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A. B. CONNER, DIRECTOR
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DIVISION OF RANGE ANIMAL HUSBANDRY

CHANGES IN BODY MEASUREMENTS OF STEERS DURING INTENSIVE FATTENING

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SYNOPSIS

This Bulletin reports a study on the use of body measurements to describe in definite terms the fatness of steers and the changes which occur in the body shape of steers as they fatten. It is a contribution to the general problem of describing farm animals in more accurate objective terms, so that differences between them, and the significance of those differences to the breeder, feeder, and livestock judge may be studied more impartially and with greater accuracy. The steers used in these experiments were being fattened as a part of a general study of the place which Brahman blood might profitably have in practical beef production in Texas. This Bulletin is a part of that study.

Measurements were made on nearly all the steers fattened during four seasons at Substation No. 7 near Spur. Measurements were made on the thin steers just before fattening began and measurements were made again on the same steers when they were fat. In all, 185 steers divided among nineteen lots were studied. This Bulletin presents a study of those data made with the sole object of learning what changes in body shape or conformation occurred during fattening, so far as body measurements could show those changes. The Bulletin will be of interest chiefly to research workers and teachers of animal husbandry and animal nutrition.

It was found that during fattening the steers increased most of all in body widths, next in body circumferences, next in widths of the pelvis region, next in body depth, next in body length, next in height of the topline from the ground, and least of all in head measurements. While the steers became broader and slightly taller and somewhat lower-set and their bones grew slightly during the fattening process, yet the fat steers were shorter and smaller-boned as well as broader and distinctly lower-set than thin steers of the same weight.

Unavoidable errors in taking body measurements limit the usefulness of those measurements in describing animal form, size, and fatness. The source and usual size of those errors are considered.

Age plays a very important role in determining how a steer's shape shall change during fattening. Relative to weight, nearly all changes were more extreme with older steers than with young ones. This was to be expected as a logical result of the fact that the gains made by the older steers consist much more largely of fat than do the gains made by younger steers. The younger steers made a very considerable increase in the absolute size of their skeletal and muscular tissues during the fattening period.

Breed differences in the way steers change their shape during fattening were clearly evidenced in these experiments in only two measurements, paunch girth and flank girth. Even in those measurements there was so much overlapping of the two groups that statistical methods were necessary to demonstrate the differences, and a determination of their exact modes of inheritance, if possible at all, would require an impracticably large number of individuals.

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CHANGES IN BODY MEASUREMENTS OF STEERS DURING INTENSIVE FATTENING

JAY L. LUSH*

When thin but healty steers are confined to small lots and are fed liberally of a good ration they gain rapidly in weight. This increase in weight consists largely of fat and lean flesh but also usually includes a small amount of increase in weight of bones, hide, hair, and vital organs, and frequently also a very considerable increase in the weight of the contents of the digestive tract and of the urinary bladder. The flesh, which is a large part of such feed-lot gains, is not deposited at a uniform rate in all parts of the body. As a consequence, steers not only gain in weight during fattening but they also change in conformation, or body shape. The purpose of this Bulletin is to show, so far as body measurements on nearly two hundred steers reveal them, the changes which take place in conformation during intensive fattening.

Most of the data were taken in a study of the differences in conformation of cattle carrying Brahman blood, and cattle not carrying Brahman blood. However, a comparison of the measurements of the same individuals when thin and when fat is equally well suited to a study of what changes in body conformation take place during the process of fattening. A study of the data with that one object in mind forms the basis of this bulletin.

PREVIOUS WORK

Many studies of body measurements of cattle have been published, especially by German workers. However, in those studies with few exceptions, the measurements have been regarded either merely as an objective means of describing the race or breed of cattle studied, or the measurement has been studied with reference to the changes which normally take place during growth from birth to maturity.

Naturally the studies of changes in conformation during growth also have a bearing on changes during fattening because usually growth is associated with varying degrees of fattening. Thus we find considerable attention being given to the effects of fattening on body conformation in such works as those of Wagner(19)** and Hansen(7) and Brody(1). The work of Henseler(8) on the effect of feeding upon the conformation of swine deals directly with this point in swine but the number of animals was quite small. Likewise the studies of Cochel

*R. E. Dickson, Superintendent of Substation No. 7, and J. H. Jones and W. E. Flint assisted in taking and recording the measurements and weights. Without such assistance this study could not have been made.

**Numbers refer to the literature cited at the end of this Bulletin.

and Severson(2) on changes in the conformation of horses during fattening, implicitly suggest that in cattle, too, we might expect to find the greatest increases taking place in the muscular parts of the body and especially in measurements of body width.

In the extensive series of experiments at the Missouri Station on the use of food by cattle, many body measurements were taken at intervals on steers on good and poor rations. These measurements do not show extreme changes during any one interval, as the steers which received the good ration all the time were quite naturally fat from weaning time on and any change from time to time would be a measure of growth *and* fattening. However, a comparison(14) of the average measurements for the steers on the good, medium, and poor rations, combined with a knowledge derived from slaughter tests that the steers differed much more in fatness than in quantity of muscle or of skeleton, does warrant the conclusions that the differences in the average measurements were largely caused by differences in the fatness of the three groups of steers. On this basis, it may be concluded that:

(a) Height at withers is affected practically not at all by fatness.
(b) Height at hips is affected very little if at all by fatness.
(c) Length from shoulder to hips is slightly affected by fatness.
(d) Length from shoulder to ischium increases distinctly with fatness.
(e) Width of hips increases distinctly with fatness.
(f) Heart girth increases very greatly with increases in fatness.

Other measurements are given for each animal but are not averaged or otherwise analyzed.

Seven measurements taken at the beginning and end of fattening of four lots of calves and three lots of two-year-old steers at the Wyoming Station(9, 10) were analyzed chiefly with reference to their relation to type (i. e. to ranginess versus low-setness) as determined visually by experienced judges. Heart girth, width at hips, depth of chest, and paunch girth all showed large increases during the fattening of two-year-old steers. Height at withers showed a small increase and the distance from the floor of the chest to the ground showed a distinct decrease. All measurements of the calves increased during fattening but the greatest increases were in heart girth, width at hips, and paunch girth. The increase in depth of chest was slightly less and the increases in cannon circumference, height at withers, and body length were much less than in the first three measurements mentioned. The increase was least of all in the distance from chest floor to the ground. Ratios of heart girth or paunch girth or chest depth to height at withers are proposed as the best objective measures of type (i. e. of low-setness as compared to ranginess).

In the steer feeding experiments reported by Evvard, Culbertson, Wallace, and Hammond(3, 4 and 5) in Leaflets Nos. 16, 22, and 23 from the Iowa Agricultural Experiment Station, heart girth, paunch girth, shoulder height, and rump height were measured on the steers both thin and fat and the average increase and percentage increase were calculated. For the most part these steers were two-year-olds with about four months between the two sets of measurements. A few were calves and yearlings. All four measurements increased during fattening but heart girth and paunch girth increased very much more than the two heights. On a percentage basis the increase in heart girth was slightly greater than the increase in paunch girth in all lots. In most lots shoulder height increased more than rump height but there were some exceptions to this. These Iowa results give a clear picture of two height measurements both increasing slightly and at very nearly the same rates during fattening while the two girth measurements increase very distinctly more than the height measurements and heart girth increases slightly but significantly more than paunch girth. As was to be expected, the measurements of the younger cattle increased more than those of the older cattle both actually and on a percentage basis.

The most extensive American study on changes in the body measurements of steers during intensive fattening is that conducted by Severson, Gerlaugh and Bentley (16, 17) at the Pennsylvania Station and published in various annual reports of that Station, especially in the annual report for the year 1916-17. The detailed measurements and weights for each animal are published but have not been averaged or summarized with the object of seeing what changes took place during fattening. However, three correlations bearing on this point are published. They are:

Gain in live weight with increase in circumference of chest	**$+ .460 \pm .044$**
Gain in live weight with increase in circumference of paunch	**$+ .306 \pm .056$**
Gain in live weight with increase in circumference of rear flank	**$+ .203 \pm .055$**

These correlation coefficients were calculated without any corrections for heterogeneity of data and are probably very considerably lower than they would have been had such corrections been made. That is to say, other factors which were not the same for all lots (for example, differences in ration, initial weight, age, etc.) doubtless operated to conceal part of the true correlation which existed between gain in live weight and gain in the three measurements named. Our own data support the conclusion that increasing circumference of chest is more closely correlated with increasing weight during intensive fattening than is either paunch circumference or rear flank circumference.

DESCRIPTION OF THE STEERS USED

There were nineteen lots of steers totalling 185 head in these experiments. Two lots of ten head each and one lot of nine head were purchased, 28 head from the SMS ranch and one locally late in the fall of 1926. They were long-aged calves cut back from the 1926 crop and short-aged calves cut back from the 1925 crop but were thrifty and of a desirable feeder conformation and already carried a little more finish when the feeding experiment began than any of the other sixteen lots did. They were predominantly of Hereford breeding but showed much Shorthorn blood, four among the twenty-nine being white and several being distinctly roan. Aside from the fact that they showed a greater range of variation in weight and size than was ideal, they were quite desirable steers for experimental purposes. These SMS steers were used to test the desirability of grinding milo heads and of chopping sorghum fodder before feeding to steers.

One lot of five steers was purchased in the fall of 1924 from Mr. James Callan of Menard. These were sired by a high-grade Brahman bull out of grade Hereford cows. They were purchased with the intention of adding them to another lot of five head of similar breeding, so as to make a single lot as large as is recommended in standard feeding experiment procedure. However, the two groups of steers remained quite different from each other in their rates of gain and in several other respects so that we have thought it best to treat them as two different groups except with respect to average daily ration. They could not be treated separately in this respect because all ten steers were fed in the same pen and of course there is no record of the proportion of feed consumed by each group.

The other fifteen lots (totalling 151 steers) were bred on the Ranch Experiment Station (Substation No. 14), about thirty miles south of the town of Sonora. They include all of the steer calves which were dropped on the Station in the six calf crops from 1921 to 1926, inclusive, except two which were lost, five which died, and twelve which were sickly or stunted or abnormal in some other way to such an extent that it was thought best to omit data concerning them from these calculations. Besides steers actually removed from the pens during the feeding period, five steers were excluded from these calculations bcause their gains were less than the average gain of their lot by at least as much as three times the standard deviation of that gain. We reasoned that when the gain was this low, the chances were more than a hundred to one that something had been wrong with these steers, even though we had not noticed it during the feeding. These six calf crops were fattened in four different feeding seasons and also included three different types of breeding. This explains why they were divided into as many as fifteen lots, each lot fed separately.

