of
lambs of a representative series of breeds, and to mark each
lamb at birth so that it could be individually identified
at each measurement.

Such work creates too much disorganisation of
farm routine for it to be possible to undertake on purely
commercial farms, but lambs were made available for study on
their experimental farms through the kindness of the
authorities of the Edinburgh and East of Scotland College of
Agriculture.

Among the different breeds of sheep in Scotland,
the Scottish Blackface and the Cheviot are famous for their
hardiness and thriftiness. Their chief assets are their
ability to live on heather-covered hills and to withstand the
rigorous climatic conditions. After 4-5 years on the hills the (draft) ewes of these two breeds are sold for the purpose of breeding at lower altitudes where they are crossed with Border Leicester rams to produce lambs suitable for fattening under mixed farming conditions. The drawback of the resulting crosses (Greyface from the Scottish Blackface and Halfbred from the Cheviot ewes) is that the wether lambs do not mature early enough to give a high proportion of fat lambs at weaning (Hammond 1947).

However, because of the earliness of maturity, the high prolificacy and the good milking qualities of the Border Leicester, the crossbred ewes which result (in particular the Halfbred which is the backbone of mixed farming) provide a most profitable type of ewe to be used again for further crossing with the Down rams for the production of more improved fat lambs. Usually the most popular Down rams used in this connection are those of the Oxford and Suffolk Down breeds.

The most important characteristics of these two breeds can be summarised as follows:

The Oxford Down:

This breed is the largest of the medium-wool mutton breeds. It has a large frame, big bones and the body is long, deep and roomy, with plenty of spread through the chest and over the loin and with a fairly fleshy "leg of mutton".
The Suffolk Down:

This breed is of medium size. The body is of medium length, straight and well fleshed on top, and of medium width and depth. The legs are fairly long and are set well apart. The mutton quality of this breed is excellent and exceeds that of the Oxford Down.

Because of the earliness of maturity, the high prolificacy and the above characteristics, the rams of these two breeds have been used extensively in crossing with other breeds in order to improve fat lamb production.

Logically, a comparison between the Scottish Blackface and its crosses (Greyface and Greyface x Down breeds) or between the Cheviot and its crosses (Halfbred, Halfbred x Down breeds) could show the effect of crossing, the amount of improvement resulting, and the potentialities of each cross, thus determining their suitability for mutton production. But this was not possible since neither Cheviot breed nor Scottish Blackface crosses were available. The breeds chosen for study were limited to those readily available on the farms and consisted of the Scottish Blackface (at Castle Law hill farm), the Halfbred and a cross of Suffolk Down rams on Halfbred (at Easter Howgate farm), and a cross of Oxford Down rams on Halfbred (at Boghall farm). These three farms lie within 2 miles of each other at the foot of the Pentland Hills,
6 miles south of Edinburgh, Midlothian.

Twins were chosen for study since this enabled the lambs to be obtained from fewer ewes and caused less disorganization in handling, and also since twins were frequent in the flocks used. A small number of Oxford-cross triplets was available and it was possible to compare the twins and the triplets of this cross.

Females were taken to avoid sex differences and the complications of castration.

Before describing the results of the investigation, the relevant literature on growth and conformation will be reviewed in order to provide a background to the study. Because of the great amount of literature available on the subject, only that which is directly related to the present work will be mentioned.
REVIEW OF LITERATURE.

It is known that growth during the foetal period does not differ qualitatively from that subsequent to birth. Growth, despite its greatly varying rates and its changes of direction from progressive during the developmental period to regressive during senescence, is one continuous process, starting with fertilisation of the ovum and ceasing with the death of the individual. The progressive part of the cycle is divided by the incident of birth into pre- and post-natal periods (Arey 1934).

Many studies have been made in the two fields (i.e., before and after birth) on different animals, and the work of Hammond (1932), Bonsma (1939), Cloete (1939), Brody (1945), Green and Winters (1945) and Wallace (1945, 1948) and of many others show the tremendous literature available.

1. Birth Weight.

The weight of the animal at birth represents that reached by its tissues and organs at the final stages of development in the uterus. Hence, birth weight is considered an important collective measure, and is generally used as a criterion of whether a factor has influenced the growth of the individual in the foetal stage.

A great number of studies have been devoted to the prenatal growth of many animals, including man. In many
cases age determination, growth of all or different parts, and the physiological changes that occur in the foetus have been studied and discussed.

Such studies made it possible to formulate quantitative "laws" of growth, especially as they relate to farm animals. Further, they led to the question of the relationship between birth weight, stage of development and the subsequent growth and development after birth.

From the literature it is clear that there are many factors influencing birth weight.

Hereditary influences on birth weight have been demonstrated by other workers - Chapman and Lush, 1932 (on sheep) claimed a large effect, while Lush and his collaborators, 1934 (on pigs) claimed a small effect.

Walton and Hammond (1938) demonstrated the part played by the maternal influence on birth weight and showed that in every cross between Shire horses and Shetland ponies the result was a foal of a size appropriate to the mother's breed and was not a medial type. Donald (1939) (on humans) agreed with this and added that a maternally controlled uterine environment could be the limiting factor in respect of average birth weight, if both the genetic and the environmental factors tended to act in the same direction.

Furthermore, Hammond (1943) stated in discussion that, with Shetland and Shire crosses, the limited nutrition
of the small Shetland mare limits the size of the crossbred foetus to the size of a purebred Shetland foetus, but the genetic constitution of the crossbred foetus in the large Shire mare prevents its reaching quite the same size as a purebred Shire foetus, in spite of the good nutritional conditions.

In the work of different authors such as Hammond (1932), Bonama (1939), Donald and McLean (1935) and Wallace (1948) - all on sheep - the effect of the environmental factors (particularly the nutritional influences) and their influence on birth weight has been demonstrated.

The main factors affecting birth weight can be summarised as follows.

I. Genetical factors:
These concern (a) the dam, (b) the sire, (c) the foetus

II. Environmental factors:
These are generally of two kinds,
(a) physiological factors,
(b) nutritional factors,

It seems necessary to give a more detailed account of these factors in order to show the field of each and how they exert their influence upon the foetus and its birth weight. A study of these factors is influenced by the following:
1. Breed.

Hammond (1932) reported that it is difficult to find out, from a study of individual cases, to what extent a ram can influence the birth weight of the lamb, owing to the nutritional effects exerted by the ewe on the foetus in utero. He concluded, from a comparison made between the birth weight of the offspring of 3 Suffolk rams used on Suffolk ewes, that these sires had an effect in increasing the weight of the flock. He confirmed the findings of Humphrey and Kleinheinz (1908) that breed differences in size at birth can be observed more clearly in singles.

It would appear that the use of rams of varying weight and size within a breed has a definite influence upon birth weight, although the differences in weight or size between sires within a breed only vary in degree from those outside the breed.

A study of the literature, however, reveals a general belief that the birth weights of crossbred lambs are significantly higher than those of purebred lambs. This was demonstrated by Sutton et al. (1934), Roux and Van Rensburg (1935) and Bonsma (1939) working on pure Merino and Merino x British breeds. The analysis of their results indicates that in the case of the British breeds of rams, heavy rams tend to produce heavy lambs. It is noteworthy in this connection that Roux and Van Rensburg (1935) claimed that the ewes exert a similar influence.
McLean (1948) found the following results when crossing Southdown rams with Corriedale ewes:

(a) In the first year no differences appeared in the mean birth weights of the progeny of the 5 high-grade studs and the 5 low-grade flock sires. Within each group of sires, however, significant differences in birth weight were produced by different rams.

(b) In the second year his analyses showed no significant differences either between the two groups or between the rams in each group.

(c) In the third year differences between the sires again become apparent.

Ensinger et al. (1943) claimed that what was supposed to be the differences between sires was caused by differences in environmental conditions from year to year. Therefore, they suggest that a comparison between sires should take place within a given year, unless adequate controls are available to serve as a basis for adjusting for seasonal differences.

Kincaid (1943) found that the lambs sired by Hampshire rams averaged 1.05 lb, heavier than those sired by Southdowns, the differences being highly significant.

Although no significant differences were found between the average birth weights of the different groups of crossbred lambs studied by Bonsma (1939), yet in the case of his Southdown x Merino cross, which was not included in his statistical
analysis, the average birth weight was, however, considerably lower than that of the other crossbred lambs. Thus it could be stated that the use of different breeds of rams has a very definite influence upon the birth weight of the lambs. This influence is limited to the genetic sphere.

Winters et al. (1946) are in support of this view. Although their data on Shropshire and Columbia and their various crosses were not adequate to answer definitely as to the extent of the superiority of different breed groups, they did, however, indicate strong breed differences with respect to productivity. (Productivity = \(3.4 \times \text{pounds of wool} + \text{pounds of lamb at 23 weeks}\).) In addition, they stated that the productivity of the ewe increases by crossing with other breeds, especially when crossed to rams of the larger breeds.

Leveck (1947), comparing birth weights obtained from native ewes (of the Coastal Plain) mated with native rams, native ewes mated with Southdown rams, and high-grade Southdown ewes mated with Southdown rams, found that not only were the Southdown-cross lambs heavier (8.19 lb.) than the native lambs (7.55 lb.) at birth, but they were also slightly heavier than the high-grade pure Southdown lambs (8.08 lb.).

However, the evidence for the definite influence of

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* The price for the four top grades of wool on the Boston market from 1920-1938 was 3.4 times the average price of top lambs during the same period on the South St. Paul market. Hence wool is converted into "lamb equivalent" by multiplying pounds of raw wool by 3.4.
rams upon birth weight of lambs which lies in the work of many authors leads to the conclusion that, apart from environmental influences, the birth weight of lambs is influenced genetically by hereditary factors, e.g., size and earliness of maturity of the sire. In fact, the birth weight of lambs is predetermined by hereditary growth factors as received from both sire and dam.

2. Sex.

It has been found that at the early stages of growth and development of the foetus no significant or marked differences could be noticed (Winters and Feuffel 1936; Wallace 1948). As the foetus grows the difference becomes clearer and remarkably larger, especially shortly before parturition (Wallace 1948).

That male lambs are heavier at birth than female lambs is the view generally accepted (Hammond 1943; Donald and McLean 1935; Phillips and Dawson 1937, 1940; Bonsma 1939; Cloete 1939; Winters et al. 1946; McLean 1948).

Hammond (1932) however, found that male lambs weighed slightly less than females when recorded within three days from birth. He attributed this to the fact that males lose weight more rapidly than females during this period.

Crew (1929) supported the view which attributed the greater weight and size of male lambs to the action of the male hormone by his findings concerning the sexual abnormality of the Freemartin.
Bonsma (1939) suggested that the hormone activity responsible for the increased growth stimulus resulting in heavier birth weight of male lambs as compared with female lambs exerts a similar influence upon young ewes, not yet fully matured, when producing their first lambs.

3. Weight and age of the mother.

Generally speaking, the weight of the mother is considered as a collective measure of both her size and her condition. Therefore it includes both hereditary and environmental factors influencing not only the prenatal development of the lamb but also its subsequent birth weight. The correlation between the weight of the ewe and the birth weight of her lamb is thus due to the combined effects of hereditary and environmental factors, and the relative importance of each cannot easily be determined.

Concerning the relation between the weight of the ewe and the birth weight of her lamb Hammond (1932) indicated that the heavier the ewe the heavier the lamb at birth, and the correlation becomes stronger as the lambs increase in weight (as observed at 10 and at 20 weeks of age).

On the other hand Finocci (1938) found no correlation between the live weight of the mother and the birth weight of the lamb in Cyprus fat-tailed sheep.

Russel (1919) as quoted by Hammond (1932) claimed
that in nearly every case of purebred or crossbred sheep, size of the lamb is determined by the size of the ewe.

Donald and McLean (1935) showed, with Romney Marsh crossbred ewes mated to Southdown rams, that heavy ewes gave birth to heavy lambs as a rule, and stated that for male lambs an increase of 1 lb. in weight usually accompanies an increase of about 10 to 15 lb. in the weight of the ewe. They found that this could be applied to female lambs up to ewe weight of 115 lb. Bonsma (1939), who showed a linear relationship between weight of ewe and birth weight of lamb, found a mean increase in birth weight of .74 lb. (males) and .71 lb. (females) for an average increase of 10 lb. in the live weight of the ewe.

It is not clear whether these investigators calculated their results by the same method for, in calculating such results either of two methods could be used: (1) regression of ewe weight on lamb weight; (2) regression of lamb weight on ewe weight. These regressions cannot be the same unless the correlation between the ewe weight and birth weight of her lamb is perfect. However, the second is a correct method of predicting the effect of the changing ewe weight on birth weight of the lamb.

Bonsma (1939) claimed that approximately 24% of the variation found in the birth weight of the lambs is accounted for by the variation in the weight of the ewes. Chapman and Lush (1932) found only 25-30% of the variation in
in birth weight was hereditary, 30-35% due to tangible environment and 40-45% to accidents of development.

Ensminger et al. (1943) found low correlation between ewes and birth weight of their lambs (intra-sire basis) in Shropshire and in Southdown flocks. They concluded that factors other than heredity from the dam, such as intra-uterine environment, parasitic infestation, or year to year variation, etc., affected these correlations.

Hammond (1932) observed that ewes which were in "good" condition at lambing produced heavier lambs than ewes in "poor" condition and concluded that such differences in birth weight of the lambs were attributable to the condition of the mother before lambing. This was confirmed by Wallace (1948) who, in an extensive study, showed the importance of the level of nutrition and its effect on the pregnant ewe. His challenging findings showed that the level of nutrition of the ewe during the last 6 weeks before lambing had a marked effect on the birth weight and vigour of her lamb. He claimed that, on the average, each additional \( \frac{3}{4} \) lb. of G.D.E. (gross digestible energy as starch) fed daily for the last month before lambing gave 1 lb. increase in mean birth weight of twins. The few single lambs he used showed less striking effects of plane of nutrition before birth.

In addition, Snell (1936) found that "1/3 full-fed" Cheviot ewes produced significantly lighter single lambs at
birth than did \(2/3\) full-fed and full-fed ewes. He showed, by means of digestibility trials, that full-fed Cheviot ewes had a higher ability to digest protein, nitrogen-free extract and crude fibre, on the average, than did the ewes in the other groups. The full-fed ewes were the only ones to show a positive nitrogen ash balance; the other ewes were losing mineral matter from their bodies.

It has been claimed by Hammond (1932), whose results agree with those of Prawochenski and Kaczkowski (1926) and of Longwell (1942), that mothers which are still growing produce smaller lambs at birth than adult mothers. His figures showed that the lambs of shearlings were smaller at birth than either those of two-shears or older ewes. Although his results showed that the difference in birth weight between lambs obtained from two-shears and those from older ewes was small, yet that difference was considerably smaller in the case of twin lambs than in singles.

Joubert (1936) claimed that the virgin ewe of mature age produces lambs equal in weight to those of ewes of the same age which have been bred before. Bonsma (1939), who agreed with Briggs (1936), found that the lambs from virgin ewes were significantly lighter than lambs from subsequent parturitions. He also found that, although there was a small difference between second and third lambs of the same ewe, this difference was not statistically significant. These findings are in agreement
with those of Hammond, as mentioned above. Further, Bonsma stated that, under similar nutritional conditions, maiden ewes (i.e., young ewes) cannot nourish their foetus as well as do mature ewes, since the available nutrients have to meet the requirements for growth of the ewe as well as for the developing foetus.

Kincaid (1943) found a linear relationship between birth weight and age of ewes, the birth weight of lambs showing an average annual increase of 0.63 lb. as the ewes increased in age from 2 to 6 years.

In cattle, Dawson et al. (1947) found a correlation between the age of the dams and the birth weight of their male calves (Beef Shorthorn) which was 0.53 (significant at P less than .01). The correlation between the weights of the dam just after calving and the birth weights of the calves was 0.49 (significant at P less than .01). The multiple correlation between birth weights of these calves and the ages and weights of the dams was 0.56 (significant at P less than .01).

4. Length of gestation period.

Using a small number of sheep Hammond (1932) observed an increase in birth weight of lambs with the duration of pregnancy. This occurred in the case of singles but not in the case of twins or triplets. Chittenden and Walker (1936) and Bonsma (1939) found that the breed of the ram had an
influence on the length of gestation period. An explanation for this is rather difficult to give. Hammond and Marshall (1925) suggested that there is a tendency for the larger and later maturing breeds to have slightly longer gestation periods than the smaller and more early maturing breeds. This seems probable because of the greater growth impulse of the early maturing breeds.

Bonfert (1933) found that the length of gestation period in Tigai sheep producing male lambs was longer than that of female lambs.

Bonsaa (1939) claimed that his results showed no significant difference in the length of gestation period between male and female lambs. He found no evidence for the belief that virgin ewes carry their lambs somewhat longer than ewes producing their second or third lambs.

5. Time of lambing.

Hammond (1932), Donald and McLean (1935) and Phillips and Dawson (1937) all agreed that the difference in birth weight between lambs born early in the season and those born late was due to the improved condition of the ewes that lambed late.

6. Number of lambs per parturition.

It is generally known that single lambs are usually heavier than twins or triplets. The twin or triplet is hampered by having to share both uterine space and nutrients during pre-
natal life. Hammond (1943) stated that limitation of uterine space does not cause the decreased weight of the individual young in large litters. He averred that the uterus is capable of growing to accommodate all the young contained in it and gave two examples with rabbits (Hammond and Marshall 1925).

Hammond (1932) found that, at birth, singles are 29% heavier and triplets 9% lighter than twins in Suffolk sheep. He concluded that this was due to the competition for nourishment in the uterus and corresponded to the decreasing size of the young at birth with increase in the size of the litter, as in pigs (Carmichael and Rice 1920) and in rabbits (Hammond and Marshall 1925).

Chapman and Lush (1932) believed that in such competition between foetuses, the one that gets a slight advantage over the others is thereby likely to gain still greater advantage. Moreover, Essen-Müller (1930) (as quoted by Donald 1939) working on humans, found no greater resemblance in birth weight among one-egg twins than in two-egg twins, although there was a greater resemblance in length. Wallace (1948) as well as other workers, has shown the importance of the level of nutrition on the different tissues of the body, and that bone tissue - of all the tissues - is the least affected by the level of nutrition. In this connection Hammond (1943) states that, since the different parts and tissues of the foetus itself compete with one another for nutrients incoming from the placenta, it is the later-developing tissues and functions which suffer most and compete most with the various maternal tissues for the nutrients available in the maternal blood stream.
II. Growth in Weight.