The six lots called "Herefords" were sired by purebred Hereford bulls and were out of grade Hereford cows which had at least five or six top-crosses of Hereford blood. For commercial purposes they were therefore practically equivalent to purebreds although of course not eligible to registration. The dates refer to the year in which the steers were born. All were born in the spring of the year between the first of February and the middle of June. The great majority of them were born between the middle of February and the middle of April. The 1921, 1922, and 1923 Herefords were all sired by one bull while the Herefords and also the back-cross steers for 1924, 1925, and 1926 were nearly all sired by another bull. Four of the 1926 Hereford steers were sired by a third bull. One of the 1926 back-cross calves was sired by a fourth bull. All four bulls were purebred Herefords.

The six lots called "Brahman" were out of the same kind of cows as the "Herefords" but were sired by high-grade Brahman bulls. The 1921, 1922, and 1923 Brahmans were sired by a bull loaned by the Pierce estate, Pierce, Texas. This bull was three-fourths Brahman and one-fourth grade Hereford and therefore these three groups of "Brahman" steers were really three-eighths Brahman and nearly five-eighths Hereford. The 1924, 1925, and 1926 Brahmans were sired by a bull donated by the McFaddin estate, Marianna, Texas. This bull was sired by a thirty-one thirty-seconds Brahman bull out of a fifteen-sixteenths Brahman cow and therefore may be called a sixty-one sixty-fourths Brahman bull, although it should be emphasized that in such a system of breeding there is considerable variation in the amount of inheritance which different individual animals may actually receive from the Brahman race, and therefore, that the use of fractions of blood as small as sixty-fourths in describing individual animals is hardly accurate enough to be justified(12). Probably it is sufficiently accurate to say that this bull was a high-grade Brahman containing a little more than fifteen-sixteenths of Brahman blood. His calves out of high-grade Hereford cows were therefore a little less than half Brahman and almost half Hereford.

The three lots colled "Back-crosses" were sired by purebred Hereford bulls and were out of cows which were of exactly the same breeding as the steers called "Brahman." These cows were, with one exception, half or full sisters of the 1921, 1922, and 1923 Brahmans. The one exception was a cow which was a half-sister to the 1924 Brahmans and which was accidentally bred so as to bring her first calf when she was two years old. The "Back-crosses" therefore contained about three-sixteenths Brahman blood, their maternal grandsire having been a three-quarter Brahman and their other three grandparents having been pure or nearly pure Herefords.

All of these Station-bred steers except the 1921 steers were kept in the pastures of the Ranch Station until shortly before their fattening was to begin, when they were shipped to Substation No. 7 at Spur, where they were placed in dry lots for intensive fattening. The 1921 steers were shipped to Spur in the spring of 1922 on account of drouth and short pastures at Sonora that season. They were grazed on rather scanty pastures at Spur for about four months and then were given a supplemental ration of a small amount of cottonseed cake and hulls. They were not actually started on full feed until nearly six months after they arrived at Spur. The 1922 and 1923 steers and the five Callan steers were placed in the feedlots immediately upon their arrival and were started on full feed within less than two weeks after their arrival at Spur. The 1924 and 1925 steers were on a preliminary feed in the feedlots at Spur a little more than a month before full feeding began. The 1926 steers were in the feedlots at Spur for more than two months before full feeding began and, during more than a month of that preliminary feeding, their preliminary ration was a fairly heavy one. Thus they actually were fed for a longer time than the length of their formal feeding period would indicate. During the last month of this preliminary feeding period the three lots of SMS steers were also in the feedlots and were receiving a fairly heavy preliminary ration.

As these tests were primarily planned as breed tests, all of the steers of each breeding were used unless they seemed to be actually sick or so stunted that they would not be representative of normal cattle. In other words, the entire crop of normal steers was included. For this reason the lots were not quite as uniform in size or type as would have been desirable in a feeding test planned to test out the feeding value of some particular feed. On the other hand, there was available for each of these steers except the Callan and SMS steers a detailed record of parentage, birth weight, weights taken regularly about once in every 45 to 50 days from birth until the steer went in the feedlot, and measurements and descriptions taken at intervals of approximately six months. Since we had this individual case history for each steer to supplement our judgment we feel that there is very little chance of our having included in these data a really abnormal steer. The most doubtful case included was one of the 1926 back-cross steers which seemed by all tests to be normal and healthy, but was over two months younger than the other four steers and therefore smaller and less well developed. The number of steers is quite small in several lots but after the undesirable results with the 1923 steers, it was thought better to feed the steers available with known histories than, for the purpose of having larger groups, to buy steers which were out of other herds and were raised under somewhat different conditions. As far as possible, by the use of appropriate statistical methods, we have sought to evaluate and make allowance for the increased unreliability of averages which are based upon small numbers.

All the steers fed in any one year were fed the same feeds but each lot was kept on full feed according to its appetite. The aim was to feed them all they would eat readily. To that end the feeder fed them as much as they would take and yet be hungry at the next feeding. He watched them closely and if any showed loss of appetite or undue looseness of the bowels, the concentrates were promptly reduced for that lot and increased gradually after the trouble had been corrected. The feeds to be fed in any one year were determined by price and other local considerations. Information about the rations and other pertinent data about the feeding are given in Table 1. The grain was ground shelled corn for the 1921 steers and milo heads for all the rest. The milo heads were ground in all cases except the last SMS lot, to which they were fed whole. The roughage was cottonseed hulls for the 1921 steers, cottonseed hulls and a little sorghum hay for the 1922 and 1923 steers, and sorgo fodder for all other lots. The sorgo fodder was chopped by being run through an ensilage cutter for all except the first lot of

Table 1. Pertinent Data Regarding Cattle, Rations, and Feeding Period.

Group	Number of Steers	Cattle					Season Fed	Length of Feeding Period	Daily Ration			Average Initial Measurements			
		Approximate age of cattle when feeding began	Initial Weight	Standard Deviation of Initial Weights	Gain	Standard Deviation of Gains			Cottonseed Meal	Grain	Roughage	Chest Depth	Wither Height	Body Length	Heart Girth
		Months	Pounds	Pounds		Pounds		Days	Pounds	Pounds	Pounds	cm.	cm.	cm.	cm.
1921 Herefords	13	19–20	545	58	349	30	1922–23	120	2.4	9.0	15.8	54.9	108.8	121.2	145.9
1921 Brahmans	10	19	570	55	319	44	1922–23	120	2.4	9.0	14.6	56.1	114.1	120.5	149.3
1922 Herefords	14	31–32	766	81	373	53	1924–25	112	2.9	14.2	19.2	(a) 62.3	(a) 118.2	(a) 138.6	(a) 164.0
1922 Brahmans	8	30–31	838	73	350	36	1924–25	112	2.9	13.9	19.7	(a) 65.4	(a) 126.0	(a) 138.8	(a) 172.6
1923 Herefords	10	18	540	73	324	43	1924–25	112	2.3	11.3	15.0	(a) 54.5	(a) 107.0	(a) 122.6	(a) 145.3
1923 Brahmans	5	19	606	74	230	39	1924–25	112	(b) 2.2	10.8	15.3	58.1	115.2	125.8	154.4
1923 Purchased Brahmans	5	18–20(c)	660	35	206	55	1924–25	112	(b) 2.2	10.8	15.3	60.5	119.7	131.2	158.9
1924 Herefords	10	20–21	604	75	329	22	1925–26	112	3.5	11.5	13.4	57.6	112.3	128.8	151.1
1924 Brahmans	14	20–21	629	72	300	36	1925–26	112	3.6	11.8	12.6	58.2	118.4	125.1	155.8
1924 Back-crosses	4	20–21	680	31	318	16	1925–26	112	3.6	11.8	14.8	58.7	117.4	130.5	158.6
1925 Herefords	10	8	428	47	281	33	1925–26	112	2.9	9.4	8.5	49.4	99.5	109.7	134.0
1925 Brahmans	14	8–9	412	46	243	25	1925–26	112	2.8	9.3	7.5	49.5	103.2	112.0	131.6
1925 Back-crosses	4	8–9	464	34	298	9	1925–26	112	3.0	9.9	9.1	51.7	101.9	110.7	140.7
1926 Herefords	13	8–9	367	62	235	14	1926–27	111	2.3	9.4	8.8	46.6	93.1	100.7	127.1
1926 Brahmans	17	9–10	410	64	229	35	1926–27	111	2.3	9.4	9.7	49.0	101.3	107.6	130.8
1926 Back-crosses	5	8–9	422	99	241	58	1926–27	111	2.4	9.5	9.7	48.8	98.8	105.8	132.9
SMS Ground heads	10	10–18(c)	581	106	227	31	1926–27	111	2.5	10.1	12.9	55.2	107.0	119.6	151.5
SMS Ground ration	10	10–18(c)	582	99	222	24	1926–27	111	2.5	10.1	12.0	54.7	107.8	118.3	150.8
SMS Unground ration	9	10–18(c)	577	101	202	26	1926–27	111	2.5	10.0	12.2	55.2	107.4	118.2	150.6

(a) The measurements on these three groups were taken two months before feeding began and are therefore slightly smaller than they should be for direct comparison with other groups.

(b) Since these two groups of steers were fed in the same lot we have no measure of the amount of feed actually consumed by each group. The figures given are averages for the entire lot of ten steers.

(c) Since we have no individual birth dates the ages of these four groups cannot be approximated as closely as the ages of the others. Birth dates are also lacking for about half of the 1921 Herefords.

SMS steers and the last lot of SMS steers. Where sick or abnormal steers were removed from a lot, the feed records were corrected by subtracting from the total feed consumed that proportion which the average weight of the steers removed constituted of the average weight of the entire lot.

DESCRIPTION OF MEASUREMENTS USED

Seventeen different linear measurements were studied. Two of these (cannon circumference and width at pin bones) were taken on only five of the nineteen groups of steers. Three measurements pertaining to the head (muzzle circumference, length of head, and width at eyes) were taken on only seven groups of steers. Height at hips was taken on only thirteen groups. Three measurements pertaining to the rump region (width at hooks, width at thurls or hip joint, and length of pelvis) were taken on seventeen groups. The remaining eight measurements were taken on all nineteen groups of steers.

The different measurements are listed and described below with pertinent remarks about their primary accuracy and are illustrated in Figures 1 and 2.

1. Chest Width. (Figure 2, W.) This was the greatest width of the chest measured just behind the shoulders. Calipers consisting of two parallel arms, the one stationary and the other sliding, on a graduated rod (Figure 3, A) were used for the measuring. There were two considerable sources of error in this measurement. The first was the variable amount of pressure used in placing the caliper arms snugly against the animal. This could not be entirely standardized no matter how careful the operator was. This was of little importance on thin animals but was of considerable importance on fat ones. The second source of error was in the position of the animal and the tenseness of the muscles along its side. As far as possible the steers were placed in a normal position before measuring and stood squarely on all four legs. But these steers could not be posed as carefully as show animals and many of them were so wild even when fat that it was absolutely necessary to put them in a chute and stanchion to measure them at all. This second source of error was more important when the steers were thin than when they were fat and had become much gentler. This was the least accurate of all measurements taken, excepting possibly width at pin bones when the steers were fat.