When plotting the body weight of a normal growing lamb (from birth onwards) against age, the result is a curve with two phases, an early phase which is of a rising slope, followed by a second phase which is of a declining slope. Between the two phases there is a point at which an inflection takes place, which represents the position at which the rate of growth stops increasing and starts to decrease. The inflection usually takes place in farm animals when about 30% of their mature weight is reached, and corresponding to about 2 months of age in sheep (Brody 1945).

The increase in body weight per unit of time is generally considered as "growth rate". Growth in weight is usually represented by one or all of the following: (a) Absolute gain per unit of time, (b) Relative (or "percentage" when multiplied by 100) rate of gain per unit of time, (c) The weight at, or up to, a given time. These methods have been reviewed in detail by many workers including Brody, 1945.

As for pre-natal growth, post-natal growth is influenced by environmental and genetic factors. Working on data collected from 414 Navajo ewes and their lambs (1506 pure- and crossbred Navajo), Sidwell and Grandstaff (1949) found six measurable environmental factors having important effects on weaning weight of the lamb. These were: year of birth, age of ewes, breeding of sire, type of birth and rearing, sex, and
age of lamb at weaning. The studies made by different authors on the influence of environmental factors, especially nutrition, that affect the growth of young animals, showed the importance of these factors and their definite profound effects. Wallace (1948) found that 96% of the variation in the weight gains made by individual lambs between birth and 112 days could be accounted for by the differences between them in respect of their consumption of milk and supplements.

After birth, the animal resumes growth but in a different environment to that in the uterus. In its new environment the growing animal depends mostly in the early stages (about the first six weeks) upon the milk of its mother as its main source of nutrients. Young lambs start to nibble small quantities of grass and other foodstuffs from the pasture when they are as young as 2 to 4 weeks of age but, generally, they do not consume appreciable amounts of supplementary food until they are about 6 weeks of age. The consumption of this supplement rises rapidly until shortly before weaning (13th week) when the increase begins to decline and the quantity eaten each week rises only very slightly over the next few weeks until weaning (Wallace 1948). Therefore, it is of vital importance that the mother should show a steady increase in milk production to meet the increasing maintenance requirements and to promote rapid growth of the lamb during the 1st to 4th weeks, during which period the lamb is almost completely dependent upon her milk. Scarcity of milk during the early life of the lamb
causes retardation of growth until late in the season (Hammond 1932). Thus, the factors affecting the milk yield of the mother and those that affect the growth of the young, have their importance not only in the development of the lamb but in mutton production as a whole.

The milk production of non-dairy breeds of sheep has been studied in detail by Bonsma (1939) and Wallace (1948), who used the method of weighing the lambs before and after suckling.

The yields of Merino and Merino-cross ewes (crossed with Romney, Rayland, Dorset Horn and Border Leicester rams) were recorded by Bonsma (1939) at weekly intervals over a 12-week lactation period. Wallace (1948) recorded average weekly yields for Suffolk and Border Leicester x Cheviot ewes during a period of 16 weeks. His figures showed that approximately 38% of the total milk yield for the 16-week period was produced in the first month, about 30% and 21% in the second and third months, respectively, and about 11% in the last month.

The shape of the lactation curves of Bonsma's higher-producing ewes closely resembles the curves shown by Wallace, with the peak in the second and third week, after which there was a steady decrease in the dam's milk yield towards the end of the lactation period.

However, it was shown in the work of both Bonsma and Wallace that there was a strong association between the total milk yield of ewes and the growth of the lamb, particularly
during the first 5 or 6 weeks. The falling-off of this correlation as the age of the lamb increased is, no doubt, due to the fact that, as the lambs grow older, they are able to consume and assimilate more other food, so that their growth becomes less dependent upon the milk supply from their dams. Bonsma (1939) suggested that a high level of milk secretion during the first few weeks after lambing is of greater importance than persistency in milk secretion for the foregoing reasons.

Ivanov (1946), studying the effect of several non-hereditary factors on lactation in 1190 Black-headed Pleven sheep, found that age was responsible for about 11.96% of the total variation in lactation, lactation duration for 18.4%, the number of lambs per ewe 5.2%, and feeding, care and climate about 14.58%. His corrected coefficient of variation was 15.6841.

The factors affecting milk yield can be summarised as follows:

1) Breed. Bonsma (1939) relates the marked advantage of the lactation curves of the crossbred ewes over those of the purebred Merino to genetic differences as well as to the quantitative differences in milk production, irrespective of breed differences. Wallace (1948) noticed that the lactation curves for the Border Leicester x Cheviot had more pronounced peaks than those of the Suffolk but he could not relate this to breed difference as there was a difference in age between the two groups.

2) Number of lactations and total milk yield. That the yield during the second lactation is significantly higher than that
of the first is the view generally accepted (Bonsma 1939, Wallace 1948). However, Bonsma found that the difference in liveweight increase between lambs reared in different years is due to differences in the milk yields of the ewes for these years.

3. Weight of the ewes. Wallace (1948) found that heavier ewes give greater milk yields. Bonsma (1939), who found a strong correlation ($r = 0.317$; significance 5%) between live weight and milk production of the ewe, claimed that 25% of the variation in milk yield within any one breed can be accounted for by the differences in the weight of the ewes.

Hammond (1932) stated that ewes in good condition at parturition gave more milk than did those in poor condition. It should be noted that weight differences between ewes may be due to differences with respect to either "condition" or to differences in "frame size" which again may or may not be related to age. It is, however, difficult to distinguish between the effects of these and it appears that both are of importance.

Snell (1936) showed that not only are well-fed ewes heavier in weight but they also produce more milk than less fed ewes (i.e., 1/3 and 2/3 full-fed). He claimed that there was a close association between the amount of feed fed in each lot studied, the average daily milk production of the ewes in these lots, and the average gain of lambs from birth to 120 days of age.

It has been claimed by Wallace (1948) that low
level of feeding during the later part of pregnancy is accompanied by a considerable reduction in the size of all the major internal organs of the ewe. It is therefore believed that the low yields of ewes ill-fed before lambing may not be due so much to any specific deficiency in mammary tissues but follows rather from the general bodily effect of poor nutrition (i.e., reduction in size of internal organs - Wallace 1948).

Improved efficiency of food utilisation by certain individual ewes causes a higher intra-uterine level of nutrition of the foetus and consequently heavier lambs at birth. The same result is also expected to take place with mammary gland tissue prior to parturition. Therefore, the association between the efficiency of ewes and the nourishment of their lambs before and after birth is not surprising (Wallace 1948). This association, however, is a result of the same physiological function responsible for the association between birth weight and milk yield of the dam found by Bonsma (1939) and Wallace (1948).

(4) Number of lambs suckling one ewe. Wallace (1948) noted that milk yields of mothers with twins were higher than those with single lambs. He stated that the actual level of production was much affected by the number of young suckled. His explanation was that singles are not capable of drawing off all the available milk during the first week, but they were able to do so later on. He suggests that if all the milk available during the first week is not drawn off, then
the level of production during the latter part of the lactation period would be adversely affected.

However, it may be that the greater stimulus of more frequent suckling may have been responsible for the high yield of the ewes with triplets.

(5) Mothering qualities. Wallace (1948) suggests that the appetite of the lamb may be of considerable importance in determining the actual milk yield of the mother. He found that early in the lactation period, each ewe allowed her lamb to suck as long as it wished, and when it was removed and then returned immediately, almost invariably let it suck again although no additional milk had been obtained. On the other hand, towards the later part of lactation, the ewe moved off before the lamb had finished sucking and would not permit it to suck again if separated and reintroduced. If, however, the ewe was then held, the lamb was able to secure a further quantity of milk. A further suggestion was that it is mainly the dam which regulates weaning, but there were some ewes in his experiment which allowed their lambs to suck as long as they wished during the whole lactation period of 16 weeks.

Wallace's figures appear to have been much higher than the majority reported by other authors. He relates this to the good mothering qualities of both the Suffolk and the Border Leicester x Cheviot ewes.

The amount of milk consumed by the lambs per pound of gain in live weight showed a marked decrease as they become older (Wallace 1948). He attributed this to the increased
utilisation of other food with increase in age of the lambs. He showed the importance of supplementary feeding of lambs by his finding that a difference of 40 lb, G.D.E. fed during the suckling period caused a difference of 14-28 lb, in liveweight at weaning. Also, 96% of the variation in weight gain by individual lambs from birth to 112 days was due to individual differences in consumption of milk and supplements.

In considering milk yield, the breed and size of the ewe and the food she receives during lactation, the size and vigour of the lamb at birth, the number of offspring reared, and the level of nutrition of the ewe before lambing, appear to be factors which have considerable influence upon the total milk yield and the shape of the lactation curve.

As the inherent growth rate is most rapid during the first few weeks after birth, it is of fundamental economic importance that the maximum possible rate of growth during this period should be attained.

Bonsma (1939) claimed that individual selection for high milk production is more important than choice of breed. He stated that growth of the suckling lambs may be considered as an indication of the milk production of the ewes and could be used as a basis for individual selection.

Finally, it was suggested by Wallace (1948) that milk yield could be roughly estimated from birth weight and the growth rate of the lambs, since the relationship between the level of milk production of a ewe and the birth weights or live weight gains made by her lambs have been established.
Body Conformation as Indicated by Skeletal Growth and Body Measurements.

Type and conformation have always been a criterion in the selection of breeding animals. It appears that differences in type and conformation will continue to affect the price for which the animals are sold.

Evidently, a change in consumption habits of the public usually reflects itself in a change in the constitution of flocks. For example, before the last world war, there was a great demand for leaner and smaller joints in fat lamb production. Smaller types of ewes were therefore gradually introduced for crossing and greater attention was paid to fat lamb production (Roberts 1947). Under the circumstances that existed during that time, this small type of lamb produced was the most profitable. When circumstances were changed during the war the stress was again on quantity rather than quality and the market control favoured the production of the larger early-maturing breeds. This was no doubt — and probably still is — the main factor which influenced the breeders to change over to the larger and heavier types, as the prices of such type of lamb and mutton, under such conditions, had been weighted against the smaller high-quality breeds.

Whatever the demand will be, the breeder of meat-producing stock judges his animals not only by their actual size, but also by their body proportions. The proportions of conformation by which animal types are differentiated by the
breeders are based mainly on the relationship between the different body dimensions.

From the butcher's point of view certain parts of the body (e.g., loin and leg of mutton) are more valuable than others (e.g., neck). Animals that carry more good quality meat in the valuable parts naturally get the best prices.

As the relative proportions of the different parts of the body change with age, and the suitability of the animal for meat production depends upon the changes that occur in conformation of the animal, such changes in conformation play a vital role in meat production.

Studies of growth in body weight as such do not provide a good measure of such changes nor do they show the relationship between the relative proportions of the body and the size and conformation of the animal.

By the use of different methods in their studies of growth and development of the different parts, organs and tissues of the body, previous investigators (Ritzman and Davenport 1917, 1920; Hammond 1932; Bonsma 1939; Wallace 1948, and others) have shown how the conformation of different animals is affected by the differences in the changes of body proportions.

In general, the methods used for estimating such growth were either to weigh or to measure (or both) the different parts, organs and tissues at different ages. Sometimes chemical analysis provided another method, since the
composition of the different tissues also changes with age (Callow 1948; Hankins 1947).

Whatever the method used, there is general agreement among authors that the relative proportions of the animal at birth change as the animal grows. The literature shows that, like the different tissues, all parts of the body do not reach the maximum state of growth at the same time. This is due to the fact that the different parts of the body and the different tissues (muscle, fat, bone and tendons) grow at different rates (Hammond 1932; Wallace 1948). There is, however, evidence that, among the tissues, the first to reach the period of most active growth is bone, followed by muscle and finally fat. The growth and development of muscle and fat exceed that of the bone tissue as the animal grows and, while the percentage of muscle and fat in the body increases, that of the bone tissue decreases with age. It is interesting to note that Hammond (1932) claimed that the areas of the body in which the skeletal structure grows most in post-natal life are the areas in which most muscle and fat are eventually developed.

However, the proportions of these tissues at any given stage of growth mean a great deal to the producer, the butcher, and the consumer who, in the final analysis, is the person to be satisfied. Best prices are always paid for cuts obtained from parts of the body that contain the minimum of bone, maximum of muscle (or lean meat), with only enough fat to give satisfactory cooking results.
While breed influences the rate and type changes that occur in the body, the plane of nutrition of the animal from birth until marketing is of great importance. When a low plane of nutrition reduces the speed of increase in live weight, the process of converting food to fat will be the first to stop, followed by muscle development, and finally bone growth.

With regard to the effect of the level of nutrition on the different parts of the body, it has been pointed out in the literature that all parts of the body are not penalized or encouraged to the same extent. There are apparent differences between individual organs and, within the carcass, the skeleton and the brain and spinal cord were found by Wallace (1948) to be relatively resistant, while the muscle and fat were most severely affected by the level of nutrition. From this Wallace concluded that the body form and conformation are not governed merely by the total size attained, but that they may also be affected by the rate at which growth has occurred.

Hammond (1932) and Wallace (1948) (working on sheep) and McMeekan (1940) (working on pigs) found that in the skeleton, although the effect of the level of nutrition was considerably less than in muscle or fat, those parts which grow most in post-natal life are more affected by change in the level of nutrition than those that grow the least. Wallace found no differential effect of level of nutrition on
the muscles of the different parts of the body. He indicated also that a high diet increases the subcutaneous fat more than the intermuscular fat, while on the low diet, the subcutaneous fat is mobilised to a greater extent. Hammond found that the subcutaneous fat is more readily influenced than the intermuscular fat by the feeding or condition of the animal.

The aim of successful lamb production is to ensure that the young animals with good body conformation develop quickly the deep fleshing of the valuable parts under continuous good feeding from birth to time of marketing. However, as most of the tissues, and particularly muscle, are affected by the slightest change of some factor, e.g., change in the level of nutrition as mentioned above, skeletal measurements can be obtained with a fair degree of accuracy and are more suitable than other measurements for showing the differences in conformation and linear growth of different live animals reared under normal conditions, as bone is not affected by the level of nutrition unless this is severely low.

This is shown in the work of Trowbridge et al. (1918) who stated that bone will grow normally but at the expense of other tissues, provided that the animal is not greatly underfed. Ritzman (1923) stated that bones, because of their comparative stability against fluctuating variations caused by feeding, climate and health, offer a fairly reliable basis of measurement.

Growth and conformational changes in sheep during prenatal and post-natal life have been studied by many workers
(Hammond 1932; Winters and Feuffel 1936; Cloete 1939; Bonsma 1939; Wallace 1948; Callow 1948). Their findings showed that, in general, during the early embryonic stage, the size of the head of the lamb is almost as large as that of the body, while the limbs are smaller by comparison. After birth, the head reaches its maximum growth earlier than the carcass. Although the lamb is born with comparatively long limbs, yet the different bones of the leg do not grow at the same rate in post-natal life. The cannon bones are well developed at birth but after birth they grow at a slower rate than the upper parts of the leg. The fore- and hind-legs above the cannon, are relatively well developed at birth but their rate of growth in post-natal life is very much greater than that of the lower parts of the leg. Hence, the growth rate of the different parts of the leg increases upwards.

The parts forming the trunk of the animal develop more than the head and the lower parts of the limbs after birth. However, the growth rate of the different parts of the trunk increases posteriorly from the head down the vertebral column.

The relationship between body conformation and productivity in livestock has been the subject of study by different workers. In sheep, the correlation found between certain body measurements and live weight has shown the importance of the development of chest measurements as well as height, width and length of the body (Finci 1939; Bonsma 1939; Cole 1942).
It is established that mutton breeds are short in the leg, long and wide in the body and somewhat deep in the chest. Hammond (1932) demonstrated the effect of domestication and improvement on body conformation. He showed how it affects growth in length, width and thickness of the bones and concluded that the main basis of differences in conformation between types of sheep is founded on changes in the conformation after birth and on the nutritional state of the animal during this time.

Hammond (1937) stated that in an unimproved breed, such as the Mouflon, the changes in proportions occur as the animal grows, but the extent of the changes is far less than it is in the improved breeds such as the Suffolk - to the extent that the body proportions of an adult Mouflon ewe are but little in advance of the improved breeds at birth. He added that the improved mutton and lamb breeds have been developed from the unimproved type by pushing the development of the animal forward by good feeding, and by selecting and breeding from those animals which showed the greatest changes in their proportions for their age. Thus, by improved methods of feeding and breeding, the age changes from low to high body weight, carcase percentage and proportions of meat to bone, had been hastened and carried further, and the age of slaughter reduced, with consequent economy in the total amount of food consumed by the animal in its life, and improved conformation.

The use of different improved mutton breeds in
crossing plays an important part in the improvement of fat lamb production. This is demonstrated in the work of many investigators, e.g., Bonsma (1939). Studying the relative effects of crossing the Merino with the different mutton breeds on the various body dimensions and consequently conformation, he found that in every case, at both 3 and 18 weeks, the crossbred lambs were superior to the purebred Merino in respect of the ten dimensions he analysed. The crossbred lambs, as compared with the Merino parents, were better developed, particularly in the transverse dimensions. Not only the actual width of body but also the various ratios of transverse dimensions to longitudinal and vertical dimensions were increased. He stated that the increase in width of the skeletal dimensions indicated a correspondingly greater potential flesh development of the loin and hindquarters in the crossbred lambs. In the second cross, however, he found that there was a further significant increase in width of chest and hindquarters as compared with the first-cross lambs. Amongst the mutton rams used, his results show the superiority of the Southdown for the improvement in mutton conformation and for the production of early-maturing fat lambs.

Belevska (1946) found that when Precoce rams were crossed with local coarse-wool short-tailed ewes of the Gorky district (U.S.S.R.) the result was a cross with better conformation than the local ewes. The second generation obtained by backcrossing with Precoce rams showed conformation
resembling that of the Precoce. The measurements of the second generation were thus better than those of the first generation or of the local animals.

Foster and Hostetler (1939) found that measurements on live sheep and lambs showed that the improved breeds (Hampshire cross) were longer and wider and had greater circumference of barrel and leg of mutton than the native breeds of North Carolina, but were very little greater in height. Leg of mutton improved still more in the second cross. They therefore concluded that continued crossing produced a noticeable improvement in conformation.
OBJECT OF THE PRESENT INVESTIGATION.

Studies of growth have pointed out that growth and development take place most rapidly in the young animal. Under suitable feeding conditions, the animal that reaches a certain killing weight in less time than a slow growing one is usually considered more economical and profitable. Hence, body weight is looked upon as one of the satisfactory quantitative measurements of animal development.

A study of growth in weight alone confines the investigator to one measure only. It does not give a complete understanding of the complex phenomena or clarify any conformational changes which take place in the body of the animal, and gives no indication of its qualitative growth.

Thus, the conformational changes which take place in the body of a growing animal and the relative development of the various parts of the body play an important role in meat production. These are considered as the qualitative growth indicators.

Studies of growth and conformation in livestock, however, show that as long as there is a relation between conformation and production capacity, any difference in the conformation of the animals will, to a large extent, determine their comparative suitability for meat production.

In the present work growth and conformation were studied in the female twin lambs of each of the four groups during the period from birth to marketing age (about 21 weeks...
from birth).

The following points relating to growth and conformation were studied in four groups of sheep (Blackface, Halfbred, Oxford-cross and Suffolk-cross) in an attempt to compare their potentialities and suitability for mutton production.

I. Birth weight:

(1) A study of birth weight showing the differences between the four groups,

(2) The relationship between the birth weight of the lamb and the weight of the ewe.

II. Growth in weight:

In this connection, growth curves, absolute gain per week and relative growth rates during the period studied (21 weeks from birth) are presented graphically to show the differences between the four groups in this respect.

Limited data on the growth in weight of pure Hampshire single lambs made it possible to compare the growth curves of the female twins of the above-mentioned groups studied with those of the single males or single females of the Hampshire breed.

III. Body conformation as indicated by skeletal growth and body measurements.

(1) A study of each of the ten body measurements chosen as they change with age from birth until the end of the 21 weeks. In this connection, growth curves and absolute gain per week for each body measurement are presented graphically,
thus showing the differences between the four groups in the shape and the trend of the curves as they grow during the period studied. In every measurement relative growth rates were calculated for every group and tabulated only.

From the data collected from each group the measurements taken at the different intervals were expressed as percentages of measurements taken at birth in order to show the relative amount of growth made by each group in each measurement.

(2) Comparisons between the growth of the four groups of twin lambs for every body measurement and consequently body conformation were based on equal length of cannon, equal length of pelvis and then equal body weight. The relationship between the growth of each of the body measurements and each of these standards of comparison are presented graphically to show the differences between the groups in this respect.

Data collected from a small number of Oxford-cross female triplets made possible comparisons of birth weight, growth in weight and growth in body measurements with those of the Oxford-cross female twins.
MATERIAL AND METHODS.

I. Source of Data.

Weights and measurements of different breeds of sheep and some crosses were obtained from two sources. Data forming the main part of this work were obtained from flocks at the University of Edinburgh's experimental farms during the period from March to August 1949.

Lambs from each flock and the farms on which they were reared were as follows:

SCOTTISH BLACKFACE:— 12 females (6 sets of twins) were born at Castle Law Hill Farm. Nine of these survived and were reared on the hills.

HALFBRED (Border Leicester ram x Cheviot ewe):— 8 females (each twin to a female) and 3 females (twins to males) were born and reared at Easter Howgate Farm at the foot of the Pentland Hills, Midlothian.

SUFFOLK-CROSS (Suffolk Down ram x Halfbred ewe):— 10 females (5 sets of twins) and 8 females (twins to males) were born and reared at Easter Howgate Farm. They ran in the same pasture as the Halfbred and were managed by the same Shepherd.

OXFORD-CROSS (Oxford Down ram x Halfbred ewe):— 8 females (4 sets of twins), 2 females (twins to males), 6 females (2 sets of female triplets) and 2 females (members of one set of triplets, the third member being male) were born and reared at Boghall Farm at the foot of the Pentland Hills. They were managed by a different Shepherd from the Halfbred.
and Suffolk-cross lambs.

The three farms on which these flocks were kept are situated to the south of Edinburgh, the distance between each varying from one to two miles. At Castle Law Hill Farm the grazing was fair; there was abundance of medium quality grass and heather. At Boghall and Easter Howgate, the two Lowland farms (mixed farming) the grazing was good and supplements were given as described below.

All the female lambs in question, whether twins or triplets, were reared as twins.

HAMPSHIRE: The data for this breed (7 females and 8 males of single pure Hampshire lambs) were obtained through the kindness of Dr. E.C.R. Reeve. They were collected from the Agricultural Research Council's Farm at Compton, Berkshire. Their weights were recorded only at birth, 37th, 98th and 147th days from birth. These lambs were reared as first-class lambs.
II. Methods of Collecting the Data.

At the beginning of the lambing season in Midlothian, female members of sets of twins or triplets were collected with the aim of studying their growth and conformation from birth to "marketing age" (about 21 weeks).

The best method of obtaining weights and measurements at a constant age is to weight and measure each lamb when it reaches that age. Owing to the difficulties that arise under farm conditions, it was decided to collect data from a fair number of lambs whose time of birth occurred as closely as possible within each flock. It took a week to collect female lambs required from each flock. The data for the three crossbred groups, Oxford-cross, Suffolk-cross and Halfbred, and for the Blackface, were collected starting from the 8th, 13th and 19th of March, and 20th of April, respectively. On these dates the first set of twins in each flock was born. Each lamb was marked, weighed and measured after 12 to 17 hours from birth. Lambs were weighed and measured (in one day in every flock) at the end of the week in which they were collected. From that day, weights and measurements were recorded at constant periods. Five successive weekly weights and measurements were taken, followed by another five at intervals of two weeks. The following intervals to these were prolonged a little as the rate of growth was slowing down. Before the sheep were sold (at 21 weeks of age) the weights and measurements were recorded,
Because of the variation of date of birth over a week for each flock, the different animals were not all measured at the same age. In order to correct for these differences in age the growth curve of each animal was plotted for body weight and every measurement and the values for definite ages (birth, 7 days, 14 days, etc.) read off. These corrections are unlikely to introduce any serious errors because growth was approximately linear over short intervals. All averages used in the Thesis are based on these corrected values.
III. Methods of Weighing and Measuring.

Weighing was carried out to the nearest \(\frac{1}{4}\) of a lb. by one person using a sling and a balance. For the taking of body measurements one person was required to hold the lamb for the measurer and another person to record as the measurer dictated.

Instruments for estimating the measurements consisted of: a pair of normal 12" engineer's "outside" callipers (for estimating length and width measurements); a long thin piece of wire, covered with rubber and marked at one end (for measurements of circumference of fore-cannon and circumference of chest); and a 100 cm. ruler marked in millimetres. All measurements were taken to the nearest millimetre.

In order to obtain reasonably accurate results, double measurements were taken for each dimension. This was done by measuring the different parts of the animal in a certain order once, then repeating these again in the same order after the lamb had been allowed to move. If each measurement is made twice before the next is taken, there is danger of underestimating the inaccuracies of measurement due to variations in the position in which each animal is measured. The position is difficult to standardise at all accurately, particularly as the animals were held for measurement by different people on different occasions. Approximately 50% of the lambs were re-measured by another measurer as a check.
on the accuracy of the first. In each case, the average of each two or four measurements was used in plotting the growth curves for correction for age differences by the method described above.
IV. Body Measurements.

In addition to weight, which was almost universally used, the use of body measurements was practised by many investigators in experiments with sheep, including studies of growth, inheritance (Ritzman and Davenport 1920) and nutrition (Voltz and Jantzson 1925).

In every case, the investigators used more than one representative measurement; some of these were described and illustrated by Hammond (1932), Brody (1945) and Phillips and Stoehr (1945).

Generally, the measurements used were of two classes, straight and circumferential. The straight measurements usually represented three kinds of dimensions, namely (i) vertical (height), (ii) longitudinal (e.g., pelvis length), and (iii) transverse (width).

The type and purpose of the experiments and the accuracy with which the measurements can be obtained are the limiting factors in determining the kind and number of measurements used in every experiment.

Phillips and Stoehr (1945) (on sheep) and Lush and Copeland (1930) (on dairy cattle), have studied the accuracy of several body measurements and found that not all of them showed the same degree of accuracy.

Moreover, the use of body measurements has been criticised in that they do not show the changes occurring in
bone thickness - changes which add considerably to the weight of the bone (Hammond 1932). Also, the use of body measurements fails to give a true reflection of the qualitative changes which occur in the growing animal, since some parts of the body carry more muscle in proportion to bone (Hammond 1932; Callow 1948; Hirzel 1939). However, the body measurements which express differences in the conformational changes of skeletal growth are used for defining differences in qualitative growth, and they have their value in that they reflect the potentialities of muscular development.

Therefore, the body measurements presented in this study were chosen from those that were considered most accurate, with the aim of studying the growth of every measurement in order to obtain a more accurate picture of the changing proportions of the body of the animal.

The measurements concerned in this study were taken on live animals from birth until 21 weeks of age, immediately after body weight was recorded. Hence, body weights and measurements were recorded on the same day in every case. Figure 1 shows the body measurements and the order in which they were taken.

The measurements taken were as follows:

(1) **Depth of Chest.**

This measurement is represented by the vertical distance measured from the top of the spinous process of the 3rd or 4th thoracic vertebra to a central point on the sternum in a vertical plane between the forelegs. (The forelegs were
vertical to the body and parallel to each other.)

(2) **Length of the Hind Cannon Bone.**

This represents the distance between the condyles of the metatarsal and the posterior end of the heel bone (Tuber calcis). In order to obtain reliable results the hind leg was kept in the position shown in Fig. 1, flexed as far as possible, when taking this measurement.

The figures given in this study for the length of cannon bone represent measurements of the right hind cannon bone (the shank) during the period studied.

(3) **Length of Tibia.**

This is the distance between the posterior end of the heel bone and the outer edge of the medial condyle of tibia (just below the patella). The measurements were made on the right hind leg when in the same position as for measurements of length of cannon bone (see Fig. 1).

(4) **Length of Pelvis.**

This is the distance between the anterior edge of the hook bone (Tuber coxa) and the posterior end of the pin bone (Tuber ischium), measured on the right-hand side of the animal.

(5) **Width of Hooks.**

This measurement represents the (horizontal) distance between the two Tuber coxae of the pelvis.
(6) Width of Hips.

This represents the width of the hips between the most lateral points of the major trochanters, while the hind legs are kept parallel and at right angles to the body.

(7) Width of Head.

This represents the distance between the outer edges of the two orbits.

(8) Length of Lower Jaw (Mandible).

This was measured from a point on the gum, between the incisors, to the angle of the lower jaw. In order to make the measurement the chin was lifted up, and the lower lip pushed down slightly, while one end of the callipers was placed on the lower gum and the other end on the angle of the lower jaw. Measured on the right-hand side of the animal.

(9) Circumference of Chest.

This measurement is sometimes known as "heart girth". It was taken round the chest (just behind the elbows and at approximately the same place as for the measurements for depth of chest) and as close to the skin as possible. By using thin rubber-coated wire and parting the wool carefully, it was possible to get a measurement close to the skin even in animals carrying a great deal of wool, but the presence of wool inevitably makes this measurement a few millimetres larger than it would be on a shorn animal. It is
believed that errors in chest girth due to the presence of wool were approximately the same in the different breeds. This is the only measurement studied in which the presence of wool introduces a serious possibility of error.

(10) Circumference of Fore-Cannon Bone.

This was measured at the most slender part of the metacarpal and as close to the skin as possible. The measurement was made on the right fore-leg in all cases.
V. Treatment of the Ewes and Their Lambs.

All the ewes that provided the lambs for this study were kept in good condition and were subjected to the usual methods of feeding and management at the University Farm. Apart from the Blackface ewes which were mated in December 1948, all the rest of the ewes were mated during the period between 25th October and 25th December 1948. Number of rams used varied in each flock according to its size on the basis of one ram to 50 ewes.

All the ewes that provided the crossbred lambs studied (i.e., Halfbred and Cheviot ewes) were "flushed" before the tupps were introduced.

About six weeks before lambing these ewes were given supplements for "steaming up". They were given 1 lb. of hay and turnips (½ cart for every 50 ewes) daily from the last of January until lambing. Under normal circumstances they would have received one cart of turnips per 50 ewes but, owing to scarcity, they were given only half this amount. From lambing time to the end of May (until the grass comes) the ewes were given young grass and a supplement of crushed oats and ewe-mixture (½ lb. for each ewe).

The Oxford- and Suffolk-crosses were docked at 6 to 7 weeks of age. The lambs which were to be used subsequently for breeding were not docked. These were the Halfbred (i.e., Border Leicester x Cheviot) and the Blackface lambs.

The crossbred lambs were weaned on 19th August 1949.
on which date the Oxford-cross and the Suffolk-cross were sent to market.

The Blackface ewes had no feeding other than what they got on the hills. That is to say, nothing but heather and bent (grass). Their lambs were weaned at the end of September 1949.

The Halfbred and the Blackface lambs were kept on their farms for breeding and cross-breeding purposes.

All the lambs of the above-mentioned four flocks were injected against dysentery immediately after birth.

They were given worm doses in June when their mothers were being shorn.

It should be noted that all the lambs in question were reared as twins, irrespective of being actually twins or triplets.

The Hampshire flock was reared under the normal highly intensive feeding breeding conditions, and the Hampshire lambs were therefore fed at a higher level than the crossbred lambs studied. They also differed in being all singles of both sexes.
RESULTS AND DISCUSSION.

N.B. All Tables (other than those concerned with birth weight) and all Figures referred to in this Section are bound separately for the convenience of the reader.

I. Birth Weight.

The period during which the ewes were mated to the Oxford, Suffolk and Border Leicester rams was from 25th October to 25th December 1948. The Blackface ewes were mated only in December 1948.

The Blackface ewes did not receive extra feeding other than that which they grazed on the hills (i.e., grass and heather). Nevertheless, these ewes, being of a thrifty breed, were found to be in reasonable condition when the lambing season started.

On the other hand, the ewes that provided the crossbred lambs received more care, typical of that under lowland conditions. They were all subjected to a method of feeding which was capable of keeping them in good condition. According to this method they were "flushed" before mating and adequately fed for 6 to 8 weeks before lambing (steaming up of the ewes).

It was observed among the crossbred lambs that, although the Oxford, Suffolk and Border Leicester rams were left with the ewes during the same mating time and for an equal number of days, yet the Oxford-cross lambs were born first, followed by the Suffolk-cross, then the Halfbred lambs (Border Leicester x Cheviot). The difference in time of lambing between the
three groups does not show whether any one group had a shorter gestation period than the others, for the period during which the ewes were mated was relatively long.

The lamb is usually born covered with sticky amniotic fluid and moisture and therefore its real dry birth weight cannot be easily determined immediately after birth. However, Hammond (1932) quoting Richter and Brauer (1914), observed that newborn lambs lost weight at first (due to evaporation of moisture), then regained the weight lost after 1.7 days, being then about the same as at birth. Donald and McLean (1935) claimed that lambs increase in weight up to 1 lb. at the end of 24 hours after birth.

As the lamb is still in an active stage of growth when it is born the sooner its real dry birth weight is determined the more accurate it will be. Bearing this in mind, when collecting the lambs for this study, birth weights were determined from 12 to 17 hours after birth. By this time the lambs were found to be dry. Also, this period of time was not long enough to cause any appreciable error due to growth of the lamb or to the milk it had consumed. Lambs used for this study were female twins of the four groups and Oxford-cross female triplets. The female twin lambs were of two kinds - those that were twins to females and those that were twins to males. The number of female-female twin lambs made it possible to compare them in the four groups. The number of female-male twins was small in the case of the
Halfbred and the Suffolk-cross groups. None was available amongst the Blackface lambs. A comparison between female-male and female-female twins was made only in the case of the Suffolk-cross group (Table 1)

**TABLE 1.**

Average birth weight of Suffolk-cross female twin lambs (lbs.)

<table>
<thead>
<tr>
<th></th>
<th>Female-female twins</th>
<th>Female-male twins</th>
<th>Average of both</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of lambs</td>
<td>10</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>Av. birth weight (lbs.)</td>
<td>9.00 ± 0.35</td>
<td>9.25 ± 0.46</td>
<td>9.11 ± 0.27</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>12.17%</td>
<td>13.92%</td>
<td>12.82%</td>
</tr>
</tbody>
</table>

The environmental conditions were similar in these two groups as they belong to one flock, and their mothers, which were of the same age, were reared and bred on the same farm.

From Table 1 the difference between the two groups of female twin lambs was found to be not significant. Therefore the results were added of the two types of female twins in each group so that the comparison between the groups could be based on greater number of lambs.

In a comparison of the birth weights of the lambs of the four groups the mean birth weights of the female twin lambs were as follows:
TABLE 2.

<table>
<thead>
<tr>
<th>Twins to 99</th>
<th>No. of lambs</th>
<th>Oxford-cross</th>
<th>Halfbred</th>
<th>Suffolk-cross</th>
<th>Blackface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twins to 99</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Mean birth weight (lbs)</td>
<td>12.3±0.30</td>
<td>9.4±0.57</td>
<td>9.0±0.35</td>
<td>7.5±0.21</td>
<td></td>
</tr>
<tr>
<td>Coeff. of variation</td>
<td>9.34%</td>
<td>17.13%</td>
<td>12.17%</td>
<td>9.47%</td>
<td></td>
</tr>
<tr>
<td>Twins to 99 + twins to 99</td>
<td>10</td>
<td>11</td>
<td>18</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Mean birth weight (lbs)</td>
<td>12.16±0.34</td>
<td>9.99±0.53</td>
<td>9.11±0.27</td>
<td>7.67±0.24</td>
<td></td>
</tr>
<tr>
<td>Coeff. of variation</td>
<td>8.77%</td>
<td>17.45%</td>
<td>12.82%</td>
<td>9.26%</td>
<td></td>
</tr>
</tbody>
</table>

From this table it can be seen that the Blackface female twins were the lightest and the Oxford-cross female twins were the heaviest at birth.