2. Loin Width. (Figure 2, L.) This was the width of the loin at a point midway between the third and fourth lumbar vertebrae, and therefore about half way between the forward edge of the pelvis and the rear edge of the last rib. The points of the caliper used (Figure 3, B) were pressed snugly against the sides of the loin but no more pressure was used than necessary to make sure that the caliper points were resting against solid flesh. This measurement was almost totally free from the influence of variations in the position of the animal but was subject to a considerable error in the amount of pressure applied. Relative to its total size it was one of the least accurate measurements.

3. **Heart Girth.** (Figures 1 and 2, R.) This was measured with a steel tape (Figure 3, D) drawn snugly around the body in a plane perpendicular to the long axis of the body at its smallest circumference, which is just behind the front legs. This measurement is very slightly affected by the animal's position and by variations in the tightness with which the tape was drawn around the body. This latter source of error was greater with the fat steers than with the thin ones. Relative to its total size this is one of the most accurate of the measurements studied.

4. **Flank Girth.** (Figures 1 and 2, K.) This was measured with the steel tape drawn snugly around the body at its smallest circumference just in front of the hook bones at the top of the body and in the highest point in the rear flank. The plane of this measurement was not exactly perpendicular to the long axis of the body, since it usually passed over the back at a point slightly farther forward than that at which it passed under the body. This measurement was subject to some error from variations in the position of the animal and also to small errors from uncontrollable differences in the tightness with which the tape was drawn.

5. **Paunch Girth.** (Figures 1 and 2, U.) This was measured with the steel tape and was the greatest circumference of the body in any plane perpendicular to the body axis. It was affected somewhat by the steer's position, varying about a centimeter with each breath. However, the position of the steer's legs and head did not affect it very much and its accuracy approaches that of the heart girth.

6. **Pelvis Width** or **Width at Thurls.** (Figure 2, J.) This was measured with a caliper (Figure 3, B) with its points placed snugly just lateral to the hip joint on each side of the pelvis. It is very accurate on thin steers but on real fat ones some error can arise through failure to use exactly the same amount of pressure at each measuring.

7. **Width at Hooks.** (Figure 2, H.) This was measured with a caliper (Figure 3, B) from the extreme lateral point of the hooks (ilium) on one side to the corresponding point on the other side. It was a very accurate measurement since the steer's position did not affect it at all and only a few of the very fattest steers succeeded in putting so much fatty tissue on the outside of the points measured, that differences in the amount of pressure applied to the calipers had opportunity to cause any noticeable error.

8. **Depth of Chest.** (Figure 1, D.) This was measured with the parallel bars (Figure 3, A). It was the smallest vertical outside diameter of the chest. This measurement was comparatively accurate, being affected only by the variable amount of pressure.

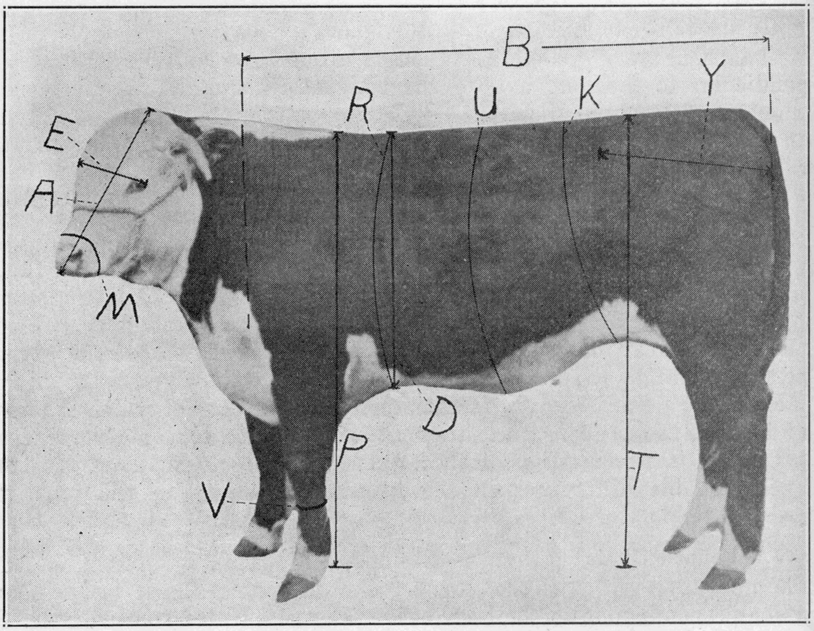

Figure 1. Sideview of Hereford Steer with Diagram Showing the Location of the Various Measurements Studied.

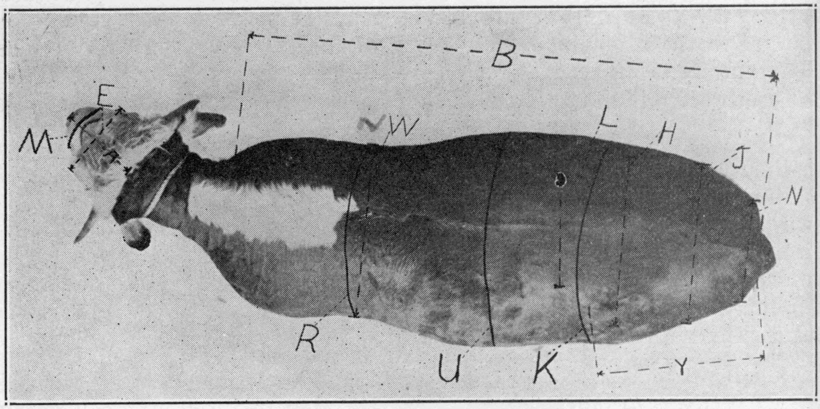

Figure 2. Top View of Hereford Steer with Diagram Showing the Location of the Various Measurements Studied.

9. Length of Pelvis. (Figures 1 and 2, Y.) This measurement was taken with a caliper (Figure 3, B) from the extreme posterior point of the pin bone (tuber ischii) to the extreme anterior point of the hook bone (ilium) on the same side, so far as that could be located definitely on the live animal. This measurement was rather accurate on the thin steers but there was a small amount of error with the real fat steers in locating the exact anterior point of the measurement.

10. Length of Body. (Figures 1 and 2, B.) This was measured with the parallel bars (Figure 3, A). It was the distance, in a line parallel to the axis of the body, from the extreme anterior point of the shoulder point (tuberosity of the humerus) to the extreme posterior point of the pin bone (tuber ischii). It was subject to considerable error due to the position of the steer, but the abnormal position could be seen easily and its effects upon the measurement could be estimated fairly well.

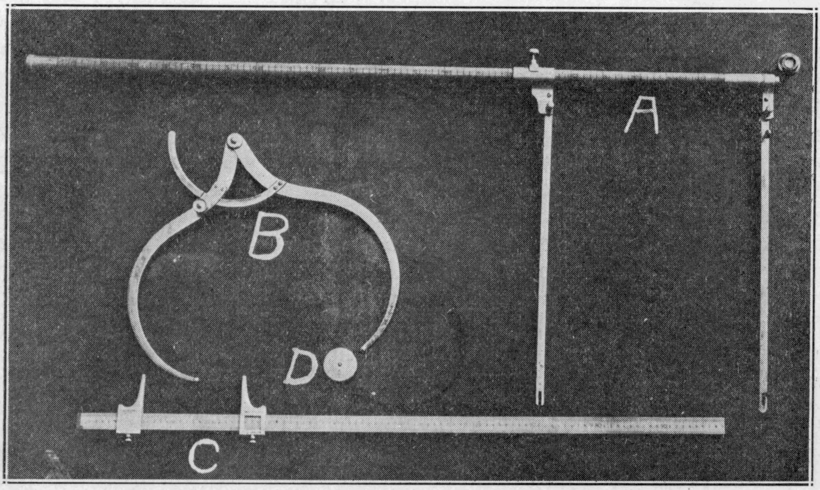

Figure 3. Instruments Used for Measuring these Steers. A, Cattle Measuring Standard with spirit level attached, Lydtin's model. B, Caliper used for measurements of pelvic region and for loin width. C, Caliper used for measuring length of head and width at eyes. D, steel tape used for measuring girths and circumferences. A large wooden caliper (not shown in the picture) catalogued by the Central Scientific Company was used in place of instruments A, B, and C on the very earliest groups of steers.

11. Cannon Circumference. (Figure 1, V.) This measurement was taken with the steel tape pulled tightly around the foreleg at the smallest place between knee and fetlock joint. It was most accurate in absolute units and relatively more accurate than any other measurement except length of head. Its sources of error were possible failure to find the very smallest place on the cannon bone and differences in the tightness of the tape when the reading was taken. Also care had to be taken that there was no dried mud or other foreign matter under the tape.

12. Width at Pin Bones. (Figure 2, N.) This measurement was taken with the calipers (Figure 3, B) and was from the extreme lateral point of the pin bone (tuber ischii) on one side to the corresponding point on the other. It was comparatively accurate on very thin steers but was extremely inaccurate on fat steers because of the difficulty of locating the exact points from which the measurement was to be taken. It is certainly the most inaccurate measurement which was attempted on fat steers.

13. Muzzle Circumference. (Figures 1 and 2, M.) This was taken with the steel tape drawn rather tightly around the nose (including the lower jaw) at the smallest place just back of the nostrils. It was subject to considerable error in the tightness of the tape and, in a few cases, there was some difficulty in getting the steers to hold their jaws closed in the normal position.

14. Height Over Withers. (Figure 1, P.) This was the vertical distance from the highest point over the withers to the ground. It is the most widely used measurement in studies of animal form and quite frequently is used as the standard for reducing all other measurements to relative figures (7). Its accuracy is dependent upon the position of the steer but is very little influenced by differences in the pressure with which the arm of the measuring standard is applied and very little by any differences in the tenseness of the steer's muscles. If the steer carries his head up, has his back level and his forefeet placed squarely under him, this is a very accurate and useful measurement. However, many of our steers were so wild that they could not be thus carefully posed and it was often necessary to estimate what correction was needed for one which kept its head down or which persisted in pulling back against the stanchion. For this reason this measurement in these data was probably less accurate than that of height over hips.

15. Length of Head. (Figures 1 and 2, A.) This was measured with a small straight-arm caliper (Figure 3, C) and was the extreme length of the head from the highest point on the poll to the end of the muzzle, measured in a straight line parallel to the long axis of the front surface of the head. It was exceedingly accurate, being subject only to a very small error in the amount of pressure applied to the caliper arm which rested against the soft tissue of the muzzle.

16. Height Over Hips. (Figure 1, T.) This was the vertical distance from the highest point midway between the hooks to the ground. Its accuracy was very dependent upon the position of the steer but only slightly dependent upon fatness or tenseness of muscles. When it was found impossible to pose a steer in normal position, corrections due to the back being arched or to the hind legs being too far forward were estimated, probably with a higher degree of accuracy in these data than was possible for height over withers.