The average birth weight of the Blackface female twin lambs differed significantly from that of the crossbred lambs. Further, the mean birth weight of the Oxford-cross differed significantly from that of any of the other crossbred groups, whereas the difference between the means of the Suffolk-cross and the Halfbred was not significant.

It is well known that, in order to obtain reliable results suitable for a comparison between different groups of lambs for a study of breed differences, it is necessary to eliminate, as much as possible, the effect of the extraneous factors, e.g., sex differences. If such effects could not be nullified they should at least be equally common in all
comparable groups. Differences between the four groups with regard to sex, number of lambs per parturition, and time of lambing, were avoided by comparing birth weights of female twin lambs collected in the first week of the lambing season of each group. The use of more than one ram in each flock makes it impossible to relate the lambs of every group to a specific ram. Table 3 shows that the mothers, although adults, were not of comparable ages.

**TABLE 3.**

Age of ewes at time of lambing (within a group all ewes were of the same age).

<table>
<thead>
<tr>
<th>Breed</th>
<th>Age in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackface ewes</td>
<td>4 - 5</td>
</tr>
<tr>
<td>Halfbred ewes (crossed with Oxford Down rams)</td>
<td>5</td>
</tr>
<tr>
<td>Halfbred ewes (crossed with Suffolk Down rams)</td>
<td>2</td>
</tr>
<tr>
<td>Cheviot ewes (crossed with Border Leicester rams)</td>
<td>4</td>
</tr>
</tbody>
</table>

It should be noted that the general practice is to mate young Halfbred ewes with the Suffolk Down rams and to mate older Halfbred ewes with the Oxford Down rams. The younger ewes are better suited for producing lambs of superior mutton and fattening qualities. It is believed that the older ewes are suitable for crossing with the Oxford-cross to produce lambs of larger frame and good mutton and fattening qualities.
Table 3 shows that the Suffolk-cross was obtained from young virgin ewes. Since the Suffolk-cross lambs were their first crop their birth weights may be lighter than those which would be obtained from older ewes, 4 to 5 years of age.

The weights of the ewes in the different groups were not comparable. This may be seen from Tables 4, 5 and 6.

**TABLE 4.**

Average weights of the Halfbred ewes that provided the Suffolk-cross female twin lambs (lbs.)

<table>
<thead>
<tr>
<th></th>
<th>Ewes with female-female twins</th>
<th>Ewes with female-male twins</th>
<th>Average of both groups of ewes</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of ewes</td>
<td>5</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>Mean weight (lbs.)</td>
<td>$121.25 \pm 1.77$</td>
<td>$131.63 \pm 2.27$</td>
<td>$127.67 \pm 2.08$</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>$3.3%$</td>
<td>$4.9%$</td>
<td>$5.9%$</td>
</tr>
</tbody>
</table>
### TABLE 5.

Average weights of mothers of female-female twin lambs

<table>
<thead>
<tr>
<th></th>
<th>Halfbred ewes (x Oxford)</th>
<th>Cheviot ewes (x B. Leicester)</th>
<th>Halfbred ewes (x Suffolk)</th>
<th>Blackface</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of ewes</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Av. weight (lbs.)</td>
<td>191.19±15.64</td>
<td>134.81±4.1</td>
<td>121.35±1.77</td>
<td>108.63±2.98</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>16.37%</td>
<td>6.07%</td>
<td>3.3%</td>
<td>6.7%</td>
</tr>
</tbody>
</table>

### TABLE 6.

Average weights of mothers of female-female + female-male twin lambs (lbs.)

<table>
<thead>
<tr>
<th></th>
<th>Halfbred ewes (x Oxford)</th>
<th>Cheviot ewes (x B. Leicester)</th>
<th>Halfbred ewes (x Suffolk)</th>
<th>Blackface</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of ewes</td>
<td>6</td>
<td>7</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>Av. weight (lbs.)</td>
<td>184.93±11.33</td>
<td>144.86±3.7</td>
<td>127.67±2.08</td>
<td>106.63±2.89</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>15.00%</td>
<td>6.8%</td>
<td>5.9%</td>
<td>6.03%</td>
</tr>
</tbody>
</table>
All ewes were weighed immediately after being shorn (when about 3 months after lambing) since it was thought that they would be in good condition by then, having regained the loss due to parturition.

Halfbred ewes with female–female twins were significantly lighter than those with female–male twins (Table 4). The difference between the birth weights of their lambs was small and not significant (Table 1). Therefore, the difference between the mothers of the two types of twins was not reflected in the weights of the female partner of these twins. Bonsma (1939) (see page 13) found that male lambs had an increasing effect on the weight of their growing mothers during pregnancy (hormone activity). The difference in weight of the above two groups of Halfbred ewes which provided the Suffolk-cross may have been caused by the same effect, since these ewes were still growing during pregnancy and were two years of age when they had their lambs. Had the live weight been recorded at mating time, a comparison between these results and the results obtained after lambing (at shearing time) would have clarified this point, and would have shown whether the males (that were twins to females) had an effect on their mother's body weight during pregnancy.

The data in Table 5 show that there were significant differences between the mean live weights of the different groups of ewes with female–female twins. When the ewes that gave birth to female–male twins were included, the arrangement
of the results in Table 6 (from heaviest to lightest) were in the same order as in Table 5.

The differences between the groups in Table 6 - as those in Table 5 - appear to be significant.

The birth weights of the crossbred lambs studied are of lambs bred from mothers which were in good condition, whereas those of the Blackface were obtained from lambs bred from mothers which were maintained under relatively poorer conditions.

The relationship between the birth weights of the female twin lambs and the body weights of their mothers, in the four groups, is presented in Figure 2, together with Bonsma's results (1939) from single lambs of both sexes (Merino x different Down rams). From this Figure it can be seen that the Halfbred ewes which provided the Oxford-cross lambs were the heaviest, followed by the Cheviot ewes which provided the Halfbred lambs. The Halfbred ewes which were crossed with Suffolk Down rams showed the next heaviest weight, followed by the Blackface ewes which were the lightest.

The birth weights of the lambs of the four groups were also in the same order.

All the points representing the relationship between birth weights of the crossbred lambs and the body weight of their mother in Figure 2 are on a straight line. That of the Blackface was slightly below the continuation of the straight line that passes through the other three groups. Figure 2
shows clearly a strong influence of the mother's weight on the birth weight of her lambs. Although this was not shown in the comparison of the two groups of Suffolk-cross lambs given above (Tables 1 and 4), the overall data (Figure 2) suggests that the weight of the mother is of over-riding importance in determining the birth weight of the lamb, and in general, there is a linear relationship between the two.

Under good nutritional conditions typical of the crossbred lambs studied, the relation can be expressed approximately as:

\[ L = 7.6 + 0.053 (E - 100) \text{ lbs} \]

where \( L \) = average birth weight of one twin female lamb and \( E \) = weight of ewe. Thus, the average birth weight of lamb increases by 1 lb, for an increase of about 19 lbs, in weight of ewe, while total birth weight of twin female lambs increases by 1 lb, for about 9.5 lbs, increase in ewe weight. It should be emphasised that these figures apply only to twin females, but probably the rate of change would not be very different for singles.

The Blackface lambs whose mothers had a much lower level of nutrition during pregnancy, fall only a little below the line of the other groups.

Bonsma's data (1939) for Merino singles are also plotted for comparison in Figure 2. These show an approximately parallel trend, though his lines appear to be a little steeper. He found a mean increase in birth weight
of 0.074 lbs. (in male lambs) and 0.071 lbs. (in female lambs) for an average increase of 1 lb. in the live weight of the ewe. The difference between his results and those of the present investigation could be accounted for by his data being only of single births, whereas single lambs were not available for the present study in all four groups. Therefore, it can be expected that the line representing such a relationship in triplets will be below that of twins and approximately parallel to it.

Conclusions.

Since it has been shown that there were environmental factors confounding the comparison between the groups, the differences appearing between the birth weights of the 4 groups, which have been detailed and discussed above, cannot be attributed to solely genetic or environmental conditions. The material was not rigorously controlled being from commercial flocks, pastured on different farms, and therefore it does not allow any estimate of the relative importance of breed differences and environmental differences, since these cannot be separated.

In the present case, the effects of weight of dam and breed of sire are confounded. Breed of sire may have influenced birth weight, but Figure 2 suggests that its effect must be very small in comparison with the effect of weight of dam. Thus, carefully designed experiments would be necessary to determine the effect of factors other than weight of dam on birth weight.
Birth weights of female twins and female triplets of the Oxford-cross.

The average birth weights obtained for the female twins and the female triplets of the Oxford-cross were as follows (Table 7).

**Table 7.**

Average birth weights of the Oxford-cross twin and triplet lambs (lbs.)

<table>
<thead>
<tr>
<th></th>
<th>Twins</th>
<th>Triplets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lambs</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Average birth weights (lbs.)</td>
<td>12.16±0.34</td>
<td>9.7 ± 0.5</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>8.77%</td>
<td>13.59%</td>
</tr>
</tbody>
</table>

The difference in birth weight between these two groups of female lambs was found to be significant. However, these Oxford-cross female twins and female triplets were obtained from Halfbred ewes of equal ages, bred, fed and managed on the same farm.

The average body weight of the ewes which provided the twins was compared with that of the ewes which provided the triplets and the results are presented in Table 8.
TABLE 8.

Average weights of the Halfbred ewes with Oxford-cross twins and triplets (lbs.)

<table>
<thead>
<tr>
<th></th>
<th>Halfbred ewes (mated to Oxford Down rams)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With twins (6 ewes)</td>
</tr>
<tr>
<td>Av. weight (lbs.)</td>
<td>194.93 ± 11.33</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>15.00%</td>
</tr>
</tbody>
</table>

From this Table it can be seen that, although the number of ewes studied was small, the results tend to show that the ewes with triplets were lighter in weight than those with twins. It is a common belief in general practice that the ewe is most likely to produce multiple births under optimum conditions of feeding. Therefore, the general practice in sheep breeding is to breed under these optimum conditions ewes selected for their ability to bear twins. This means selecting at the same time ewes which will produce multiple births. This does not necessarily mean that the selected ewes should be among the heaviest ewes within a breed, since this selection is based on the performance of the ewe. Therefore, it is possible that the ewes with triplets, in spite of their light body weight were more capable of producing multiple births. Clark (1934), who found that the practice of "flushing" tends to lead to a higher ovulation rate (provided that the ewes are
not already in good condition) concluded that gain in weight of itself is not necessarily indicative of a higher ovulation rate. The results of the present work support his findings.
APPENDIX.

Hampshire Data.

(Provided by Dr. E. C. R. Reeve)

The average birth weights of single male and female Hampshire lambs are shown in Table 9. The difference between the average birth weights of the lambs of the two sexes was found to be significant. Unfortunately, no data for the ewes which provided these lambs were available to show the relationship between birth weight of lambs and weight of ewe.

**TABLE 9.**

Average birth weights of Hampshire single lambs (lbs.)

<table>
<thead>
<tr>
<th>No. of lambs</th>
<th>Male lambs</th>
<th>Female lambs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Average birth weight (lbs.)</td>
<td>$14.85 \pm 0.72$</td>
<td>$12.54 \pm 0.87$</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>$13.7%$</td>
<td>$18.43%$</td>
</tr>
</tbody>
</table>
II. Growth in Weight.

(a) Changes of body weight with age.

The two growth curves representing the average of the weekly body weights of female-female twins and female-male twins of the Suffolk-cross lambs (Figure 3, Table 10) showed practically no differences, either in the shape of the curves or between the weekly weights of similar ages in the two groups over a period of 21 weeks. Also, no differences appeared when the Logs of the weekly weights were plotted against age. Absolute gain per week (Table 11) and the relative growth rates (Table 12, Figure 4), which were calculated by the method given below, showed that there were but negligible differences between these two groups. From this, it was understood that in the two Suffolk-cross groups, the growth of the female twin lambs was identical, regardless of whether they had a female or a male sib.

Therefore, in comparing the growth in weight of the four groups it was decided to obtain results from both types of female lambs in each group so that the comparison could be based on a greater number of lambs and, consequently, better growth curves could be secured.

The average body weights obtained at the different intervals during the 21 weeks from birth for each of the four groups studied are tabulated in Table 13, and the growth curves are presented in Figure 5.
The growth curves of the four groups studied showed a slight tendency for growth rate to increase during the first 5-7 weeks and a tendency for it to decrease after about 3 months (Figure 5). This decrease is particularly marked in the Blackface and can be ascribed to the poorer nutritional conditions under which they were reared.

It can also be seen from Figure 5 that the Oxford-cross lambs were largest at birth and during the whole period studied. The Halfbred and the Suffolk-cross (with small differences between them during the 21 weeks after birth) followed the Oxford-cross in weight: the Halfbred was superior to the Suffolk-cross until about the 16th week, after which the latter went ahead. The Blackface lambs were smaller than the crossbred lambs at birth and remained smaller during the whole period studied.

Among the crossbred groups, differences in body weight showed a tendency to decrease with age during the first few weeks (until about 5-7 weeks of age) after which these differences tended to increase gradually until the end of the period studied. The differences in weight between the Blackface and any of the crossbred lambs gradually increased from birth until the end of the period.

No data are available in the literature for the normal growth of any of the above female twin lambs. However, the data of the female twin Suffolk lambs published by Hammond (1932), when compared with those of the female Suffolk-cross lambs studied in this investigation (Table 13, Figure 5) showed
that the weights of both groups were almost equal from birth until the 3rd week, after which the Suffolk-cross lambs were significantly heavier.

Body weight data of the Hampshire single males and females, supplied by Dr. E.C.R. Reeve, are tabulated in Table 14 and plotted in Figure 5. It is clear that the males were heavier than the females from birth until the 21st week of age, and that both males and females, being singles, were the heaviest of all lambs concerned in this work.

When the Log. of body weight was plotted against age (Figure 6) differences between the various groups studied appeared clearly.

Factors which cause variation of birth weights have been discussed above (Section I) and it is probable that these have similar effects on the variation of the growth of body weight. Therefore, differences found between the groups in growth in weight cannot be related to genetical differences only for, as mentioned previously, there were differences between the environmental conditions of the different groups of lambs studied.

Apart from genetical factors, nutrition plays a major part in the growth of the animal, particularly early in life. The young lambs are usually dependent on their mother's milk in their early life. After the 3rd or the 4th week they start to nibble the grass from the pasture. The amount of grass consumed daily by the lambs increases gradually
until weaning time. By then the animal is found to be accustomed to grazing habits. Any amount of grass which the lambs consume before weaning could be considered as a supplement to their mother's milk.

Since lambs feed increasingly off the pasture up to weaning, it follows that differences may occur between groups of lambs, both in the type of pasture which is available and in the use which they make of it. The first type of difference may occur between the Blackface on the one hand and the crossbred lambs on the other, since these two groups were reared on different types of farms (hill farm as compared with lowland farm). The second type of difference is very difficult to measure without feeding experiments, and may occur between the crossbred groups which were reared on the same type of farm (lowland).

The Suffolk-cross and the Halfbred differ genetically, yet no significant differences were found between these types when reared on the same farm. This does not necessarily mean that the two types do not differ, since the pasture which suits one might not suit the other.

(b) Absolute gain in weight per week.

Absolute gains per week were calculated for each group from the data in Table 13, tabulated in Table 15, and presented diagrammatically in Figure 7. In calculating the absolute gain per week the following formula was used:
Average absolute gain in weight per week = \( \frac{W_2 - W_1}{t_2 - t_1} \)

= \( \frac{\text{diff}}{\text{dt}} \)

where,

\( W_2 \) = body weight at the end of the interval \( t_2 \)
\( W_1 \) = body weight at the end of the interval \( t_1 \).

In all the crossbred groups the average absolute gain per week increased from birth until it reached a peak at the 5th-7th week. The value reached at this peak was greater in the Oxford-cross, which retained this high value until the 13th week after birth. In other words, the Oxford-cross lambs showed a persistency in their absolute gain per week from about the end of the 5th week until the end of the 13th week. In the case of the other two crossbred groups no persistency could be seen, for their absolute gain decreased during the successive weeks until it became relatively very small at the 21st week. The value reached at the peak in the Blackface was markedly smaller than in the crossbred groups, and was reached at an earlier age (3rd-4th week). In general, the absolute gain per week was less than in the crossbred groups over the whole period studied.

No doubt the same factors that interfered and caused the differences observed between the growth curves of the lambs of each group also interfered with respect to the differences observed between the groups in the mean weekly gain in question.
(c) **Relative growth rate of body weight.**

The average relative growth rates of the increase in body weight in every group are tabulated in Table 16 and presented graphically in Figure 8. In calculating the relative growth rates for each group the following formula was used:

\[
\text{Relative growth rate} = \frac{\text{Absolute gain in weight per unit of time}}{\text{Average of weights at the beginning and the end of the interval}} = \frac{\frac{W_2 - W_1}{t_2 - t_1}}{\frac{1}{2}(W_1 + W_2)} = \frac{\frac{dW}{dt}}{\frac{1}{2}(W_1 + W_2)}
\]

Where

\[W_2 = \text{body weight at the end of the interval } t_2,\]
\[W_1 = \text{body weight at the end of the interval } t_1.\]

The relationship of relative growth rates to age shown in Figure 8 illustrate several differences between the groups. These are:

1. During the first week the Blackface lambs had the greatest relative growth rate, followed by the Halfbred, the Oxford-cross, and then by the Suffolk-cross.

2. Two of the groups (the Suffolk-cross and the Halfbred) showed an increase of their relative growth rate to a maximum reached in the second week. The other two groups (the Blackface and the Oxford-cross) showed from a birth a decline of the relative growth rate, showing no maxima, as in the other two groups.

3. The relative growth rate of the Blackface declined rapidly from birth.
(4) The decline in the relative growth rate of the Oxford-cross took place from birth until the end of the 4th week. Then, the relative growth rate maintained by them remained somewhat unchanged until about the 7th week, after which it declined until the end of the period studied.

(5) During the 2nd week the Halfbred and the Suffolk-cross, due to the increase which they showed, reached a value analogous to that of the Blackface in this period.

(6) After the second week, the relative growth rates of the Suffolk-cross declined until the 21st week. The relative growth rates of the Halfbred followed those of the Suffolk-cross over the same period and there were no marked differences between them.

(d) Body weights expressed as percentages of birth weight.

Body weights obtained at the different intervals were expressed as percentages of birth weight for every group and tabulated in Table 16. The Blackface lambs had a greater percentage increase of weight than the crossbred lambs during the first 4 weeks, but less thereafter. The Suffolk-cross and the Halfbred lambs (with small differences between these two groups early in the period but somewhat greater differences in favour of the Suffolk-cross lambs later) made greater growth than the Oxford-cross lambs during the whole period.
Conclusions.

Although the crossbred lambs were significantly heavier than the Blackface lambs from birth onwards there were generally no major differences in their relative growth rates except in the first week when the Blackface lambs had the fastest growth rate. As the Blackface is a slower growing breed than the other groups, this indicates that the crossbred lambs were not capable of maintaining the faster relative growth rate, but simply maintained the advantage established at birth.

It is suggested that the nutrients on which the crossbred lambs were fed early in the period were probably not sufficient to ensure maximum growth very early in life, and consequently this might have affected their growth rates. It is also possible that the ewes which provided the crossbred lambs did not supply them with enough milk to meet the demands of the fast growing animals as compared with the Blackface ewes.

Since no major differences of relative growth rates were found between the four groups studied, which differ widely in genetic origin, it can be concluded that either (1) although the groups are of different genetic origin, they do not differ genetically in respect to relative growth rate, or (2) that unless the level of nutrition is constant from birth in all the comparable groups, differences in hereditary growth rates cannot be observed.
Growth in weight in the female twins and female triplets of the Oxford-cross.

A comparison between the average body weights of the female twins and the female triplets of the Oxford-cross is shown in Table 13. It should be noted that these triplets were reared as twins - two lambs suckling one ewe.

The Logs. of the average body weights of the twins and those of the triplets were plotted against age in Figure 9. No other curves showing the growth of their body weights are presented as the differences between them can be easily seen from this Figure.

The twins were always heavier than the triplets, and the differences between the Logs. of their weights decreased slightly from birth until the end of the period.

This comparison shows clearly that the greater the number of lambs born per ewe the smaller the weight of the lamb at birth or at any subsequent age, and that the weight of the lamb at weaning depends on its birth weight.

When comparing the figures for absolute gain per week of the twins with those of the triplets (Table 15) those of the latter were slightly smaller (particularly early in life) than those of the former, but both exhibited the same trend over the period studied.

The relative growth rates of the twins were slightly greater than those of the triplets early in the period, but were slightly smaller later (Table 16, Figure 10).
When their body weights were expressed as percentages of birth weight (Table 17) it was found that the twins showed slightly greater growth in weight than the triplets early in the period (about the 7th week) but less thereafter.

Differences in body weight at weaning between the twins and the triplets could be attributed to two causes:

1. Differences in birth weight,
2. Differences in the increase of body weight during post-natal life.

Differences in birth weight are mainly due to nutritional factors in utero. For, as the amount of nutrients supplied by the mother to the embryo is limited, it is possible that a twin may receive a larger amount of nutrients, which would enable it to grow more than a triplet in pre-natal life. Hence, at birth the weight of a twin would be heavier than that of a triplet.

Differences between the twins and the triplets in the increase of body weight during post-natal life could also be attributed to nutritional factors, even though the triplets were reared as twins. For, as the twins exhibited more growth than the triplets early in life, but less so later on, it seems that the triplets, being smaller and weaker than the twins early in life, were not able to obtain sufficient quantities of milk from their mothers to enable them to grow at rates equal to those of the twins, and it appears that only when the lambs received supplements to their mother's milk did the growth of the triplets increase at a relatively faster rate.
III. Body conformation as indicated by skeletal growth and body measurements.

All animals studied were weighed and measured at the same time. Since animals were born over a week interval, it was necessary to correct for differences in age. The method of correction has been given above (see page 43). The corrected body measurements were averaged over each group and the following analysis and discussion deals only with group averages of body measurements.

The corrected averages in each group were plotted against age to show the growth curves. These can be compared (a) within a group of animals, between different body measurements, (b) within a certain body measurement, between different groups of animals, and (c) overall body measurements, between different groups of animals.

The growth curves can be analysed as:

1. Absolute gain per week,
2. Relative growth rate,
3. Percentage of the first measurement taken at birth.

In addition, a comparison can be made between different breeds of sheep on the basis of a standardised body weight or body measurement. This can show the variation in growth of body measurements in relation to the standard weight or measurement.

Therefore, the different body measurements were plotted against length of cannon bone, length of pelvis, and body weight, to show relative differences in the four groups.
of lambs studied. Length of cannon bone, length of pelvis and body weight were chosen as standards of comparison for the following reasons:-

(1) **Length of cannon bone.**

The cannon bone grows the least in length in post-natal life and is easier to measure with accuracy than other body measurements. This measurement was used by other investigators (cf. Hammond 1932) who pointed out the advantages of using it as a standard in slaughter experiments for the following reasons: (1) easily cleaned, (2) slow rate of growth, and (3) easily obtained without cutting up the carcase.

(2) **Length of pelvis.**

The pelvis is one of the important parts of the body round which the most valuable meat is carried. Its length can be measured easily and with fair accuracy and it has a fast rate of growth in post-natal life.

(3) **Body weight.**

This is the quantitative measurement on which mutton is sold. A comparison of the relationships between body weight and body measurements reflects differences between weight and conformation in the different breeds. This also might indicate their comparative suitability for mutton production.

Since each body measurement was analysed by the same methods, e.g., absolute gain per week, relative growth rate, etc., a certain amount of repetition is unavoidable.
(a) Changes of body measurements with age.

The averages of the different body measurements as they change with age are tabulated and presented graphically in the following Tables and Figures:

<table>
<thead>
<tr>
<th>Table</th>
<th>Figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of hind cannon</td>
<td>18</td>
</tr>
<tr>
<td>Circumference of fore cannon</td>
<td>19</td>
</tr>
<tr>
<td>Width of head</td>
<td>20</td>
</tr>
<tr>
<td>Length of jaw</td>
<td>21</td>
</tr>
<tr>
<td>Length of tibia</td>
<td>22</td>
</tr>
<tr>
<td>Length of pelvis</td>
<td>23</td>
</tr>
<tr>
<td>Width of hips</td>
<td>24</td>
</tr>
<tr>
<td>Width of hooks</td>
<td>25</td>
</tr>
<tr>
<td>Depth of chest</td>
<td>26</td>
</tr>
<tr>
<td>Circumference of chest</td>
<td>27</td>
</tr>
</tbody>
</table>

It can be seen, as mentioned previously for body weight, that there is a slight tendency for growth rate to increase during the first 5-7 weeks of age and a tendency for it to decrease after about 3 months. This decrease is particularly marked in the body measurements of the Blackface (except that of width of head), due probably to the poorer nutritional conditions under which the Blackface lambs were reared.

From birth until the end of the 21 weeks studied, the Oxford-cross had the greatest dimensions, followed by the Suffolk-cross and the Halfbred (with small differences between them), and then by the Blackface.

In every measurement, the differences found between the crossbred groups at birth were small and showed very slight change with age. Those found at birth between the Blackface...
and any of the crossbred groups in every measurement – except for that of width of head – were not only greater than those found between the crossbred groups, but they also showed greater increase with age. Reference to Table 18, Figure 11, and Table 23, Figure 6 shows this quite clearly for length of hind cannon and length of pelvis.

Head width was slightly smaller at birth in the Blackface than in the crossbred groups, and this difference did not increase much with age, so that later on there was much less difference in this measurement between the Blackface and crossbred lambs of the same age than in other dimensions.

From this it can be inferred that the Blackface had a relatively wider head than the other groups during the period studied.

(b) Absolute gain per week.

In calculating the absolute gain per week for every body measurement the same formula used in calculating absolute gain in weight per week was used in this connection.

The figures for absolute gain per week for every measurement and all groups are presented in the following Tables and Figures:

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Tables</th>
<th>Figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of hind cannon</td>
<td>28</td>
<td>21</td>
</tr>
<tr>
<td>Circumference of fore cannon</td>
<td>29</td>
<td>22</td>
</tr>
<tr>
<td>Width of head</td>
<td>30</td>
<td>23</td>
</tr>
<tr>
<td>Length of jaw</td>
<td>31</td>
<td>24</td>
</tr>
<tr>
<td>Length of tibia</td>
<td>32</td>
<td>25</td>
</tr>
<tr>
<td>Length of pelvis</td>
<td>33</td>
<td>26</td>
</tr>
<tr>
<td>Width of hips</td>
<td>34</td>
<td>27</td>
</tr>
<tr>
<td>Width of hooks</td>
<td>35</td>
<td>28</td>
</tr>
<tr>
<td>Depth of chest</td>
<td>36</td>
<td>29</td>
</tr>
<tr>
<td>Circumference of chest</td>
<td>37</td>
<td>30</td>
</tr>
</tbody>
</table>
The absolute gain per week was greater in the first few weeks than towards the end of the period. This occurred in all the groups for every measurement without exception.

The absolute gain per week declined more rapidly from birth in the Blackface than in the other groups. Although the Blackface had a relatively high absolute gain during the first week it had the smallest one during the last two weeks in the period. This applied over all measurements (e.g., length of hind cannon, Table 28, Figure 21; length of pelvis, Table 33, Figure 26). The poorer level of nutrition under which the Blackface lambs were reared could account for the rapid decline in their gains.

Not only did the crossbred groups show a slower general decline than the Blackface over the whole period studied, but they also exhibited a somewhat slower decline earlier than later in the period.

The differences found between the crossbred groups were smaller than those observed between the Blackface and any of the crossbred groups. The smallest differences found between the Blackface and any of the crossbred groups were in width of head.

Among the crossbred groups, the Suffolk-cross and the Halfbred lambs showed closely similar results.
(c) Relative growth rates.

In calculating the relative growth rates for every body measurement the same formula used in calculating the relative growth rates of body weight was used in this connection.

The relative growth rates of the different body measurements are tabulated in the following Tables:

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of hind cannon</td>
<td>38</td>
</tr>
<tr>
<td>Circumference of fore cannon</td>
<td>39</td>
</tr>
<tr>
<td>Width of head</td>
<td>40</td>
</tr>
<tr>
<td>Length of jaw</td>
<td>41</td>
</tr>
<tr>
<td>Length of tibia</td>
<td>42</td>
</tr>
<tr>
<td>Length of pelvis</td>
<td>43</td>
</tr>
<tr>
<td>Width of hips</td>
<td>44</td>
</tr>
<tr>
<td>Width of hooks</td>
<td>45</td>
</tr>
<tr>
<td>Depth of chest</td>
<td>46</td>
</tr>
<tr>
<td>Circumference of chest</td>
<td>47</td>
</tr>
</tbody>
</table>

The relative growth rates of all the measurements declined with age in every group. Comparing the results obtained for the four groups it was observed in all the body measurements that the Blackface lambs had greater relative growth rates than the crossbred lambs during the first week (and also during the second week in the case of some measurements, e.g., width of head, Table 40 and depth of chest, Table 46), after which the relative growth rates of the Blackface lambs declined rapidly with age. In this connection, length of hind cannon (Table 38) and length of pelvis (Table 43) could be referred to as examples. There is no evidence, however, that this decline was steady from the beginning until the end of the period studied. From about the second or the
third week onwards the crossbred lambs had greater relative growth rates than the Blackface lambs. Not only was the decline in the relative growth rate of the crossbred lambs slower in general than that observed in the case of the Blackface over the 21 weeks from birth, but this decline was slower early - rather than late - in the period studied.

The differences observed early in the period (from about the 4th until about the 9th week of age) between the Blackface lambs and any of the crossbred groups (in favour of the latter) were somewhat greater than those found between them later on.

Differences in relative growth rates were smaller among the crossbred groups than between the Blackface and the crossbred groups.

In the case of width of head (Table 40) the Blackface lambs showed greater relative growth rates than the crossbred lambs in the first two weeks, after which only small differences between them (in favour of the crossbred lambs) were observed.

The relative growth rates of all the measurements in the Blackface declined continuously during the period studied. However, the decline of the width of head measurement was somewhat slower relative to that of the other body measurements, and this difference in behaviour of the width of head measurement requires explanation. Such an explanation can be found in the presence of the horns in the
Blackface female lambs which could account for the wider head possessed by this group as compared with the crossbred groups of hornless females studied.

In a study of the growth of the horns of the Blackface female twin lambs (Figure 31) it is shown that, during post-natal life, the horns appear externally (out of the epidermis) at about 8-10 days after birth. Growth of the horns from this age seems to be linear.

It is possible that the growth activity of the horns in the Blackface female twin lambs greatly affects that of the width of head during the first two weeks from birth and, as the horns become visible and continue to grow, then this growth activity of the horns continues to affect the growth of width of head but to a somewhat lesser degree.

(d) **Body measurements expressed as percentages of first measurements taken at birth.**

(1) **Over all lambs.**

For the 56 female lambs concerned in this study irrespective of breed or of their being twins or triplets, the averages obtained at the different intervals, for every body measurement, were expressed as percentages of the corresponding measurement taken at birth and are shown in Table 48 and Figure 32.

The results thus presented illustrate that the most rapid growth occurs during the earlier stages of life, decreasing with advancing age, as would be expected. The overlapping of the curves indicates that the decline in the rate of growth of these measurements took place at different
rates and times. There was no evidence that this decline was steady during the 21 weeks from birth in every measurement.

It is shown in Figure 32 that these measurements were not in the same order at every interval, nor did they show the same differences. This suggests that, during post-natal life, the different parts of the body differ not only in their growth rates but also in their relative proportions.

At the 21st week of age the measurements showed a wide range in the growth of the different parts of the body as may be seen from the following: (Figures to the nearest whole number).

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width between hook-bones</td>
<td>254%</td>
</tr>
<tr>
<td>Circumference of chest</td>
<td>220%</td>
</tr>
<tr>
<td>Depth of chest</td>
<td>209%</td>
</tr>
<tr>
<td>Width of hips</td>
<td>206%</td>
</tr>
<tr>
<td>Length of pelvis</td>
<td>203%</td>
</tr>
<tr>
<td>Length of tibia</td>
<td>171%</td>
</tr>
<tr>
<td>Length of jaw</td>
<td>166%</td>
</tr>
<tr>
<td>Width of head</td>
<td>162%</td>
</tr>
<tr>
<td>Circumference of cannon</td>
<td>152%</td>
</tr>
<tr>
<td>Length of cannon</td>
<td>146%</td>
</tr>
</tbody>
</table>

It can be observed that the greatest increase over the 21 weeks after birth was made in the transverse measurement of "width between the hook-bones" and the smallest increase was made in "length of the hind cannon-bone". After width between the hook-bones, circumference of chest showed the next highest increase, followed in succession by depth of chest, width of hips and length of pelvis - with
small differences between the last three body measurements. These were followed by length of tibia, length of jaw and width of head. Circumference of fore-cannon came next and was only slightly greater than length of hind cannon.

These results indicate that both depth and circumference of chest measurements exhibited greater growth than either width of hips or length of pelvis. However, taking into consideration the measurements, width between hook-bones, width of hips and circumference of chest, it can be stated that the trunk showed a great increase in width.

This seems to be in agreement with the findings of Bonsma (1939) who showed graphically the weekly averages of different body measurements obtained during 18 weeks from birth, expressed as percentages of their corresponding measurements taken at 3 weeks after birth. His data, which were collected from 237 lambs (Merino and Merino x British breeds) grouped together irrespective of sex or breed, showed that the greatest growth occurred in width of chest and width between hook-bones. These were followed by depth of chest and circumference of heart girth, which exhibited approximately equal growth.

Although in both Bonsma's results (before reaching the 18th week) and in the present investigation (during the 21 weeks studied) circumference of chest showed a slight increase in growth rate over depth of chest, the difference in the amount of growth made by these two measurements appearing in
the results at 21 weeks of age (Figure 32) does not make the present results contradictory since the fleece is undoubtedly a factor affecting the accuracy of circumference of chest measurements. The present results for chest and pelvis measurements are not in agreement with those obtained by Hammond (1932) who found that the pelvis had a greater rate of growth than the ribs.

The present results concerned with the measurement of the leg for length of hind cannon and length of tibia agree with Hammond's findings. It is evident that the cannon bone, being well developed at birth, showed the least increase in length during the 21 weeks studied, and the tibia, being not so well developed at birth, showed greater increase in length than the cannon bone during the same period.

It appears from Table 48 and Figure 32 that the difference between circumference and length of cannon bone as they grow, increased with age early in life but decreased later on (after the 15th week of age). This indicates that early in the period cannon bone increased in circumference more than in length but towards the end of the period it increased in length slightly more than in circumference. This could be taken as suggesting that, towards the end of the period studied (15th - 21st week) growth of circumference of cannon bone was more retarded than that of length of cannon bone.

Assuming that the figures for circumference of cannon

...
represent the growth of the cannon-bone in thickness, it
could be stated that, at birth, the cannon-bone, being well
developed in length and less so in thickness, grew more in
the latter than in the former in post-natal life. Then,
at about 21 weeks of age, growth in both thickness and in
length was retarded but to a greater degree in thickness than
in length.

From the results obtained for every body measurement
at the 19th and 21st week, given in Table 48 and Figure 32, it
can be observed that growth of all body measurements concerned
in this study was retarded towards the end of the period.
Hammond (1932), who observed similar behaviour in his results
on skeletons of ewes, attributed this retardation to the
supply of "generative ferment" (necessary for the formation
of cartilage) - which is also used by the gonads (required
more by the ewe than by the ram) - and to the effect of the
nutritional factors during growth.

(2) Between female twins of the four groups.