17. **Width at Eyes.** (Figures 1 and 2, E.) This was measured with a small straight-arm caliper (Figure 3, C) and was the greatest width of the head at a point about level with the eyes. Since the skull is rigid and has only a thin covering of skin at this point, this measurement was quite accurate.

The attempt was made to safeguard at all times the accuracy of the primary measurements in every practical way. Each measurement was taken three times and between times the measuring instrument was removed entirely from its position, so that any error which might have arisen through the incorrect placing of the instrument might be minimized. So far as it could be done without slowing down the work materially, the first readings were taken for all measurements in which the same instrument was used before the second readings were taken for any of them, and the second readings were all completed before any of the third readings were taken. By this device it was sought to give the observer time to forget the first reading and thus to remove any unconscious bias against a second reading which was materially different from the first. Also this gave the steer time to change position although many of them retained the same position throughout the measuring. The observer consciously refrained from looking at the measurement scale until he was sure the instrument was in proper position. This precaution was also planned to guard against any unconscious bias of the observer toward certain numbers or already recorded measurements. All measurements were made by the writer himself in all cases.

These various precautions went very far toward minimizing or eliminating all errors of measurement except those caused by the steer's failure to stand in a perfectly normal position. No practical objective way to eliminate this source of error was found. To have taken one reading of each measurement on a steer, then to have turned him loose and an hour or so later to have caught him again for the second set of measurements and to have repeated this later for the third set would have met this difficulty partially but was not feasible under the limitations of these experiments. Moreover, such a large amount of handling the steers seemed likely to interfere with other practical aspects of the experiment, such as the daily gains, amount of bruising shown by carcasses, etc., which seemed of much more importance than extreme refinement of accuracy in these measurements.

Under these circumstances it is evident that the measurements involving the least fat and muscle and affected by the angles of the fewest joints were the most accurately taken. Unfortunately those are the measurements which give the least direct information about the disposition of the lean and the fat tissue on the steer's body!

The only available data designed primarily to show the accuracy of these various measurements were collected on Jersey cows. Those data, previously unpublished, are given in a summarized form in Table 2, and should give a rough guide to the comparative accuracy of the different measurements. They do not apply exactly, because the dairy cows differed from the steers in general shape and also were gentle and could be posed in a position closely approaching normal. However, these data may apply fairly well to the thin steers. The figures were obtained by measuring each of nine cows aged from two to thirteen years eleven times. Between measurements each cow was led off the platform where the measuring was done and at least two other cows were measured before another set of measurements were taken on the first cow. For estimating the accuracy of the measurements, the resulting data are the statistical equivalent of 91 sets of measurements taken on a single cow. The standard error of each measurement was calculated by methods similar to those used in a previous study of the accuracy of weights(13). The error thus found in centimeters, when multiplied by 100 and divided by the average size of the corresponding measurement on the nine cows studied, becomes what we have termed the "coefficient of error" in Table 2. This figure expresses the standard error of the measurement as a percentage of the average size of the measurement. It differs from the usual coefficient of variation in that this includes only the errors of measuring and changes in the cow's position and does not include any variation caused by real differences in the average measurements of the cows used.

Table 2. Actual and Relative Errors of Various Measurements as Determined on Nine Dairy Cows in Fair Flesh.

Measurement Studied	Average Standard Deviation of Measurements Made Upon the Same Cow. (Centimeters)	Coefficient of Error (per cent)
Head Length	.22	.49
Cannon Circumference	.08	.54
Width at Hooks	.31	.67
Height over Withers	.92	.77
Heart Girth	1.37	.83
Paunch Girth	1.78	.87
Height over Hips	1.09	.90
Pelvis Width	.36	.91
Width at Eyes	.20	.93
Depth of Chest	.67	1.03
Width at Pin Bones	.29	1.09
Flank Girth	1.90	1.10
Length of Pelvis	.61	1.26
Loin Width	.48	1.55
Length of Body	2.53	1.79
Muzzle Circumference	.75	2.00
Chest Width	1.30	3.68

METHODS OF CALCULATION

These measurements were studied not for any intrinsic interest attaching to the measurement itself, but for the information which that measurement might reveal about the changes in body shape or conformation during the fattening period. In the idea of shape or conformation it is not the absolute size of the measurement which matters, but it is the relative size of the measurement, relative, that is, to other measurements or to weight or to some other expression for the general size of the animal. Thus we may have a large steer and a small steer of very similar conformation. The absolute measurements and the weights of the two steers will be very different but the ratios of one measurement to another will be very nearly the same for both steers. In studying changes in conformation, therefore, we are studying changes in the ratios of measurements rather than changes in the measurements themselves. Conformation or shape is a matter of *relative* measurements.

In such a study it is important that the best measurement or index of general size be chosen as the standard to which each of these measurements is to be compared. There are two standards rather generally used for this purpose, namely, height over withers and weight. The former has certain mathematical advantages and probably would be preferable with dairy cattle. However, the extreme importance of weight in feeding experiments with beef cattle and also the fact that weight is a good index of general size and in a way sums up the effects of all measurements, thereby minimizing the effects of individual variation in any one or two measurements, seemed to compel the use of weight in this study as the standard with which to compare actual measurements. It seemed necessary to use the cube root of the weight rather than the weight for the following reasons. In two geometrically similar solids of uniform and equal densities, any linear dimension of the one is in the same ratio to the corresponding dimension of the other as the cube root of the weight (or volume) of the first is to the other. Now while cattle have neither a uniform nor a constant density, yet that density probably does not vary widely(20) and it is scarcely possible that such variations as do occur will be large enough to affect very noticeably ratios derived from weights and linear measurements. For example, the process of fattening which might be expected to increase density by the deposition of fat in the spaces around the vital organs has also some compensating action in the opposite direction through the fact that the fatty tissue does increase the body dimensions somewhat and has a lighter specific gravity than the rest of the animal tissues. It may be objected that we never have two steers which are exactly similar in the geometrical sense of the word. But that is exactly the point which we wish to study. A ratio is wanted which will reveal changes which take place in the geometrical shape of a steer's body when he changes from a thin condition to a very fat one rapidly. The most serious objection to this ratio (measurement to cube root of weight) as an index of changing shape during fattening is that it also changes somewhat with age and, on steers as young as these, the changes which would have occurred with the increase in age during the three-to-four-month feeding period are distinctly noticeable. The observed changes in the ratios during fattening are, therefore, the combined results of age-changes and fatness-changes. The age-changes are, of course, less extreme on the older steers. Also many studies of age-changes have been made on other cattle, especially on dairy cattle. From these other studies and from the observed differences in shape-changes in the older and the younger steers in this study a fairly satisfactory estimate can be made of the extent to which the observed changes in this study were really caused by increasing fatness independent of normal growth.

The method of calculating the ratios is illustrated in Table 3 for some of the 1921 Herefords.

Table 3. Illustrating the Method of Calculating the Ratios.

Steer Number	October 31—November 2, 1923				February 28—March 2, 1924			
	Width of Chest (Centimeters)	Weight (Pounds)	Cube Root of Weight	Ratio	Width of Chest (Centimeters)	Weight (Pounds)	Cube Root of Weight	Ratio
95	31.03	496.7	7.919	3.918	40.17	880	9.583	4.192
97	32.47.	509.3	7.986	4.066	41.07	854.7	9.490	4.328
98	36.73	591.3	8.393	4.376	44.10	954	9.844	4.480
101	30.63	453.3	7.682	3.987	40.67	758.7	9.121	4.459
102	28.10	438.0	7.594	3.700	38.23	736.7	9.031	4.233
103	30.97	586.7	8.371	3.700	42.73	914.7	9.707	4.402

The method of calculating the change in ratios during fattening is illustrated in Table 4.

Table 4. Change in Relative Width of Chest during Fattening. 1921 Hereford Steers.

Steer Number	Ratio when Thin	Ratio when Fat	Difference	Percentage Change
95	3.918	4.192	+.274	+ 7.0
97	4.066	4.328	+.262	+ 6.4
98	4.376	4.480	+.104	+ 2.4
101	3.987	4.459	+.472	+11.8
102	3.700	4.233	+.533	+14.4
103	3.700	4.402	+.702	+19.0
105	3.976	4.344	+.368	+ 9.3
106	3.570	4.296	+.726	+20.3
107	3.964	4.503	+.539	+13.6
108	3.703	4.331	+.628	+17.0
109	3.430	4.347	+.917	+26.7
110	3.796	4.288	+.492	+13.0
111	4.043	4.658	+.615	+15.2
Total	50.229	56.861	6.632	+176.10
Average	3.864	4.374	.510	+ 13.55
Standard Deviation	.247	.157	.220	6.48
Coefficient of Variation	6.4%	3.6%	43.1%	47.8%

The usual biometrical formulae were used in these calculations except that the idea which Fisher(6) calls "degrees of freedom" and which in its simplest form is expressed in Bessel's formula was taken into account in calculating the standard deviation. This seemed rather important on populations as small as most of these were. While the fact that we are dealing here with ratios and percentages might seem to require the use of logarithms or reciprocals instead of the actual figures, yet the ratios within any one group do not vary widely and individual percentage changes as large as 20.0 are quite rare. The use of the actual figures under these circumstances does not introduce any very noticeable error and does make calculation easier and makes it possible for most readers to follow the argument much more easily than if logarithms or reciprocals were involved. There was a table similar to Table 4 for each group of steers for each measurement or 247 such tables in all. As it is not feasible to publish all those tables, the most essential items of information from each of them (the calculations at the bottom of the last column) are summarized in Tables 5 to 21, inclusive, one table for each measurement studied. The figures in that last column thus show the relative rates of increase in the measurement and in the cube root of the weight. If the measurement and the cube root of the weight increase at the same rate during fattening the change in the cubic ratio will be zero. That is what would happen if the increase in weight during fattening were equally distributed all over the body. Therefore *percentage changes which are sensibly greater than zero indicate that the part measured increases in size during fattening relatively faster than the steer as a whole does.* Likewise, *percentage changes which are sensibly less than zero indicate that the part measured increases in size during fattening relatively less rapidly than the steer as a whole does.* A negative percentage change does not mean that the part measured has actually decreased in size. It merely means that that part has increased less rapidly than the weight has increased and presumably, therefore, that the increase in weight was deposited much more in other parts of the body than it was in the part described by that measurement.

RESULTS

Chest Width

The data showing the percentage changes in relative chest width are given in Table 5.