The various body measurements taken at the previously
mentioned intervals were expressed as percentages of measurements
taken at birth, for every group. The results in this
connection are tabulated in the following Tables:
Tables

Length of hind cannon 49
Circumference of fore cannon 50
Width of head 51
Length of jaw 52
Length of tibia 53
Length of pelvis 54
Width of hips 55
Width of hooks 56
Depth of chest 57
Circumference of chest 58

When the results obtained for every group were arranged in descending order at every interval, it was observed that the order of the measurements varied with age and was different in every group. It would obviously be over-complicated to discuss these differences of order at each age, and therefore only that at the 21st week is considered. The results obtained for every group at 21 weeks of age are given in Table 59. This Table shows that the Suffolk-cross and the Halfbred lambs had the same order of measurements as that which was found at the same age for the over all average of the 56 lambs studied. On the other hand, the Oxford-cross twin lambs and also the Blackface lambs (each with different order) showed different orders of measurements than either the Halfbred or the Suffolk-cross.

All the crossbred lambs showed greater growth than the Blackface lambs in practically every body measurement except in width of head, for which the Blackface lambs exhibited slightly greater growth than any of the crossbred lambs. In the case of depth of chest the Suffolk-cross and the Halfbred lambs showed greater growth, and the Oxford-cross lambs less growth, than the
Blackface lambs.

Discussing only the crossbred groups, in the following measurements the Halfbred lambs showed the greatest growth, followed in descending order by the Suffolk-cross lambs and then by the Oxford-cross lambs: length of hind cannon, length of jaw, circumference of chest, circumference of fore cannon, width of hips.

In the measurements, width between the hook-bones, depth of chest and width of head, the Suffolk-cross lambs exhibited the greatest growth, followed by the Halfbred and then by the Oxford-cross lambs in that order.

The Oxford-cross lambs showed greater growth in length of pelvis than the Halfbred lambs which, in turn, exhibited greater growth than the Suffolk-cross lambs in this connection. In length of tibia, the Halfbred lambs exhibited the greatest growth, followed in order by the Oxford-cross lambs, and then by the Suffolk-cross lambs.
Conclusions.

The above results confirm those found by Hammond (1932) in that, at birth, in addition to the fact that the different parts of the body are in different stages of development, the conformation of the lamb at this time differs from that found at older ages.

The only constancy of form in the four breeds studied — as indicated by the above results — was in the change of the absolute gain per week and the relative growth rates, which were declining with age. The mode of change, however, was somewhat different in the fast-growing crossbred lambs than in the slow-growing Blackface lambs which showed more rapid decline.

At birth, the observed differences in form and conformation between the four groups of lambs are undoubtedly due to the differences between them in the growth rates at which the different parts of the body grew in utero.

It was seen that in the subsequent intervals from birth none of these groups preserved the conformation observed at birth, while increasing with age. This could be attributed to the different growth rates at which the different parts of the body grew after birth. The conformation of an animal is directly affected by changes in growth rates of the different parts of the body as the animal grows.

Hence, in postnatal life, differences in conformation between these groups are not only due to the observed differences
at birth, but also to those found between them in the growth rates of each of the different parts of the body.

At any given age the differences between the Blackface and the crossbred lambs in the growth of the various body measurements, and consequently differences in conformation, were merely due - as mentioned previously when discussing "growth in body weight" - to clear environmental (mostly nutritional) and genetical differences. Those found between the crossbred lambs were probably due to the same causes, though the nutritional environment after birth did not vary very much.

It remains doubtful whether the environment had the same effect on the Halfbred and the Suffolk-cross lambs for, in spite of being the result of two different crosses, the Halfbred and the Suffolk-cross lambs which were born and reared on the same farm and were subjected to the same type of feeding and management, showed very little difference in their measurements and body conformation.
Growth of the body measurements of the twins and the triplets of the Oxford-cross.

Data and results for the growth of the different body measurements of the triplets are tabulated with those of the twins in the previously mentioned tables. Comparisons between the growth curves of their body measurements are presented graphically in the following Figures:

<table>
<thead>
<tr>
<th>Figures</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>Length of hind cannon</td>
</tr>
<tr>
<td>34</td>
<td>Circumference of fore cannon</td>
</tr>
<tr>
<td>35</td>
<td>Width of head</td>
</tr>
<tr>
<td>36</td>
<td>Length of jaw</td>
</tr>
<tr>
<td>37</td>
<td>Length of tibia</td>
</tr>
<tr>
<td>38</td>
<td>Length of pelvis</td>
</tr>
<tr>
<td>39</td>
<td>Width of hips</td>
</tr>
<tr>
<td>40</td>
<td>Width between hook-bones</td>
</tr>
<tr>
<td>41</td>
<td>Depth of chest</td>
</tr>
<tr>
<td>42</td>
<td>Circumference of chest</td>
</tr>
</tbody>
</table>

It can be seen from these results that the triplets had smaller measurements than the twins from birth until the end of the period studied.

During this period the differences between these two groups, in every measurement (in favour of the twins), were found to have increased from birth and then decreased with age. In length of hind cannon, circumference of fore cannon, length of jaw, depth of chest and circumference of chest, the differences between them increased with age from birth, reached the maximum at the 7th week and then declined with age. With regard to the rest of the measurements, the maximum differences between the twins and the triplets were reached at the 5th week.
after birth for length of pelvis and length of tibia, at the 4th week for width between hook-bones, and at the 3rd week for width of head.

In general, for every measurement, the growth curves of the twins were steeper than those of the triplets during the period from birth until the ages at which the differences between their corresponding measurements reached the maximum. After these ages, the curves of the triplets were slightly steeper than those of the twins. Both twins and triplets exhibited the same trend in the change of their absolute gain per week and the relative growth rates during the period studied, although the triplets showed slower growth early in the period (within the first 7 weeks after birth) than the twins, but slightly faster thereafter.

When their body measurements were expressed as percentages of each corresponding measurement obtained at birth it was observed that, at 21 weeks of age, the triplets exhibited greater growth than the twins in all the body measurements except in the case of length of tibia, in which case the twins showed somewhat greater growth than the triplets.

From these results it can be seen that, in spite of being members of the same group (Oxford-cross) the twins had a different conformation than the triplets, not only at birth, but also during the whole period studied.

Neither the twins nor the triplets preserved the same
conformation they had at birth.

Difference in conformation found later in life between the twins and the triplets could be attributed to:
(1) Differences in their corresponding body measurements observed at birth, (2) Differences in the increase of these body measurements in post-natal life.

The differences observed at birth and during post-natal life between the different body measurements of the twins and those of the triplets, and consequently in their conformation, could be generally attributed to nutritional factors as mentioned previously (see page 77).
Growth of body measurements in relation to that of standard body measurements or body weight.

On each animal used in this study a number of different measurements were made. These can be compared with each other to give estimates of the changes in proportions of the animal. Obviously, considering the number of measurements, all possible comparisons cannot be made. Therefore it was decided to take two measurements as standards and to compare their change relative to that of other measurements. The standard measurements taken were the length of hind cannon, which is a leg measurement, and length of pelvis, which is a trunk measurement. These were selected because (a) they can be easily and accurately measured, (b) the length of hind cannon represents a slow-growing dimension, and the length of pelvis represents a relatively fast-growing dimension. In addition, body weight was taken as a standard of comparison to show the relationship between the growth of the different body measurements and that of body weight, as this might reflect differences in conformation between groups.

When two measurements are plotted against each other, the plots are found to follow either straight or curved lines. This can be seen from Figure 43, where the width of head is plotted against length of cannon, and from Figure 47, where length of pelvis is plotted against length of cannon. In the comparison of body measurements to length of cannon the points relating the different body measurements
to the length of hind cannon bone were found to lie on a straight line in all cases except for width of head (Figure 42), circumference of fore cannon (Figure 43) and width of hips (Figure 44). For each of these body measurements the line was curved slightly concave to the longitudinal axis, so that the rate of change of each of them relative to cannon length was greater in early than in late post-natal life.

The above method of plotting a measurement against another gives a graphical illustration of the changes in proportion of an animal. These, as stated above, can be simplified by drawing lines through the points. The comparison of (a) the length of these lines, (b) their linearity or curvilinearity, and (c) their position relative to those of other breeds, may lead, as discussed below, to an appreciation of how breeds and crosses differ in the changes of proportions which occur during growth.

Differences in the length of the lines can be interpreted as showing differences in the extent to which proportions change during a fixed period. Differences between straight and curved lines indicate in the case of curved lines either that one measurement is growing at a decreasing rate relative to the other, or vice versa. This can be interpreted as showing that one dimension is ceasing its growth at an earlier age than another dimension.

Two forms of curve occur. Those in which an increase of curvature occurs at the lower parts of the lines (Figure 65), and those in which an increase of curvature occurs at the upper
parts of the lines (Figure 44). The former type of curve shows that the growth rates of the dimension given on the vertical scale are relatively greater during the first part of the growth period than during the last part in relation to the dimension given on the horizontal scale. The latter type of curve shows exactly the opposite relationship, i.e., the growth rates of the dimension given on the vertical scale are relatively smaller during the first part of the growth period than during the last part in relation to the dimension given on the horizontal scale.

If the lines are straight they can be taken to show that the relationship between the different dimensions remains constant (Figure 59).

In addition to comparisons of the length and form of the lines relating one dimension to another, comparisons can be made of the lines between groups. In general for any pair of measurements the type of curve was the same over all groups (Figures 44 and 60). Differences between groups may be of four types, (a) the lines are parallel, (b) the lines converge during the latter part of the period, (c) the lines diverge during the latter part of the period, and (d) the curves or lines overlap. These are illustrated (a) by Figure 49 in which the lines of the Blackface, Suffolk-cross and Oxford-cross are parallel, and (b) and (c) by the same Figure (Figure 49) in which the line of the Halfbred diverges from that of the Suffolk-cross, and converges with the line
of the Oxford-cross. This behaviour of the Halfbred group was obvious for nearly all the comparisons in which the relationship between body measurement and length of cannon was given by a straight line. In Figure 44 the occurrence of overlapping lines is clearly illustrated. This can be explained by the different groups showing cessation of growth of circumference of cannon at different sizes of cannon bone, and it is of particular interest to note that the Blackface groups ceased increasing in circumference of cannon at a shorter length of cannon than the other groups.

The above introduction has briefly illustrated the types of comparisons which can be made between lines representing the growth of one body measurement in relation to another body measurement or to body weight. In the following sections detailed comparisons are made in the attempt to utilise these methods of comparison to show whether differences occur between the four groups in conformation.

(a) Growth of body measurements in relation to length of hind cannon bone.

For the female twin lambs of every group studied, the relationship between the growth of each of the different body measurements and that of length of hind cannon bone during the first 21 weeks from birth is presented graphically in the following Figures: in which the measurements of the different body dimensions were plotted against those of length of hind cannon bone, for each of the four groups.
A linear relationship resulted except in the case of width of head (Figure 42), circumference of fore cannon (Figure 43) and width of hips (Figure 44). In each of these three body measurements the line was curved slightly concave to the longitudinal axis so that the rate of change of each of them relative to cannon length was greater in early post-natal life than later. The observations on the relative growth rates of these three body measurements and that of length of cannon are in support of this view, since each of these three body measurements had distinctly greater relative growth rates than those of length of cannon early in the period but, towards the end of the period, while width of hips had a slightly greater relative growth rate than that of length of cannon, width of head and circumference of cannon had slightly less growth rates. These observations were seen in all the four groups studied without exception.

It should be noted that the lines representing such relationship between a body measurement and the length of hind cannon were noticeably shorter in the case of the Blackface lambs than the lines of the crossbred lambs. This could be
attributed to the fact that the Blackface lambs are slow-growing animals whereas the crossbred lambs are relatively fast-growing animals.

In all the above mentioned Figures (43-51) except those showing the growth of width of head (Figure 43) or circumference of cannon (Figure 44) it can be observed that, at a given length of cannon, the Blackface lambs showed the greatest body measurements, followed in descending order by the Suffolk-cross, the Halfbred and then by the Oxford-cross lambs.

In the case of width of head (Figure 43) this order of the groups was maintained only at a given small length of cannon (up to about 16 cm.). At a given longer length of cannon the Blackface lambs still maintained the greatest width of head but were now followed by the Suffolk-cross, the Oxford-cross and then by the Halfbred. It can also be seen from Figure 43 that the curve of the Blackface is almost parallel to that of the Suffolk-cross; that of the Oxford-cross approximates to, while that of the Halfbred diverges from, the curve of the Suffolk-cross.

From Figure 44, showing the growth of circumference of cannon in relation to that of length of cannon, it can be observed that, at a given small length of cannon (up to about 15 cm.) the Blackface lambs showed the greatest circumference of cannon, followed in descending order by the Suffolk-cross, the Halfbred and then by the Oxford-cross lambs. At a given greater length of cannon the curves overlapped and the
differences between the groups were about to appear as the curves tail off. Moreover, the differences noticed between the four groups in circumference of cannon (Figure 44) were found to be smaller than those observed between them at the same length of cannon in any of the other body measurements.

It could be concluded from the curves shown in Figure 45 that the differences between the Blackface and the crossbred groups in width of hips, though large at a small length of cannon, showed a tendency to decrease with the increase of length of cannon. Comparing the three crossbred groups, the most notable feature is that the lines relating width of hips to length of cannon for the Suffolk- and the Oxford-crosses are in general parallel, i.e., they follow a similar growth pattern. The comparison of the Halfbred with either the Oxford- or the Suffolk-cross shows a more complex relation since the line for the Halfbred diverges from that of the Suffolk-cross with increase of length of cannon, and converges with that of the Oxford-cross, i.e., it showed slightly different growth pattern from either the Suffolk- or the Oxford-cross, approximating to that of the Suffolk-cross at the smaller length of cannon and to that of the Oxford-cross at the longer length of cannon. The small differences observed between the four groups in length of jaw (Figure 46) at a given length of cannon increased with the increase of the given length of cannon (i.e., the four lines diverged as the growth of the
two body measurements increased). Differences between the groups in length of jaw appeared clearly at a given greater length of cannon.

In Figures 47-51, showing the growth of length of pelvis, width between the hook-bones, depth of chest, circumference of chest and length of tibia in relation to that of length of cannon, the lines for the Blackface, the Suffolk-cross and the Oxford-cross lambs were parallel to each other. Hence, at a given length of cannon, the differences between these three groups of lambs in these five body measurements are the same at any given length of cannon. In the case of the Halfbred lambs, the lines representing the relationship of the growth of each of these body measurements to that of length of cannon diverged from those of the Suffolk-cross lambs and approached those of the Oxford-cross lambs with the advance of growth.

However, it was observed that at a given length of cannon, the differences between the Blackface lambs and any of the crossbred groups in all the body measurements, except in the case of circumference of fore cannon, were greater and more magnified (though somewhat less magnified in the case of length of tibia) than those found between the crossbred groups.

An obvious point of the above comparisons is that different breeds of sheep can be compared usefully in post-natal life by measurements made when they reach a given length of cannon, since such measurements will differ. These differences
in body measurements found at such a given length of cannon can be interpreted generally as differences in skeletal conformation between animals having the same length of cannon. In such comparisons between breeds, age is not taken into consideration, since the different breeds compared may or may not have the same length of cannon at similar ages.

In the above comparisons it was shown that at a given length of cannon the Blackface had, in general (except in the case of circumference of cannon), greater body measurements than the other groups. This indicates that when the Blackface is compared with the crossbred groups on equal length of cannon, it has the best conformation. It should be noted that the body measurements of the Blackface at the given length of cannon represent measurements at older ages than in the other groups. Therefore, since the comparison in this connection was between animals of different ages, and older animals always have the advantage in that they come nearer to the ideal conformation than the young ones (Hammond 1932), this gives an explanation of the above results.

Body measurements expressed as percentages of length of hind cannon.

For every group and at every interval the various body measurements can be compared in terms of their ratios to the standard measurement, namely the length of cannon bone. These ratios are expressed as percentages, i.e.,

\[
\text{Body measurement } \times 100 \div \text{length of cannon}
\]

In the following discussion the percentages will be referred to as such, e.g., the term "width of head percentage" means:
the ratio of width of head to length of cannon, expressed as a percentage. This will simplify the discussion.

The results are tabulated in the following Tables:

<table>
<thead>
<tr>
<th>Table</th>
<th>Circumference of cannon percentage</th>
<th>Width of head</th>
<th>Length of jaw</th>
<th>Length of tibia</th>
<th>Length of pelvis</th>
<th>Width of hips</th>
<th>Width of hooks</th>
<th>Depth of chest</th>
<th>Circumference of chest</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td></td>
<td>61</td>
<td>62</td>
<td>63</td>
<td>64</td>
<td>65</td>
<td>66</td>
<td>67</td>
<td>68</td>
</tr>
</tbody>
</table>

It can be seen from these Tables that the change of circumference of fore cannon percentage (Table 60) and width of head percentage (Table 61) with age, differed from the other body measurement percentages in that they increased and then decreased, whereas those of the other body measurements continually increased. This difference can be attributed to these measurements growing first at a much faster rate and then later at a slightly slower rate than the length of cannon. The behaviour of each body measurement percentage as it changes with age was similar in each group.

Small differences were observed between the four groups in circumference of cannon percentage at every interval (Table 60). In this Table it can be seen that the decrease of circumference of cannon percentage occurred earlier in the Blackface than in the Half bred. The Oxford-cross and the Suffolk-cross, in which the decrease occurred at the same time, followed the Halfbred.

Small differences were observed between the crossbred groups in width of head percentages (Table 61), but the Blackface lambs showed somewhat greater percentage than the crossbred.
groups in this connection. This indicates that the Blackface lambs had a relatively wider head in relation to length of cannon as compared with the other groups. It is noteworthy that, during the first two weeks from birth, width of head percentage increased in the case of the Blackface at a greater rate than it did later on. It is suggested that this may be due to the increasing effect of the growth of the horns during this period on width of head measurement (see page 85). However, the decrease in width of head percentage of the Oxford-cross occurred earlier than in the Suffolk-cross. The Halfbred and the Blackface, in which the decrease occurred at the same time, followed the Suffolk-cross.

In the case of the other body measurements percentages which increased with age (Tables 62-68) the four groups of lambs studied showed small differences in their body proportions at every given age. These small differences may, however, be extremely important, since Hammond (1932) discusses similarly small differences of proportions as being indexes of differences in conformation between animals. This point will be discussed at length in the general conclusion. However, differences between the four groups in the rate of increase of these body measurement percentages with age can be seen to occur and are summarised in the following (arranged from the fastest (1) to the slowest (4));
This shows that, in general, the Oxford-cross and the Suffolk-cross, being more improved breeds, showed a relatively faster increase in these body measurements percentages than either the Halfbred or the Blackface.

It was observed that a body measurement percentage involving a fast-growing measurement (e.g., width of hooks) and a slow-growing measurement (e.g., length of cannon) increased at a faster rate than that involving two slow-growing ones (e.g., length of jaw and length of cannon).

The observed increase or decrease of the above body measurements percentages was retarded towards the end of the period studied due to the retardation of growth that occurred in every body measurement for every group.
Body measurements of the twins and the triplets of the Oxford-cross, expressed as percentages of length of hind cannon.

Body measurements percentages for the Oxford-cross triplet lambs are presented along with those obtained for the Oxford-cross twin lambs in Tables 60-68. When comparing these results not only were the body measurements percentages of the twins similar to those of the triplets, but also the body measurements percentages in both groups behaved similarly as they changed with age.
Growth of body measurements in relation to length of pelvis.

In the preceding section the various body measurements have been compared in their relationship to the growth of the length of cannon; this dimension was taken as a standard of comparison because it grows at a slow rate after birth. In the present section the same body measurements are compared in their relationship to the growth of the length of the pelvis; this dimension was taken as a standard because it grows at a fast rate after birth.

The relationship between the growth of each of the different body measurements and that of length of pelvis during the first 21 weeks from birth is presented graphically in the following Figures where the measurements of each of the different body dimensions were plotted against those of length of pelvis in every group.

<table>
<thead>
<tr>
<th>Figures</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of head</td>
<td>52</td>
</tr>
<tr>
<td>Width of hips</td>
<td>53</td>
</tr>
<tr>
<td>Circumference of fore cannon</td>
<td>54</td>
</tr>
<tr>
<td>Length of jaw</td>
<td>55</td>
</tr>
<tr>
<td>Length of tibia</td>
<td>56</td>
</tr>
<tr>
<td>Depth of chest</td>
<td>57</td>
</tr>
<tr>
<td>Width between hook-bones</td>
<td>58</td>
</tr>
<tr>
<td>Circumference of chest</td>
<td>59</td>
</tr>
</tbody>
</table>

The comparison of these Figures with Figure 46, where length of pelvis is plotted against length of cannon, shows that for a given length of pelvis, differences between the four groups in length of cannon were greater than those
observed between them in any other body measurement. This suggests that by using length of cannon as a standard of comparison more differences between the groups of lambs compared could be revealed than by using any other body measurement.

Figures 52-59 demonstrate that, in every group, a linear relationship resulted when plotting the different body measurements against length of pelvis, except in the case of width of head (Figure 52), width of hips (Figure 53) and circumference of fore cannon (Figure 54). In the case of each of these body measurements the result was a flat curve. This occurred in each of the four groups of lambs studied. These curves, however, were flatter than those obtained when the measurements of each of these three dimensions were plotted against length of cannon (Figures 43, 45 and 44).

The curved lines found in the case of width of head (Figure 52) and also in the case of circumference of cannon (Figure 54) can be taken as due to the greater differences observed early in life than those observed later between the relative growth rates of each of these two body measurements and those of length of pelvis (in favour of length of pelvis).

In the case of width of hips (Figure 53) the curved nature of the line can be taken as due also to the greater growth made in width of hips than in length of pelvis early in life, and in length of pelvis than in width of hips later in the period. (See relative growth rates Tables 39, 40, 43 and 44)
The lines or curves representing the growth of any body measurement in relation to length of pelvis - like those found previously in Figures 43-51 - were shorter in the case of the Blackface than in the crossbred groups, due to the Blackface being a slow growing breed.

It can be seen from these Figures that only when plotting the measurements of circumference of cannon (Figure 54), length of jaw (Figure 55) and length of tibia (Figure 56) did clear differences between the Blackface and the crossbred groups appear. At a given length of pelvis the Blackface showed the smallest measurements in these three Figures, followed by the Halfbred, the Suffolk-cross and then by the Oxford-cross, in this ascending order. Differences between the Blackface and the crossbred groups in circumference of cannon (Figure 54) increased with the increase of the given length of pelvis. In the case of length of jaw (Figure 55) and length of tibia (Figure 56) there was a slight tendency for the differences between the Blackface and the crossbred groups to increase, followed by a tendency for it to decrease, with the increase of length of pelvis.

At any given length of pelvis differences between the crossbred groups in these three body measurements were very small. However, although at a given length of pelvis differences between the four groups studied in the rest of the body measurements were small, it can be seen that in the case of width of head (Figure 52) and also depth of chest (Figure 57),
the Halfbred showed smaller measurements among the four groups studied. The differences between the Halfbred and any of the other groups, however, showed a tendency to increase, followed by a tendency to decrease with the increase of length of pelvis.

At a given length of pelvis the Blackface showed a slightly smaller, and the Suffolk-cross a slightly greater, width of hips (Figure 43) than the rest of the groups. In the case of width of hooks (Figure 53), at a given length of pelvis the Oxford-cross exhibited somewhat smaller measurements than the other groups. Negligible differences were found between the four groups in circumference of chest (Figure 59) at any given length of pelvis.

Body measurements expressed as percentages of length of pelvis.

The various body measurements were compared in terms of their ratios to the standard measurement, namely length of pelvis. These ratios were expressed as percentages, i.e.,

$$\frac{\text{Body measurement} \times 100}{\text{length of pelvis}}$$

To simplify the following discussion, the percentages will be referred to as such, e.g., the term "width of head percentage" means the ratio of width of head to length of pelvis, expressed as a percentage.
The results are tabulated in the following Tables.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Table</th>
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<tbody>
<tr>
<td>Width of head percentage</td>
<td>69</td>
</tr>
<tr>
<td>Circumference of cannon percentage</td>
<td>70</td>
</tr>
<tr>
<td>Length of jaw</td>
<td>71</td>
</tr>
<tr>
<td>Length of tibia</td>
<td>72</td>
</tr>
<tr>
<td>Width of hooks</td>
<td>73</td>
</tr>
<tr>
<td>Depth of chest</td>
<td>74</td>
</tr>
<tr>
<td>Circumference of chest</td>
<td>75</td>
</tr>
<tr>
<td>Width of hips</td>
<td>76</td>
</tr>
</tbody>
</table>

From these Tables it can be seen that the following body measurements percentages decreased with age in every group: width of head (Table 69), circumference of cannon (Table 70), length of jaw (Table 71), length of tibia (Table 72) and also length of cannon percentages (reciprocals of length of pelvis percentages in Table 64). All the body measurements concerned in these percentages grow in post-natal life at slower rates, not only than length of pelvis, but also than the rest of the other body measurements studied.

Width of head percentage was distinctly greater in the Blackface than in the crossbred groups. There were only small differences between the four groups in circumference of cannon (Table 70) and length of jaw (Table 71) percentages at every interval. The Blackface lambs had a slightly smaller length of tibia percentage (Table 72) than the crossbred groups early in the period, but this difference later decreased. The Blackface had slightly smaller length of cannon percentages at the beginning of the period and slightly greater ones later on. (Reciprocal of length of pelvis, Table 64).
The width between hook bones (Table 73), circumference of chest (Table 74) and depth of chest (Table 75) percentages all concern body measurements that grow at faster rates than length of pelvis. These increased with age in every group. The differences observed early in post-natal life (during the first 7 weeks after birth) between the Blackface and any of the crossbred groups in width between hook bones (Table 73) and circumference of chest (Table 74) percentages were smaller than the small differences observed between them in these percentages during the rest of the period.

While depth of chest percentages (Table 75) increased with age in the case of the Blackface, they fluctuate in the case of the crossbred groups. In every group, however, depth of chest percentages observed towards the end of the period studied were somewhat greater than those found towards the beginning of the period. The change with age of these percentages in every group was within a very small range, but the Blackface had a slightly greater range than the crossbred groups. The fluctuation occurring in the change of depth of chest percentages in the case of the crossbred groups is probably due to some inaccuracy in the measurements concerning depth of chest, particularly early in the period studied. For, when comparing the relative growth rates at which length of pelvis and depth of chest grew (see Tables 43 and 46) it can be seen that in the...
case of the crossbred groups, length of pelvis showed greater relative growth rates than depth of chest during the first 2 weeks in the period, after which depth of chest showed sometimes greater and sometimes smaller relative growth rates than length of pelvis.

In the case of the Blackface, depth of chest exhibited greater relative growth rates than length of pelvis from the beginning until the end of the period. Had the measurements of depth of chest of the crosses been accurate, the relative growth rates of this body dimension in the case of the crossbred groups would also have been greater than those of length of pelvis from the beginning until the end of the period and, consequently, depth of chest percentages like those of the Blackface lambs would have shown an increase with age.

Width of hips percentages (Table 76) showed first an increase then a decrease with age in every group. The range in which the percentage changed with age in each group was small. Such behaviour of this percentage in every group is due to the difference in the relative growth rates at which width of hips and length of pelvis grew, since it can be seen that early in the period width of hips grew at a faster rate than length of pelvis, but that later it grew at a somewhat slower rate.

Apart from width of head percentages, differences between the four groups in all the other body measurements
percentages were small at every interval. Towards the end of the period studied it was noticed that the increase or the decrease of these body measurements percentages was retarded, due to the retardation of growth of the body measurements.
Body measurements of the twins and the triplets of the Oxford-cross, expressed as percentages of length of pelvis.

Body measurements percentages for the Oxford-cross triplet lambs are presented along with those obtained for the Oxford-cross twin lambs in Tables 69-76.

The comparison between the results of the twins and the triplets showed that their different body measurements percentages were similar and behaved similarly as they changed with age.
Growth of the different measurements in relation to body weight.

The relationships between the growth of each of the different body measurements and that of body weight during the first 21 weeks from birth, for all the groups, are presented graphically in the following Figures:

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<th>Figures</th>
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<td>68</td>
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<td>69</td>
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</tbody>
</table>

Length of cannon
Length of tibia
Length of jaw
Circumference of fore cannon
Length of pelvis
Circumference of chest
Width of hips
Width of hooks
Depth of chest
Width of head

In every group, when plotting each of the different body measurements against body weight a curve resulted. The occurrence of a curved and not a straight line representing the relationship between body weight and the various body measurements is due to differences in growth progression between the body measurement and body weight, since the body measurements grow in an arithmetical progression and body weight grows in geometrical progression (Brody 1945). In other words, it is simply due to the relatively faster growth in body weight as compared with that of any of the body measurements studied.

It can be seen that more differences between the groups were clearly noticeable when the measurements of length of cannon, length of tibia and length of jaw (Figures
60, 61, 62, respectively) were plotted against those of body weight, than in all the other body measurements. In these three cases, it is evident that for a given body weight the Blackface showed the smallest and the Oxford-cross the greatest measurements amongst the four groups. The Suffolk-cross and the Halfbred (with small differences between them) showed greater measurements than those of the Blackface, but smaller ones than those of the Oxford-cross.

The Halfbred exhibited nearly equal length of tibia as the Suffolk-cross, but slightly shorter jaw and slightly longer cannon when these two groups were compared on an equal basis of body weight. However, for a given body weight, the differences observed between the Blackface and any of the crosses in these three measurements were greater than those found between the crossbred groups themselves.

Differences between the Blackface and the Suffolk-cross or the Oxford-cross in length of cannon (Figure 60) in this respect, seem not to have changed much with the increase of body weight, as the lines representing the relationship between this measurement and body weight in these three groups were almost parallel.

While the small difference observed between the Halfbred and the Suffolk-cross in length of cannon increased with the increase of body weight, that found between the Halfbred and the Oxford-cross decreased. This can be seen from the curve representing the Halfbred group diverging from that of the Suffolk-cross and approaching that of the Oxford-
Differences between the groups in length of tibia (Figure 6) were increasing with the increase of body weight, since the curves diverged.

It also appears that the differences between the groups in length of jaw did not change much with the increase of body weight. The observed differences between the four groups in the relationship of circumference of cannon, length of pelvis, circumference of chest, to body weight (Figures 63, 64, 65) were less than those found in the case of the previous measurements. However, for a given body weight, the Blackface showed the smallest circumference of cannon, length of pelvis and circumference of chest, followed in order by the Halfbred and the Suffolk-cross (with small differences between these two groups) and then by the Oxford-cross which showed the greatest measurements in this connection.

The differences found between the Blackface and any of the crossbred groups in circumference of cannon increased considerably with increase of body weight. The small differences observed between the crossbred groups in circumference of cannon increased slightly with increase of body weight.

At a given body weight only small differences were found between the four groups in either length of pelvis or circumference of chest. Nevertheless, these differences increased slightly with increase of body weight.
At a given body weight the Blackface showed the smallest width of hips measurement (Figure 66), followed by the Halfbred, the Oxford-cross, and then by the Suffolk-cross which showed the greatest width of hips.

Not only was the difference between the Blackface and any any of the crossbred groups greater than the difference between the crossbred groups, but it also was found to increase with the increase of body weight. The small difference found between the Halfbred and the other crossbred groups also increased slightly with increase of body weight. That between the Oxford-cross and the Suffolk-cross did not change much with increase of body weight.

At a given body weight the Blackface showed the smallest width between hook bones (Figure 67), followed in ascending order by the Oxford-cross, the Suffolk-cross and then by the Halfbred (with small differences between the last two groups). Although the differences between the four groups in width between hook bones increased with increase of body weight, these differences were very small for any given body weight.

At a given body weight the Halfbred showed a somewhat smaller depth of chest than the rest of the groups. Only very small differences occurred between the Blackface, the Suffolk-cross and the Oxford-cross for this measurement. Differences between the Halfbred and any of these groups were greater than those found between the three groups. There is
a tendency for the differences found between the Halfbred and the other groups to increase with the increase of body weight.

At a given body weight the Halfbred showed the smallest width of head amongst the four groups (Figure 69), followed in ascending order by the Suffolk-cross and the Blackface (with a small difference between them) and then by the Oxford-cross which showed the greatest width of head.

Differences between the Oxford-cross, Suffolk-cross and Blackface were smaller than those found between the Halfbred and any of the other groups.

The observed differences between the four groups in width of head showed an increase, then a slight decrease, with the increase of body weight.

**Body measurements expressed as percentages of body weight.**

The various body measurements were compared in terms of their ratios to body weight. These ratios were expressed as percentages, i.e.,

\[
\text{Body measurement} \times 100 \\
\text{body weight}
\]

To simplify the following discussion, the percentages will be referred to as such, e.g., the term "width of head percentage" means the ratio of width of head to body weight, expressed as a percentage.

The results are presented in the following Tables:
From the tables it can be seen that the percentage of each body measurement decreased with age. This was due to the greater growth made in body weight as compared with that made in the body measurements.

In general the Blackface had the greatest percentages among the four groups during the 21 weeks studied. The Oxford-cross twin lambs, on the other hand, had the smallest percentages.

The Suffolk-cross lambs showed greater percentages than the Halfbred lambs at the beginning of the period, but towards the end of the period they showed somewhat similar percentages.

Towards the end of the period studied the decrease of these body measurements percentages was retarded due to the retardation of growth.
Body measurements of the twins and the triplets of the Oxford-cross expressed as percentages of body weight.

Although the Oxford-cross triplets showed greater percentages in every body measurement than the corresponding twins during the whole period, this was more obvious at the beginning of the period than towards the end.
GENERAL CONCLUSIONS.

The present study of growth in sheep evolved under difficult conditions of experimental control, resulting in the comparisons between breeds and crosses being confounded with differences of environment, since the different breeds and crosses could not be raised on the same farm or under similar conditions. The Blackface group was raised on a normal hill farm. The three crossbred groups, Halfbred, Oxford-cross and Suffolk-cross, although all were raised on lowland farms, cannot be stated not to differ in feed and management conditions since the Oxford-cross was raised on one farm and the Halfbred and Suffolk-cross were raised on another farm. Therefore, differences between these groups, although probably genetic, certainly include differences due to the different levels and types of feed on the different farms. These comparisons between groups, although taken as comparisons between the breeds and crosses, are almost certainly comparisons of the different environments as well. This does not negate the worth of this study which was primarily intended as a survey of methods and approaches to the problem of obtaining rigorous measurements of conformation.

The Blackface breed is, under normal hill conditions, smaller, lighter and of poorer conformation than the various crossbred groups studied and it is in fact noted for its ability to survive under very poor conditions. The Halfbred is a
lowland sheep, famous for its high fertility and milk production. The Oxford and the Suffolk rams are believed to produce more rapidly-growing and earlier-maturing lambs from the Halfbred ewes.

From the results the first and most obvious comparison is that of body weight. Commencing at birth, when the Blackface group was lighter than any of the crossbred groups, the Blackface grew at a consistently slower rate than any of the crossbred groups, ending at marketing age (21 weeks after birth) when the crossbred groups were heavier and generally larger than the Blackface. The Suffolk-cross differed little in weight from the Halfbred at birth or subsequently, but the former tended to be heavier after about the 16th week of age. The Oxford-cross lambs were about 3 lbs, heavier at birth than the Suffolk-cross and the Halfbred, but this difference is probably due largely to the fact that they had mothers averaging nearly 60 lbs, heavier than the other groups, and it is uncertain whether breed of sire had any additional effect. The Oxford-cross lambs gained more rapidly than the others, but this may be partly due to their greater birth weight and the possibility that their dams, being older, had a higher milk production.

Therefore, differences in growth in weight may be due (a) to variation in birth weight affected by size of dam, (b) to variation of the level of feeding between the different farms, and (c) to inherent growth rate differences. It has
been shown that the mothers of the Oxford-cross lambs were heavier than those of the Suffolk-cross lambs or the Halfbred lambs. These differences between weight of dam, since they are correlated with differences between lamb weights, can be taken as showing that weight of dam is an important determinant of weight of lamb. As has been mentioned previously, use of the Oxford Down breed in crossing to the Halfbred, in place of the Suffolk, is probably due to the former producing larger lambs of slightly inferior mutton quality.

A primary aim of the study was to determine if body measurements could give an estimate of conformation.

Within the body of the animal there are parts which are considered more valuable than others from the butcher's point of view. In an animal of good conformation the valuable parts are the predominating parts of the whole body and complete the balance in relation to the other parts.