Table 5. **Summary of Changes in Relative Chest Width during Fattening.**

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	+13.5	6.5
1921 Brahmans	10	+15.3	13.6
1922 Herefords	14	+17.7	7.3
1922 Brahmans	8	+17.8	11.2
1923 Herefords	10	+ 9.6	9.2
1923 Brahmans	5	+12.8	9.3
1923 Purchased Brahmans	5	+ 1.0	7.2
1924 Herefords	10	+19.3	9.8
1924 Brahmans	14	+ 2.7	5.5
1924 Back-crosses	4	+ 8.8	1.9
1925 Herefords	10	+ 8.0	5.8
1925 Brahmans	14	+ 9.8	7.2
1925 Back-crosses	4	+ 4.6	10.2
1926 Herefords	13	+ 7.4	7.8
1926 Brahmans	17	+10.1	10.4
1926 Back-crosses	5	+10.7	3.0
SMS Ground heads	10	+ .4	4.2
SMS Ground ration	10	— .9	8.3
SMS Unground ration	9	+ 1.8	5.7
Total	185		
Weighted Average		+ 9.29±.41%	8.20%

In every group but one, chest width increased more rapidly than weight did. There is unmistakable evidence of group heterogeneity, according to Fisher's Z-test for significance of difference in variance. In fact, Z is more than three times as large as the limit beyond which P falls below .05. (P is the probability on a scale of zero to 1.00 that all these groups of steers were random samples taken from the same population, so far as this measured characteristic was concerned.) It is clear that the averages of the different groups differ from each other far more than would be caused by errors of sampling from a single homogeneous population. For this reason a calculated probable error or coefficient of variation for this weighted average does not have quite the usual significance. The size of the weighted average itself depends upon the character of the different groups of steers which were included in its calculation. Thus, if more groups like the 1921 and 1922 steers had been included the average change would have been larger while if more groups like the SMS steers had been included the average change would have been less. The close correspondence between the average changes made by groups of the same age and fed during the same feeding period is good evidence that the age and condition of the steers and the conditions peculiar to each feeding trial had a marked influence upon the amount of the average change. This similarity of the changes made by groups of the same age fed at the same time is very noticeable in all except the 1923 and 1924 steers, where conditions peculiar to each group of steers seem to have been more important in determining the average amount of change than were conditions which applied to all the steers of the same age which were being fed at the same time and measured at the same time. The calculated probable error expresses only the error of sampling within each group. It is a measure of the net effect of two classes of errors,—the errors in taking the measurement when the steers were either thin or fat and sampling errors arising from the fact that not all steers within the same group changed at the same rate either in measurements or in weight. The calculated average and the probable error are subject to the usual interpretation when applied to samples from a universe consisting only of the nineteen populations from which these nineteen groups actually studied were (presumably) random samples, and only when the sample contains the same proportion of steers from each of these various populations as was contained in the sample of 185 steers from which this average and this probable error were calculated. It is not safe to generalize from these figures that the relative chest width of all steers fed for 110 to 120 days increases about 9.3 per cent during fattening. It probably is safe or at least is much safer to generalize to the extent of saying that in all fattening steers the relative chest width increases faster than the relative chest depth or relative body length (to be shown later).

These same limitations apply to the interpretation of the average change of the other measurements still to be shown. Measurements taken on all nineteen groups of steers can be compared directly. Those which were taken on only seventeen groups or fewer must be discussed with additional reservations.

There seems to be no breed difference in the changes in relative chest width. There are six comparisons between Herefords and entirely comparable groups of Brahmans. In five of these the Brahmans show the greater increase but the 1924 Herefords show so much greater increase than the 1924 Brahmans that the average difference (regarding each group as a unit) is 1.18 per cent and the Herefords show the greater increase. This difference is quite without significance, P being between .70 and .75 (Fisher's modified "Students method").

From the individual ratios it is very evident by inspection that there is a very low correlation or even a negative correlation between the thin and fat ratios of each animal. This seems to mean that there is a large error in taking the primary measurement. A relatively narrow chest width when the steer is thin might be due either to a chest which was actually quite narrow or it might be due to errors in taking the measurement. If due to the former it would be expected still to be relatively narrow when the steer becomes fat although of course it may not be impossible for some narrow-chested steers at the beginning of feeding actually to surpass the average steers of their lot in the width of chest before the feeding period is ended. On the other hand, if the error in taking measurement is very large, an apparently narrow-chested steer at the beginning is apt to have been nearly an average steer and is almost as apt to receive a wide measurement as a narrow one when fat. These correlations were not all calculated but the one for the largest group (the 17 head of 1926 Brahmans) was found to be —.006. From inspection of the ratios in other groups this correlation seemed to be fairly typical of the general situation.

The changes in relative chest width during fattening may be summed up by saying that this measurement increases much more rapidly than weight does and in fact more rapidly than any other measurement included in this study. It is, however, a very erratic measurement, and hence very limited in usefulness as an indicator of fatness in single steers. Most of the wide variation in this measurement is tentatively ascribed to primary errors in measuring. Probably it would be found to be much more reliable on thoroughly gentle steers and if the measuring instrument used has larger contact surfaces, so as to minimize differences in the pressure with which the instrument is applied.

Loin Width

The summary of the data showing the changes in relative loin width is given in Table 6.

In all but two of the groups the loin width increased faster than the weight did. The two exceptions are both groups containing very small numbers and one of them (the 1923 purchased Brahmans) was quite different from the other groups in respect to gains and most of the shape changes. The changes show only about half as large a standard deviation as the changes in chest width. Next to chest width this measurement shows a greater increase during fattening than any other of the measurements studied. Fattening is distinctly a process which widens the loin.

The nineteen groups of steers do not form a homogeneous population. (Z is more than three times as large as it is at the point where P falls to .05.) Special circumstances applying to individual groups or to certain ages or to certain feeding seasons have much to do with determining the value of the average changes in relative loin width.

Table 6. Summary of Changes in Relative Loin Width during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	+7.6	5.0
1921 Brahmans	9	+6.9	7.3
1922 Herefords	14	+6.1	5.8
1922 Brahmans	8	+2.8	5.7
1923 Herefords	10	+6.9	4.1
1923 Brahmans	5	—3.1	2.9
1923 Purchased Brahmans	5	—1.6	2.1
1924 Herefords	10	+3.1	4.9
1924 Brahmans	14	+0.4	4.1
1924 Back-crosses	4	+3.4	4.0
1925 Herefords	10	+1.3	3.5
1925 Brahmans	14	+3.2	3.5
1925 Back-crosses	4	+3.3	2.8
1926 Herefords	13	+9.0	4.0
1926 Brahmans	17	+6.7	4.1
1926 Back-crosses	5	+5.8	3.5
SMS Ground heads	10	+9.6	4.9
SMS Ground ration	10	+9.3	1.9
SMS Unground ration	9	+7.5	2.4
Total	184		
Weighted average		+5.18 ± .22	4.39

There is a suggestion of a breed difference in this measurement. In five of the six comparisons the Herefords increased more than the Brahmans did. The average difference (giving each group equal weight) is 2.9 per cent but P is about .16 and therefore this difference cannot be regarded as surely significant. It suggests a breed difference but does not prove one.

Heart Girth

The summary of data showing the changes in relative heart girth is given in Table 7.

Except for the six groups fed during the last season and one other small group, the change is distinctly positive although it is smaller than in the case of the two measurements already discussed. The nineteen groups are very distinctly not samples from a single homogeneous population. Z is nearly four times as large as it is at the limit at which the probability of the population being a homogeneous one falls below .05. A considerable part of this heterogeneity is caused by conditions common to all lots fed at the same time. Thus all but one of the last six lots (fed in the winter of 1926-27) show very small changes, while both the first two lots show large changes. All but one lot of the 1922 and 1923 steers (fed in the winter of 1924-25) show large changes and all but one lot of the 1924 and 1925 steers (fed in the winter of 1925-26) show positive changes of a medium size. There is a suggestion of a breed difference here. The six Hereford groups averaged .77 more increase than the six comparable Brahman groups. However, this difference is not convincing because the probability is about .12 that a difference this large or larger in either direction could have been the result of chance. The data suggest but do not prove that the Herefords increased more rapidly in heart girth than the Brahmans.

Table 7. Summary of Changes in Relative Heart Girth during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	+3.3	2.4
1921 Brahmans	10	+2.8	2.0
1922 Herefords	14	+4.1	1.8
1922 Brahmans	8	+3.2	2.4
1923 Herefords	10	+3.0	2.2
1923 Brahmans	5	+ .8	2.6
1923 Purchased Brahmans	5	+2.5	.9
1924 Herefords	10	+2.8	2.2
1924 Brahmans	14	+1.0	1.2
1924 Back-crosses	4	+2.4	1.9
1925 Herefords	10	+1.6	1.6
1925 Brahmans	14	+2.1	2.0
1925 Back-crosses	4	— .2	1.3
1926 Herefords	13	+ .2	1.5
1926 Brahmans	17	+ .4	2.3
1926 Back-crosses	5	— .7	1.8
SMS Ground heads	10	— .6	1.3
SMS Ground ration	10	+ .3	2.1
SMS Unground ration	9	—1.8	1.4
Total	185		
Weighted average		+1.55 ±.10	1.92

Flank Girth

The summary of data showing the changes in relative flank girth is given in Table 8.

Table 8. Summary of Changes in Relative Flank Girth during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	+2.7	2.7
1921 Brahmans	10	+ .5	3.9
1922 Herefords	14	+4.2	2.0
1922 Brahmans	8	+2.1	4.6
1923 Herefords	10	+2.2	2.9
1923 Brahmans	5	— .6	4.3
1923 Purchased Brahmans	5	—2.1	1.7
1924 Herefords	10	+3.9	2.5
1924 Brahmans	14	+ .8	1.8
1924 Back-crosses	4	+2.5	2.9
1925 Herefords	10	+ .6	2.8
1925 Brahmans	14	+1.7	2.8
1925 Back-crosses	4	— .8	4.6
1926 Herefords	13	— .1	2.1
1926 Brahmans	17	—3.0	2.4
1926 Back-crosses	5	—1.9	2.4
SMS Ground heads	10	+2.4	2.8
SMS Ground ration	10	+ .3	3.2
SMS Unground ration	9	+ .6	3.6
Total	185		
Weighted average		+ .97 ±.14	2.88

The average change is distinctly positive although a good many of the single groups are negative. The entire population of 185 is quite heterogeneous, Z being about three times as large as it is at the limit where P falls below .05.

There is good evidence of a breed difference in this measurement. The unweighted average of the six Hereford groups is +1.98 greater than the unweighted average of the six corresponding Brahman groups. The probability of a difference this large or larger occurring just as a matter of chance is .03. The difference is therefore statistically significant and we may conclude that the Herefords do increase faster than the Brahmans in relative flank girth. Several reasons for this difference may be suggested. It is barely possible that the Brahmans on account of their greater wildness, especially when thin, hold their flank muscles much more tense when being measured and thus have a larger measurement when they are thin than the Herefords do. When the Brahmans become fat the flanks are fuller and lower and such tenseness of muscles would hardly influence the measurements at all. While this possibility must be admitted, in the author's opinion another explanation is much more plausible. The Brahman normally carries a fuller flank and a smaller paunch relative to general size than the Hereford does. When thin the Hereford becomes quite small and "drawn" in the region of the rear flank. Not so with the Brahman, which has a conformation more like that of the hog or the horse in this respect. The thin Brahman has a larger relative flank girth than the equally thin Hereford, whereas when fat there is not much difference in this respect. The apparently greater increase of the Herefords in flank girth is, in the author's opinion, a real one and is due to the fact that the Brahmans do not shrink as much as the Herefords do in flank girth when thin. The back-cross steers were intermediate in this respect, averaging somewhat more nearly like the Brahmans but being quite irregular.

Flank girth is a considerably more variable measurement than heart girth, due largely to the greater influence of the animal's position upon the accuracy of the flank girth measurement. Since it also increases less with increasing fatness, flank girth is, for most purposes, a distinctly less useful measurement than heart girth is. It is quite likely that variations in the amount of stomach and intestinal contents ("fill") would materially affect both this measurement and paunch girth.

Paunch Girth

The summary of data showing the changes in relative paunch girth is given in Table 9.

The average change is negative but is so irregular and so small relative to its probable error that it is quite insignificant even apart from the fact that the nineteen groups of steers are not random samples from a single homogeneous population. Z is more than three times as large as it is at the limit for which the probability that this population is homogeneous falls below .05. The reasons for this heterogeneity are not clear, but they seem to be associated with age and with the conditions which pertained to each feeding period and to each time of measurement. This is shown by a very general tendency for the Hereford and the Brahman groups which were born in the same year to resemble each other very closely in the average changes which they made.

Table 9. Summary of Changes in Relative Paunch Girth during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	—2.5	3.2
1921 Brahmans	10	—3.8	2.2
1922 Herefords	14	+5.2	3.4
1922 Brahmans	8	+2.9	4.4
1923 Herefords	10	+1.7	2.3
1923 Brahmans	5	— .8	2.4
1923 Purchased Brahmans	5	—3.3	2.3
1924 Herefords	10	+1.9	1.9
1924 Brahmans	14	— .4	2.8
1924 Back-crosses	4	+ .9	1.2
1925 Herefords	10	— .6	1.5
1925 Brahmans	14	+ .6	2.8
1925 Back-crosses	4	+1.6	4.1
1926 Herefords	13	—6.2	3.0
1926 Brahmans	17	—5.4	4.6
1926 Back-crosses	5	—1.9	1.7
SMS Ground heads	10	+3.9	1.8
SMS Ground ration	10	+1.1	3.3
SMS Unground ration	9	+2.3	1.8
Total	185		
Weighted average		— .35 ± .15	2.97

There is fair but hardly conclusive evidence of a breed difference. The unweighted average decrease of the six Brahman groups is 1.25 more than for the comparable Hereford groups. The probability that this large a difference could be due to chance alone is about .07. Unpublished slaughter data show that the Brahmans have very distinctly smaller digestive tracts. This is, in the author's opinion, the explanation of why the Brahmans show a greater relative decrease in paunch girth during fattening. Their digestive tracts have not the ability to grow as large under conditions of full feeding as do the digestive tracts of the Herefords. This explanation is also supported by the fact (evident in Table 1) that the daily feed consumption of the Herefords in proportion to their live weight was greater in every case than that of the Brahmans when both lots were fed according to appetite. However, the back-cross steers show an increase in relative paunch girth whereas both the Hereford and the Brahman comparable groups show a distinct decrease.

Pelvis Width

The summary of data showing the changes in relative pelvis width is given in Table 10. Measurements of pelvis width were not made on the 1921 steers.

The average change in pelvis width is negative but is so small that it could not be considered significant even if the entire population had proved to be homogeneous in this respect. There is unmistakable evidence of group heterogeneity, Z being more than three times as large as it is at the limit at which the probability of the entire group being a homogeneous one falls below .05.

Table 10. Summary of Changes in Relative Pelvis Width during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1922 Herefords	14	—1.3	3.8
1922 Brahmans	8	—2.1	2.9
1923 Herefords	10	—2.0	2.4
1923 Brahmans	5	—1.8	2.4
1923 Purchased Brahmans	5	—4.2	3.7
1924 Herefords	10	—1.0	2.8
1924 Brahmans	14	+3.2	2.9
1924 Back-crosses	4	+3.0	3.6
1925 Herefords	10	+2.4	2.8
1925 Brahmans	14	+1.2	3.4
1925 Back-crosses	4	+3.6	3.1
1926 Herefords	13	+1.3	2.4
1926 Brahmans	17	+ .8	1.3
1926 Back-crossses	5	—3.4	4.5
SMS Ground heads	10	—2.3	1.1
SMS Ground ration	10	—1.2	2.0
SMS Unground ration	9	— .5	1.4
Total	162		
Weighted average		— .05 ±.14	2.73

There is no evidence of a breed difference in this respect, as the probability is somewhat greater than +.70 that an average difference as large as or larger than the observed difference could easily have arisen by chance alone.

There is no clear-cut evidence of an age difference. Conditions peculiar to the 1925-26 feeding period seem to have had an important effect as five of those six groups show large positive changes and only two other groups show any positive changes at all.

Pelvis width seems to almost or not quite keep pace with increasing weight during fattening.

Width at Hooks

The summary of data showing the changes in relative width at hooks is given in Table 11. Measurements of width at hooks were not made on the 1921 steers.

Again the statistical test shows that these 17 groups do not form a single homogeneous group in this respect, Z being nearly three times as large as the limit for which the probability of homogeneity falls below .05. The average change is positive but this fact can be regarded as significant only within the limits prescribed by the evident heterogeneity of the population.

The Brahmans show a more rapid increase than the Herefords in width of hips but this difference seems likely to have been quite accidental, the probability of that being .20.

Table 11. Summary of Changes in Relative Width at Hooks during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1922 Herefords	14	—1.9	3.9
1922 Brahmans	8	+1.1	2.0
1923 Herefords	10	—2.0	2.9
1923 Brahmans	5	— .2	1.3
1923 Purchased Brahmans	5	— .5	.7
1924 Herefords	10	+ .1	2.8
1924 Brahmans	14	— .5	2.9
1924 Back-crosses	4	+2.1	2.3
1925 Herefords	10	+ .8	1.6
1925 Brahmans	14	+ .8	3.2
1925 Back-crosses	4	+2.0	2.9
1926 Herefords	13	+1.4	1.5
1926 Brahmans	17	+2.1	2.1
1926 Back crosses	5	+3.3	1.1
SMS Ground heads	10	+3.0	1.4
SMS Ground ration	10	+3.2	1.5
SMS Unground ration	9	+2.7	1.0
Total	162		
Weighted average		+ .89±.13	2.41

There seems to be an age difference here because the last nine groups (all of which were younger than the first eight groups) show positive changes which are rather large in most cases. New-born and very young calves are relatively narrow at the hooks and wide at the thurls. From about weaning time to sexual maturity this condition is rapidly reversed in steers and still more rapidly in heifers. The younger groups of steers in this study were fed during that period of their normal growth when the hooks are widening very rapidly to meet the demand of the body for wider and stronger places of attachment for the muscles and other tissues which are to support the rapidly increasing weight and volume of the digestive organs(7). In view of this special condition applying to width at hooks, the positive sign of the weighted average change should probably be interpreted as due more to normal growth in this measurement than to a direct effect of fattening itself.

Depth of Chest

The summary of data showing the changes in relative depth of chest is given in Table 12.

The general change is distinctly negative, only one group showing a positive change and that a very small change. The changes made by the different groups are quite uniform in amount except for the rather large decreases shown by the 1924 steers and the rather small decreases shown by the 1925 steers. No explanation is suggested for the divergence of these steers from the general trend. The 1924 and 1925 steers were measured and fed at the same time and therefore any effect of season or feed or peculiarity in the taking of the measurement should have been the same for those groups.

Even including the 1924 and 1925 steers, heterogeneity is less extreme than in the case of the measurements thus far discussed. When all 19 groups are included Z is about one and a half times as great as it is at

Table 12. Summary of Changes in Relative Depth of Chest during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	—2.0	1.7
1921 Brahmans	10	—2.5	2.2
1922 Herefords	14	—2.3	2.4
1922 Brahmans	8	—2.2	3.3
1923 Herefords	10	—1.9	1.7
1923 Brahmans	5	—2.6	2.9
1923 Purchased Brahmans	5	—2.2	3.2
1924 Herefords	10	—3.0	1.6
1924 Brahmans	14	—3.8	1.6
1924 Back-crosses	4	—2.2	1.5
1925 Herefords	10	—1.5	2.1
1925 Brahmans	14	+ .2	1.7
1925 Back-crosses	4	—1.1	2.0
1926 Herefords	13	—2.2	1.1
1926 Brahmans	17	—1.9	3.4
1926 Back-crosses	5	—2.2	2.0
SMS Ground heads	10	—2.0	1.6
SMS Ground ration	10	—1.4	1.3
SMS Unground ration	9	—2.2	1.1
Total	185		
Weighted average		—1.95±.11	2.13

the limit for which the probability of homogeneity falls below .05. With the 1924 and 1925 steers excluded, the other thirteen groups seem to form a homogeneous population with regard to changes in relative chest depth. This seems to suggest strongly that relative chest depth is very little influenced by age, breed, or the other special conditions peculiar to each group of steers. Fattening is very much less a matter of deepening than it is of widening the chest.

There is no evidence of a breed difference. The Herefords show a little less extreme decrease in relative chest depth than the Brahmans do but the probability that a difference this large or larger could occur by chance alone is more than .80 and the difference therefore is utterly without significance.

Length of Pelvis

The summary of data showing the changes in relative length of pelvis is given in Table 13. Measurements of length of pelvis were not made on the 1921 steers.

The general change is distinctly negative although three groups are faintly positive and there is a very great variation in the size of the different group averages.

Heterogeneity is very marked, *Z* being nearly four times as large as it is at the point for which the probability of homogeneity falls below .05. Some of this appears due to influences operating on all the groups fed at the same time. Thus all six groups fed the last season have rather small changes. This falls far short of explaining all the heterogeneity, however, as the different 1922 groups and also the different 1925 groups differed widely from each other. The unreliability of the individual measurements is not a satisfactory explanation of this heterogeneity, for the standard deviation is rather small and the measurement seems to have been a rather accurate one.