The use of body measurements in judging conformation has been criticised by different authors (see page 46). However, with live animals, the use of skeletal measurements, such as those used in this study, gives an indication of the changes that occur in their skeletal proportions but does not give a complete indication of their general conformation since this requires dissection for estimating the qualitative changes that occur in the body of the growing animal, the degree of fleshing, and the proportions of bone, fat and muscle in the carcass.

The above analysis of body weight and body measurements
together were used in estimating the changes of skeletal proportions and conformation of the live animals of every group.

Summarising, the following descriptions of the groups can be made.

(1) Blackface.

In relation to its size this breed had a short and slender cannon bone, somewhat shorter jaw, tibia, pelvis, narrower hips and smaller circumference of chest, deeper in the chest, wider in the head, and slightly wider between the hook bones. This indicates that the Blackface at about 21 weeks of age was smaller in size, lighter in body weight, had shorter legs and hind-quarters, a narrower trunk, and poorly sprung ribs, all in relation to its size. Furthermore, the parts around which the valuable mutton is carried were not as large as in the crossbred groups.

(2) Halfbred.

In relation to its size, it had a somewhat longer and more slender cannon bone, shorter tibia, pelvis and jaw, smaller width of head, width of hips, circumference and depth of chest, and wider distance between the hook bones than the Suffolk-cross.

(3) Suffolk-cross.

With a smaller body size and weight than the Oxford-cross, it had a relatively shorter and thicker cannon bone than the Halfbred, though not as thick as the Oxford-
cross. It had greater width of hips, depth and circumference of chest in relation to its size than either the Oxford-cross or the Halfbred. The distance between the hook bones was narrower than in the Halfbred but wider than in the Oxford-cross. In the rest of the body measurements the Suffolk-cross had relatively greater dimensions in relation to its size as compared with the Halfbred, but smaller ones as compared with the Oxford-cross.

(4) Oxford-cross.

With its relatively heavier body weight and larger body measurements, it had a relatively longer and thicker cannon bone, longer tibia, pelvis and jaw, and broader head in relation to its size than the other crossbred groups. On the other hand, this group was narrower between the hook bones than the Halfbred or the Suffolk-cross, but was greater than the former and slightly smaller than the latter in width of hips, depth of chest and circumference of chest.

Summarising, it is not unreasonable to state from the above results that in the four groups of sheep studied, the Blackface can be taken as having a poor conformation, the Halfbred as having a better conformation, and the other two crossbred groups (namely Oxford-cross and Suffolk-cross) as having the best conformation.

Estimates of the rates of growth of different
body proportions were determined and analysed. These have been given in full in the text as the body measurements at 21 weeks as percentages of the body measurements at birth. It is of interest to compare these growth rates between the four groups. To facilitate such a comparison the order of these growth rates (arranged from the fastest (1) to the slowest (4)) for the various body dimensions and for body weight are given below.

<table>
<thead>
<tr>
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<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
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<tbody>
<tr>
<td>Length of pelvis</td>
<td>O</td>
<td>H</td>
<td>S</td>
<td>B</td>
</tr>
<tr>
<td>Width of hooks</td>
<td>S</td>
<td>H</td>
<td>0</td>
<td>B</td>
</tr>
<tr>
<td>Depth of chest</td>
<td>S</td>
<td>H</td>
<td>0</td>
<td>B</td>
</tr>
<tr>
<td>Circumference of chest</td>
<td>H</td>
<td>S</td>
<td>0</td>
<td>B</td>
</tr>
<tr>
<td>Width of hips</td>
<td>H</td>
<td>S</td>
<td>0</td>
<td>B</td>
</tr>
<tr>
<td>Circumference of cannon</td>
<td>H</td>
<td>S</td>
<td>0</td>
<td>B</td>
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<tr>
<td>Length of jaw</td>
<td>H</td>
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<td>0</td>
<td>B</td>
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<tr>
<td>Length of cannon</td>
<td>H</td>
<td>S</td>
<td>0</td>
<td>B</td>
</tr>
<tr>
<td>Length of tibia</td>
<td>H</td>
<td>O</td>
<td>S</td>
<td>B</td>
</tr>
<tr>
<td>Width of head</td>
<td>B</td>
<td>S</td>
<td>H</td>
<td>0</td>
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<tr>
<td>Body weight</td>
<td>S</td>
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</table>

O = Oxford-cross  
S = Suffolk-cross  
H = Halfbred  
B = Blackface

It is obvious that the Blackface grows at a slower rate compared with the other three groups. The three crossbred groups show differences on total score overall dimensions: the Oxford-cross grows at the slowest rate, the Suffolk-cross at a faster rate, and the Halfbred at the fastest rate. This method of scoring the groups on their relative positions in a growth rate comparison puts them in the order: Blackface slowest, Oxford-cross, Suffolk-cross, Halfbred fastest.
Since this sequence does not agree with that of quality of conformation, which is Oxford-cross and Suffolk-cross the best, Halfbred and Blackface the worst, it follows that the score of growth rate cannot give an estimate of conformation. Therefore other estimates must be investigated.

Various authors (see Hammond 1932) have suggested that conformation can be estimated from the ratio of trunk size to leg size primarily, and from the ratio of trunk width and depth to trunk length, secondarily. The results analysed above, of the relative growth of trunk measurements to length of cannon, are of special interest to the primary estimate of conformation quality.

The curves relating one body measurement to another show in some cases little differences between the groups of animals studied, and in others large differences. Two examples illustrate this: (1) Length of tibia against length of cannon with practically no spread between the groups, and (2) Width of hooks against length of cannon with a very large spread between the groups. Before discussing the practical importance of these differences, an explanation may be put forward. Since comparisons are to be made with a part of the body showing slow growth after birth, i.e., length of cannon, differences between the rates of growth of the body measurements will be reflected in differences of spread between the lines relating these measurements to length of cannon. For example, width between hook bones, circumference of chest and depth of
chest are the fastest growing dimensions amongst those measured (Figure 32) and they show the greatest spread of the lines relating them to length of cannon (Figures 48, 49, 50), whereas the circumference of cannon, width of head, length of tibia and length of jaw, which are slow growing dimensions (Figure 32) show, when plotted against length of cannon, very little spread (Figures 43, 44, 46 and 51). This provides an explanation of degree of spread as due to the growth of the dimensions concerned; fast growing dimensions show greater spread than slow growing dimensions when plotted against length of cannon.

These differences of spread between the relation of body measurements to length of cannon indicate which are the best measurements on which to base selection, since obviously those dimensions which show the greatest variation in their ratios to cannon length will allow the greatest ease of discrimination. Therefore, in the present series of measurements, the width between hook bones, circumference of chest and depth of chest are indicated as the most useful dimensions on which to base selection for change of body proportions.

With regard to body proportions, Hammond (1932) states: "It will be seen that the unimproved breeds are very high in the leg, rather short in the body, and deficient in width and depth of chest. The improved mutton breeds, on
the other hand are short in the leg, long in the body and wide in the chest, but not so deep in the chest as the milk types, which in other respects are intermediate between the two, as is also wool type. As far as we have been able to judge by eye, and by measurement of photographs, the young of wild and of improved breeds have a more similar conformation at birth; during subsequent life, however, the wild type does not proceed so far in development as the improved breed and remains in a stage of conformation passed through by the latter. It would appear that the main basis of the differences in conformation between the various types of sheep is founded in changes in conformation which take place after birth and on the nutritional state of the animal (either by breeding or feeding) during this time.

"As to how the meat breeds, with relatively short legs, have been evolved from the wild types, with relatively long legs, is an open question. Has it been done by selecting animals with small head and legs at birth and developing them to a greater extent than normal, by careful management and good feeding, and by the selection of those which responded to this process, or has it been merely by better feeding and increasing the absolute size of the whole animal? We would suggest that as the Mouflon is smaller than most of the present breeds of sheep, and as the Tuscan ox is smaller than most of the present day breeds of cattle, that the latter process was the
method originally employed; but in modern times, more especially with the Beef Shorthorn and Aberdeen-Angus, in addition to this, the former method has been used. The history of Beef Shorthorn cattle seems to suggest this, the original cattle being large, while the modern Scotch Shorthorn is smaller."

This means that two methods of obtaining better conformation are available: (1) A change of total size, (2) A change of body proportions, these to be measured at constant ages, or corrected for differences in age since Hammond (1932) states that: "The changes in the conformation of the body with age - for example, increase in the relative size of the loin, ribs and upper parts of the limbs, and decrease in the relative size of the head and lower parts of the limbs - make the judging of animals of different ages no easy matter...... the older animal always has the advantage (among animals of otherwise equal merit) in that it comes nearer the ideal conformation, i.e., with a larger proportion of loin and trunk compared with the extremities (head and legs)."

In the present data only small differences were found between the four groups in their skeletal proportions at any given age to the length of cannon (Tables 60-68). Further, the ratio of body measurements to length of cannon increases with age and the four groups again differed slightly in the rate at which these ratios increase with age (see page 108),
Therefore, when selecting for better conformation on the basis of skeletal proportions it is suggested that animals should be selected which have the largest ratios between trunk measurements (particularly measurements of the parts which are most valuable commercially, e.g., pelvis measurements) and length of cannon, both at birth and at marketing age. This greater ratio at birth could possibly be obtained by (a) selecting for slow growing length of cannon only, (b) selecting for fast growing trunk measurements only, or (c) selecting for both, i.e., selecting at the same time for a slow growing length of cannon and relatively fast growing trunk measurements. In all these methods, the high ratio at birth indicates an early growth at a relatively greater rate for the trunk measurements in relation to length of cannon. Selection on this basis is first for animals with a high ratio at birth. Then a second selection is made for animals with a high ratio at marketing age. Selection at marketing age in this sense is based on the rate of increase of the high ratios at birth.

Since trunk measurements grow at their maximum rate after birth, whereas leg dimensions have almost completed their growth by birth, it would seem feasible that selection for a fast rate of growth of trunk dimensions post-natally, will result in a greater ratio of trunk to leg size. Therefore, if selection for increased ratio of trunk to length of cannon, as suggested above, is combined with selection for increased
rate of growth of trunk dimensions, it seems probable that the maximum increase of trunk to leg ratio would result. This will lead to an animal with larger trunk and relatively shorter cannon in relation to its size, and therefore with better body conformation.

It should be noted, however, that when selecting for greater ratio at birth, fast growing animals with the same high ratio involving a long cannon will end at marketing age with a greater size than those with small length of cannon, but both will have good conformation. On the other hand, it appears that slow growing animals will end at the same age with relatively smaller size and somewhat inferior conformation, but usually such animals reach a better conformation at older age. This is indicated from observations on the Blackface. At birth, the ratios of trunk:cannon measurements (e.g., length of pelvis or circumference of chest:length of cannon) of this breed were found not to differ much from those of the improved crossbred groups, which indicates that the Blackface is also an improved breed. But as this is a slow growing breed, this ratio did not increase at a fast rate as in the crossbred groups. By good management, feeding and breeding, the improvement that could possibly take place in the Blackface would be in that the ratio trunk:cannon measurements would increase from birth at a relatively faster rate resulting in a better type of conformation.

However, as this breed in its present state reaches
a better quality of mutton (Hirzel 1939) and somewhat moderate conformation at older ages, it has its importance in mutton production.

With the help of the above selection indexes and by better feeding and management, such types of mutton breeds could be improved, resulting in animals with good conformation and superior ability to put on weight. In addition, a selection programme would only be complete if it included estimation of mutton quality.

Finally, the importance of the level of nutrition at different stages of development cannot be neglected since, during pre-natal life, the cannon bone grows at a faster rate than the trunk and at birth the cannon bone is usually found to be more developed than the trunk. During post-natal life the trunk grows at a faster rate than the cannon bone and develops later in life. As in fast growing animals improvement took place by feeding and breeding, it seems that this gave the parts of the body that grow in pre-natal life and those that grow in post-natal life unequal chances. For, as the level of nutrition during pre-natal life is relatively rather limited as compared with that given during post-natal life, the parts of the body that grow in post-natal life had a better chance, and by increasing the feed during this time the improvement was more noticeable in those parts.

As indicated by observations on the Blackface, it seems that in slow growing breeds the level of nutrition
during pre-natal life affected the trunk more than the leg measurements (e.g., length of cannon) since these were growing at faster rates than the trunk during this time and had the priority of supply with nutrients, and during post-natal life, the trunk was affected by the restricted level of nutrition and the result was a slow growing animal with a relatively small size.

The analysis in this investigation is obviously not complete. If it is repeated or carried further, studies of sequential measurements on the same live animals must include the following points:-

(1) Animals for such studies should be obtained from breeds which differ widely in conformation.

(2) To test the effect of the sire on birth weight, a number of sires of different sizes and breeds should be mated in the same season to a number of ewes of similar weight, size and breed, and comparisons should be made between the birth weights of the lambs resulting.

(3) On these animals a number of accurate body measurements should be taken weekly from birth.

(4) Within each breed, groups of animals should be maintained on different levels of nutrition in order to test the significance of the level of nutrition on conformation.

(5) Singles, twins and triplets should be compared within and between groups.
Finally, at marketing age, an estimate of conformation should be made by people capable of judging carcass quality.
SUMMARY.

1. Measurements of growth were made on four groups of sheep: Halfbred, Oxford-cross, Suffolk-cross and Blackface. In these only female twins were used, with as similar ages as possible. In the Oxford-cross, triplets were reared as twins to compare growth of twins and triplets reared under the same conditions. Various dimensions were measured at regular intervals during a 21-week period from birth. These dimensions were:

- Depth of chest
- Length of hind cannon bone
- Length of tibia
- Length of pelvis
- Width of hooks

- Width of hips
- Width of head
- Length of lower jaw
- Circumference of chest
- Circumference of fore cannon bone

2. The growth differences between these four groups of sheep cannot be partitioned between genetic and environmental causes since the Oxford-cross lambs were on one lowland farm, the Suffolk-cross and the Halfbred lambs were on another lowland farm, and the Blackface lambs were on a hill farm.

3. At birth the Oxford-cross lambs were the heaviest, followed by the Halfbred, the Suffolk-cross and then by the Blackface.

4. Weight of ewe had an over-riding effect on birth weight of her lamb. Between the four groups of female twin lambs studied, the relationship between weight of ewe and weight of lamb can be expressed approximately as:
Average birth weight of female twin lamb =

\[ 7.6 + 0.053 \text{ (weight of ewe} - 100) \text{ lbs.} \]

Thus an average birth weight of a female twin lamb increases by 1 lb, for an increase of about 19 lbs, in weight of ewe, while total birth weight of twin females increases by 1 lb, for about 9.5 lbs. increase in ewe weight, irrespective of breed. It was not possible to determine whether breed of sire had any effect on birth weight.

5. In the Oxford-cross group, the birth weight of a female twin was heavier than that of a female triplet. The ewes which produced triplets were lighter than those which produced twins.

6. In the female twins of the four groups the Oxford-cross was the heaviest from birth onwards, followed by the Halfbred and the Suffolk-cross (with small differences between them) and then by the Blackface which was smaller than the crossbred groups from birth until the end of the period.

There was a slight tendency for growth rate to increase during the first 5-7 weeks and to decrease after about 3 months. This decrease was particularly marked in the Blackface and can be ascribed to the poorer nutritional conditions under which they were reared.

7. No marked differences in the relative growth rates of body weight were observed between the four groups except in
the 1st week when the Blackface lambs had the fastest growth rates. As, however, the Blackface is considered a slow-growing breed, this indicates that the crossbred lambs were not capable of maintaining the faster relative growth rate, but simply maintained the advantage established at birth.

Since the breeds differ widely in genetic origin, it is concluded that, either (1) they do not differ genetically in respect of relative growth rate, or (2) unless the level of nutrition is constant from birth, differences in hereditary growth rates cannot be observed.

8. Growth of the different body measurements was compared between and within the four groups. In addition, comparisons were made between the different groups studied on the basis of a standardised body weight or body measurement, since this can show the variation in growth of the different body measurements in relation to the standard weight or measurement. The standard body measurements chosen were: length of cannon and length of pelvis, for they can be measured easily and with fair accuracy, and also because the former represents a slow-growing dimension whereas the latter represents a relatively fast-growing one.

Therefore, the different body measurements were plotted against the standards of comparison to give a
graphical illustration of the changes in proportion which occur during growth.

9. The comparisons of (a) length of these lines, (b) their linearity or curvilinearity, and (c) their position relative to those of other breeds, may lead to an appreciation of how breeds differ in changes of proportions which occur during growth.

10. By means of growth analysis and by the above methods of comparison it was possible to judge quality of conformation between the four groups studied, Oxford-cross and Suffolk-cross having the best conformation, Halfbred next, and the Blackface the poorest.

11. The above method of plotting body measurements against the standard measurements showed that the greatest differences occurring between groups are usually observed when plotting the fastest growing body measurements against the slowest. Therefore, width of hooks, circumference of chest and depth of chest showed the greatest spread when plotted against length of cannon. At a given length of cannon the Blackface had always greater body dimensions. It follows that at a given body size the Blackface showed the shortest leg length.

12. The ratios of various body measurements to length of cannon were at first sight constant between the groups at any given age. However, closer examination showed constant
small differences in these ratios between the groups. At marketing age the Oxford-cross and the Suffolk-cross had the greatest ratios in general, the Halfbred was intermediate and the Blackface had the smallest ratios. It is suggested that these small differences of ratios are important for estimation of quality of conformation.

13. In selecting for better conformation the ratios between the trunk measurements (particularly those of the most valuable parts of the body) and length of cannon, could be used as indexes on which selection should be based.
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ACKNOWLEDGEMENTS.

Gratitude is expressed to Professor C.H. Waddington for affording laboratory facilities; to Professors C.H. Waddington and S.J. Watson and Dr. R.G. White for supervising the work; to Dr. E.C.R. Reeve for suggesting the problem and (with Dr. F.W. Robertson) for helpful discussion; to Mr. A.S. Fraser for practical assistance with the taking of weights and measurements on the farm and for discussion; to Mr. G.R. Knight for technical assistance; and finally, to the Authorities of the Edinburgh and East of Scotland College of Agriculture, without whose cooperation this work could not have been done.