Table 13. Summary of Changes in Relative Length of Pelvis during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1922 Herefords	14	—4.3	2.8
1922 Brahmans	8	+ .2	3.3
1923 Herefords	10	—3.1	2.3
1923 Brahmans	5	—5.8	2.8
1923 Purchased Brahmans	5	—1.3	2.5
1924 Herefords	10	—4.7	2.7
1924 Brahmans	14	—3.7	2.2
1924 Back-crosses	4	—1.0	1.1
1925 Herefords	10	—2.9	1.0
1925 Brahmans	14	— .9	2.5
1925 Back-crosses	4	—2.2	1.5
1926 Herefords	13	+ .1	1.5
1926 Brahmans	17	+ .1	1.7
1926 Back-crosses	5	— .7	1.3
SMS Ground heads	10	—1.5	1.7
SMS Ground ration	10	— .3	1.1
SMS Unground ration	9	— .4	1.5
Total	162		
Weighted average		—1.85 ± .11	2.09

There is no good evidence of a breed difference, for, while the Herefords show the greater decrease, a difference that large or larger might be expected by chance alone to occur 46 times out of a hundred. The greater droopiness of the Brahman rumps may have led to a greater error in taking this measurement on them but there is no apparent reason why that error should have been consistently biased in one direction on one group of Brahmans and in the other direction on other groups of Brahmans.

Length of Body

The summary of data showing the changes in relative length of body is given in Table 14.

Table 14. Summary of Changes in Relative Length of Body during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	—7.9	4.1
1921 Brahmans	10	—2.4	2.3
1922 Herefords	14	—7.5	3.6
1922 Brahmans	8	—5.2	2.4
1923 Herefords	10	—2.8	2.4
1923 Brahmans	5	—6.9	3.4
1923 Purchased Brahmans	5	—6.6	3.6
1924 Herefords	10	—8.2	3.0
1924 Brahmans	14	—4.4	2.5
1924 Back-crosses	4	—6.2	2.7
1925 Herefords	10	—2.5	2.5
1925 Brahmans	14	—4.1	4.2
1925 Back-crosses	4	—1.6	1.2
1926 Herefords	13	+ .2	2.6
1926 Brahmans	17	— .0	3.3
1926 Back-crosses	5	+ .3	2.5
SMS Ground heads	10	—2.3	3.1
SMS Ground ration	10	+ .2	3.5
SMS Unground ration	9	—1.0	3.3
Total	185		
Weighted average		—3.53 ± .16	3.15

The change is very distinctly negative in all except the six lots fed the last season. In three of those it is actually positive although very slight. The generally slight change in the last six groups is doubtless largely due to the facts that those steers were quite young and also made relatively smaller gains than most of the other groups. It seems safe to conclude that as a general rule body length increases during fattening at a distinctly slower rate than weight does.

The evidence for heterogeneity is quite convincing, Z being more than four times as large as it is at the limit at which the probability of homogeneity falls below .05. This is not all due to the slight changes of the six groups fed during the last year. The remarkable difference between the two 1921 groups and that between the comparable 1924 groups are probably too great to be explained as errors of random sampling from a single homogeneous population. Whatever may be the causes, this group heterogeneity is very evident.

There is no good evidence for a breed difference. The Herefords show a little greater decrease but the probability of a difference this large or larger occurring as a matter of chance alone is .53 and therefore the observed difference is without significance.

There is a slight general tendency for the older groups of cattle to show the greater decreases but the statistical significance of this is very doubtful.

Measurements of body length are subject to considerable inaccuracy on account of changes in the animal's position. Not only does the position of the front feet affect this measurement on account of carrying the shoulder point forward or backward, but the humping or swaying of the back and the position of the pelvis in connection with the bending of the back or with the position of the hind feet also affects the measurement of body length greatly. With animals as wild as some of these (especially the Brahmans) were, the inevitable failure to get the animals posed in exactly comparable positions at all times may have been responsible for very much of the variation in results. Theoretically this measurement should be one of the most reliable indications of general animal size, and probably it will be found more useful for well-trained and gentle animals than these figures indicate.

Cannon Circumference

The summary of data showing the changes in relative cannon circumference is given in Table 15. Cannon circumference was measured at both the beginning and end of the feeding period in only one feeding season. This measurement had been included in the original plan of the experiment as an indicator of that characteristic known to practical cattlemen as "size of bone." It was seen at once that the change was certain to be negative but that cannon size, unlike wither height and some other measurements, might be affected by the increasing weight of the animal. The cannon bones might require to be larger to support the increases in body weight caused by increasing fatness. For this reason it was felt certain that relative cannon circumference would prove to be intermediate in changes during fattening between wither height and the measurements more directly dependent upon body size. Accordingly, observations were not taken on it at later feeding trials.

Table 15. Summary of Changes in Relative Cannon Circumference during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1922 Herefords	14	—6.6	2.1
1922 Brahmans	8	—6.7	1.1
1923 Herefords	10	—3.5	1.7
1923 Brahmans	5	—7.2	1.8
1923 Purchased Brahmans	5	—5.1	1.6
Total	42		
Weighted average		—5.74 +.19	1.78

The changes are all negative and strongly so. The five groups are not a homogeneous population, *Z* being nearly twice as large as it is at the limit beyond which the probability of homogeneity falls below .05, but this lack of homogeneity is due almost entirely to the 1923 Herefords, which, like the 1922 steers, were measured initially two months before the intensive fattening began but were younger and still growing rapidly in skeleton. The 1923 Brahmans included in their feeding period all of the period of intensive fattening but only about two-thirds of the period of skeletal growth included in the period between measurements for the 1923 Herefords. This will largely or entirely explain the greater decrease of the Brahmans. The greater decrease of the Station-bred Brahmans as compared to the purchased Brahmans is very likely to have all resulted from the distinctly greater gains made by the Station-bred animals. In short all the observed group heterogeneity is easily explained as resulting from definitely known circumstances connected with the feeding. Changes in relative cannon circumference may be expected to be approximately the same in cattle of the same age which gain at the same rate. There is no evidence here of a breed difference.

Width at Pin Bones

The summary of data showing the changes in relative width at pin bones is given in Table 16. This measurement, like the preceding one, was taken on both thin and fat steers during only one feeding season. Our first experience with it on fat steers indicated to us that we could not take it with any reasonable degree of accuracy on fat steers and, after this was verified the following season, this measurement was henceforth omitted from studies of fat steers although retained for the studies of growth and for breed comparisons on relatively thin animals.

The changes are distinctly negative, which is rather to be expected when it is remembered that the ends of the caliper were pressed in very firmly against the bone. The group heterogeneity is probably significant, Z being about one and a half times as large as it is at the limit for which the probability of homogeneity falls below .05.

Table 16. Summary of Changes in Relative Width at Pin Bones during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1922 Herefords	14	—2.2	5.9
1922 Brahmans	8	—7.2	3.8
1923 Herefords	10	—2.9	5.8
1923 Brahmans	5	—9.5	7.4
1923 Purchased Brahmans	5	—16.2	9.9
Total	42		
Weighted average		— 5.85 ± .70	6.76

There is a faint indication of a breed difference, the Brahmans showing the greater relative decrease. However, this need not be considered other than accidental because the 1923 Brahmans and Herefords are not entirely comparable since the period between the thin and the fat measurements was not the same for both groups. Even if we regard these two lots as strictly comparable, a difference at least as large as the observed one might be caused by chance alone as often as 8 or 9 times out of a hundred. Therefore, it is not necessary to regard the observed breed difference as other than accidental.

The inherent inaccuracy in this measurement arises from the fact that the contour of the fat steer is very rounded at this point and width decreases rapidly from front to rear. Therefore, external measurements with the caliper barely resting against the skin are not reliable because it is almost impossible to locate exactly corresponding points on different animals and a slight deviation in locating the proper points would make a very large deviation in the observed measurement. Now if the calipers are pressed very firmly against the flesh just lateral to the pin bones, the measurement can be fairly accurate on thin steers or on dairy cows. But if the animals are very fat the flesh is very much thickened here, not only laterally but also to the rear. This makes it exceedingly difficult to press the caliper points against the flesh at corresponding places and with the same degree of pressure on different fat steers. It is the author's opinion that this measurement is practically useless in studies on fat steers unless some much more accurate way of taking it can be devised.

Muzzle Circumference

The summary of data showing the changes in relative muzzle circumference is given in Table 17. This measurement was taken on both the thin and the fat steers during only two feeding seasons. The first data showed that the actual measurement increased only slightly with fatness and yet was not as free from the influence of fatness as other measurements like length and width of head or height over withers or height over hips. As muzzle circumference was less important from several points of view than these last-named measurements, it was dropped from the plans after the second feeding season.

Table 17. Summary of Changes in Relative Muzzle Circumference during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	—9.1	2.5
1921 Brahmans	10	—6.7	3.6
1922 Herefords	14	—7.7	3.4
1922 Brahmans	8	—4.0	1.4
1923 Herefords	10	—6.7	1.8
1923 Brahmans	5	—5.7	3.3
1923 Purchased Brahmans	5	—4.0	2.2
Total	65		
Weighted average		$-6.79 \pm .23$	2.79

The changes are all negative and distinctly so. The groups were heterogeneous but not extremely so, Z being about one and a half times as large as it is at the limit at which the probability of homogeneity falls below .05. The very large decrease shown by the 1921 Herefords is probably enough by itself to account for the significant group heterogeneity.

There is some indication of a breed difference, the Herefords showing the greater decrease in all three comparisons. However, the probability that this could be due to chance alone is about .09 and therefore it need not be regarded as significant. If there is a real difference in this respect it is probably caused by the smaller tongue and smaller lower jaw of the Brahman, which make its muzzle circumference rather smooth in outline even when the steer is thin and lead to the result that any deposition of fat which may occur in this region must necessarily increase the circumference of the already smooth and rounded Brahman muzzle more than the same amount of fat would increase the squarer and more angular Hereford muzzle. These statements in regard to the smaller size of the Brahman tongue and lower jaw are based partly upon extensive observation and partly upon slaughter data (as yet unpublished) from these and some three hundred other steers.

It seems safe to conclude from these data that muzzle circumference is slightly influenced by the deposition of fat but very much less so than the circumferences of the body or than most of the other measurements of the body itself.

Height Over Withers

The summary of the data showing the changes in relative height over withers is given in Table 18. As this is the most widely used single measurement in studies of cattle, it was studied on all the cattle in this experiment even though it very quickly became evident that wither height was scarcely influenced at all by the deposition of fat.

The changes are all negative and very distinctly so. The nineteen groups as a whole are distinctly heterogeneous, Z being nearly four times as large as it is at the limit for which the probability of homogeneity falls below .05. However, observation of Table 18 shows that this is almost entirely caused by age and feeding season. Thus all the last six groups show very nearly the same change. So do the 1925 steers, the 1924 steers, the 1922 steers, and the 1921 steers. The 1923 Station-bred Brahmans are the only steers which show a change very different from that of the other groups of the same age which were fed at the same time. Even this deviation is not extreme and can probably be regarded as an error of sampling since there were only five steers in the group. Thus it seems that, as regards height at withers, all steers of the same age and fattened and measured under similar external conditions react in very nearly the same way. This measurement thus should be fully as applicable to all sorts of steers under comparable conditions as any of the other measurements thus far discussed. This conclusion is in agreement with the widespread use of this measurement in growth studies of cattle generally.

Table 18. Summary of Changes in Relative Height over Withers during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	—8.9	2.5
1921 Brahmans	10	—9.3	3.7
1922 Herefords	14	—7.1	2.5
1922 Brahmans	8	—6.4	1.6
1923 Herefords	10	—5.6	2.0
1923 Brahmans	5	—3.1	1.0
1923 Purchased Brahmans	5	—6.3	1.3
1924 Herefords	10	—7.1	2.2
1924 Brahmans	14	—7.5	2.5
1924 Back-crosses	4	—7.5	2.1
1925 Herefords	10	—6.1	1.8
1925 Brahmans	14	—4.7	3.3
1925 Back-crosses	4	—5.5	3.7
1926 Herefords	13	—4.2	1.7
1926 Brahmans	17	—3.6	4.6
1926 Back-crosses	5	—3.1	1.1
SMS Ground heads	10	—3.2	1.4
SMS Ground ration	10	—4.0	2.4
SMS Unground ration	9	—3.1	1.8
Total	185		
Weighted average		—5.68±.12	2.41

The Herefords show a larger relative decrease than the Brahmans do, but a difference this large or larger might occur due to chance alone about 18 times out of 100 and therefore need not be considered as significant. Moreover, the slightly larger gains made by the Herefords would cause them to show a little larger decrease even if everything else were equal. Therefore, no significance whatever can be attached to the observed breed difference.

Length of Head

The summary of the data showing the changes in relative length of head is given in Table 19. This measurement was taken only during the first two seasons. It quickly became apparent that the relative decrease would be large and yet the measurement did not involve a part of the body which was intrinsically important itself from the standpoint of the amount or distribution of the meat on the body. Therefore, measurements of head length on fat steers were discontinued after the second feeding season.

Table 19. Summary of Changes in Relative Length of Head during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	—8.6	1.7
1921 Brahmans	10	—7.4	1.5
1922 Herefords	14	—8.2	1.6
1922 Brahmans	8	—7.3	1.3
1923 Herefords	10	—5.8	2.7
1923 Brahmans	5	—5.6	.9
1923 Purchased Brahmans	5	—5.6	2.4
Total	65		
Weighted average		—7.25 ± .15	1.82

The changes are distinctly negative. The groups are heterogeneous, *Z* being more than one and one-half times as large as it is at the limit for which the probability of homogeneity falls below .05. However, the larger decreases are shown by the older groups or by the groups making the larger gains in each feeding season and the effect of those two factors is probably sufficient to explain all group heterogeneity. The Herefords show the larger decrease but this also corresponds to the greater gain made by the Herefords and was therefore to have been expected. Moreover, the observed breed difference was not statistically significant as it would be expected about 15 times out of 100 just as a matter of chance alone.

It may be concluded that head length is a process of normal growth which proceeds at a rate governed largely by age and influenced almost not at all by whether or not the nutritional state of the animal is such as to permit the deposition of fat at a rapid rate. In young animals head length is increasing faster but fat deposition takes place more slowly than in older ones. Consequently head length relative to weight decreases more rapidly during the fattening of older than of younger animals and more rapidly in animals which make large gains than in those which make small gains.

Height Over Hips

The summary of the data showing the changes in relative height over hips is given in Table 20. This measurement was not taken during the third feeding season as we had come to the conclusion that it practically duplicated the measurement of height over withers, height over hips being larger, by an almost constant amount. Since height over withers was so much more universally used we planned to concentrate on that and to omit height over hips. However, observations during the third feeding season and in the studies on the breeding herd at the same time raised the question as to whether, with cattle as wild and as difficult to pose as these, height over withers was as accurate a measurement and as little influenced by changes in the animal's position as height over hips. Largely for this reason height over hips was included again in the work of the fourth feeding season. The results seem to show that height at hips is even more unaffected by fat deposition than height at withers is but that the two measurements are almost equally variable, the standard deviations of the percentage change being almost identical (2.39 per cent and 2.41 per cent) when both are corrected for group heterogeneity. The greater decrease shown by height at hips arises mostly from differences between the younger groups of cattle. While height at hips shows the greater decrease even in the first seven groups, a difference that large or larger in either direction might be expected due to chance alone about 30 times out of 100. This difference, therefore, need not be considered as significant. During the last feeding season, when cattle from one to two years younger than those in the first seven groups were fed, height over hips showed a decrease so much greater than that shown by height over withers that there is less than one chance in fifty that it could have occurred by chance alone. It is therefore statistically significant. Other studies, such as those of Hansen(7) and Brody(1), have shown that height over hips is larger relative to height over withers in young calves than in older ones, the two measurements tending more nearly toward equality as maturity is approached. In other words, during normal growth height over withers increases more than height at hips does. This probably furnishes a complete explanation of the observed difference between the relative changes shown by height over withers and height at hips. The former approaches its mature condition at a later age than height at hips does and thereby reflects on a more magnified scale the changes which accompany normal growth. Aside from this it is not certain that there is any difference in the changes of the two measurements relative to weight with increasing fatness. However, for reasons based on anatomy one might expect height over withers to increase more with fatness because, (1) more fat is deposited immediately over the withers than immediately over the hips, (2) increasing fat deposits might very well tighten and shorten the muscles which support the chest from the shoulder blades and thus raise the fore part of the body, (3) the increasing weight which comes with age and fatness would probably have a greater tendency to draw the hips down by altering the normal angle of the pelvis with the ground than it would to lower the withers by altering the normal angles of any of the joints in the forelegs. This last effect is often seen in mature cows which are in well-advanced stages of pregnancy. For these reasons relative height at hips reflects the changes of body shape with increasing fatness slightly more accurately and to a more extreme degree than height over withers does. On the other hand, the difference in this respect is certainly small and height over withers is much more widely used and is a better indicator of normal growth without fattening on account of its later approach to its mature dimensions. Our data seem to show little to choose between them from the standpoint of accuracy although from observation we had expected height at hips to be more accurate on steers which were wild and hard to pose and often persisted in pulling back against the stanchion or halter, as many of these did. On the dairy cows height over withers proved to be slightly more accurate than height over hips.

Table 20. Summary of Changes in Relative Height over Hips during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	—9.3	3.8
1921 Brahmans	10	—8.0	4.0
1922 Herefords	14	—8.3	1.8
1922 Brahmans	8	—5.8	1.5
1923 Herefords	10	—7.0	1.7
1923 Brahmans	5	—7.5	.8
1923 Purchased Brahmans	5	—6.0	2.4
1926 Herefords	13	—6.4	1.3
1926 Brahmans	17	—5.4	2.3
1926 Back-crosses	5	—7.1	1.9
SMS Ground heads	10	—6.1	2.5
SMS Ground ration	10	—4.5	2.1
SMS Unground ration	9	—4.3	1.2
Total	129		
Weighted average		—6.64 ±.14	2.39

The observed changes are all distinctly negative. Group heterogeneity is unmistakable, *Z* being more than twice as large as it is at the limit at which the probability of homogeneity falls below .05. This group heterogeneity seems to be fully explainable as caused by the younger groups still growing more in height at hips than the older groups and of course between groups of the same age there is a general tendency for the group making the larger gain to show the greater percentage decrease relative to weight.

The Herefords show the greater decrease but a difference this large or larger would be expected by chance alone about 19 times out of 100. Morover, the fact that the Herefords made larger gains would naturally lead to a larger percentage decrease in this relative measurement on them. There is, therefore, no reason to think that a breed difference exists in the reaction of the steers with regard to this measurement during fattening.

Width at Eyes

The summary of the data showing the changes in relative width at eyes is given in Table 21. This measurement was not taken after the first two feeding seasons as it was evident that the relative measurement would show an extreme decrease and yet this measurement was not directly related to any part of the body on which fat was being deposited to any noticeable extent or which was important from the standpoint of the meat on it.

The changes are all very distinctly negative. Group heterogeneity is evident, *Z* being more than one and one-half times as large as it is at the limit at which the probability of homogeneity falls below .05. This group heterogeneity is very largely a reflection of differences in the gains made by the different groups, the change being less in the case of the group making the smaller gain in every comparable case except that of the 1922 steers.

Table 21. Summary of Changes in Relative Width at Eyes during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	—10.4	1.9
1921 Brahmans	10	— 9.2	2.0
1922 Herefords	14	— 8.8	1.9
1922 Brahmans	8	— 9.7	1.9
1923 Herefords	10	— 8.0	1.4
1923 Brahmans	5	— 7.0	2.4
1923 Purchased Brahmans	5	— 6.7	1.6
Total	65		
Weighted average		— 8.88 ± .16	1.86

The Herefords show the larger decrease but the observed decrease is actually less than might have been expected as due to chance alone and therefore is quite without significance.

Neither length of head nor width at eyes is a very useful measurement in estimating the fatness of a steer. The head dimensions approach their mature size at an earlier age than any other dimensions. They are probably quite subject to individual variations,—at least we frequently see steers which are of the same age and of the same general kind of breeding but which differ markedly in the width or length of their heads. These measurements are markedly influenced by sex-condition, the width especially being very much increased in bulls. Finally they do not directly measure a part of the body which is itself economically important in meat production. Their changes during fattening are of a passive or negative nature. Because they have nearly reached their own mature dimensions and do not reflect fat deposition at all, they decrease relative to body weight very rapidly during fattening, such decreases being as a rule largest in the animals which make the largest gains and least in the animals which make the least gains.

These objections to head measurements as indicators of fatness, either by themselves or relative to some other measurement or to weight, do not of course preclude the possibility that they may be quite useful in other ways. Thus if it is true, as is widely supposed, that a short wide head is correlated with a short wide body and with the ability to make large and economical gains, then head measurements might be very useful in closer studies of that fact and its applications.

DISCUSSION OF MEASUREMENTS RELATIVE TO WEIGHT

Steers which were of the same breeding and were fed, weighed, and measured under the same external conditions changed their relative measurements during fattening at rates which were far from uniform for any one measurement. The weighted average standard deviation given at the bottom of each summary table is the best measure we were able to devise for that lack of uniformity. It is the standard deviation corrected for group heterogeneity as used by Richey and Willier(15) except that in this case it is also corrected for the loss of degrees of freedom which takes place in correcting for group heterogeneity. Those standard deviations, arranged in the order of their magnitude, are repeated here:

Cannon Circumference	**1.78**
Length of Head	**1.82**
Width at Eyes	**1.86**
Heart Girth	**1.92**
Length of Pelvis	**2.09**
Depth of Chest	**2.13**
Height over Hips	**2.39**
Height over Withers	**2.41**
Width at Hooks	**2.41**
Pelvis Width	**2.73**
Muzzle Circumference	**2.79**
Flank Girth	**2.88**
Paunch Girth	**2.97**
Length of Body	**3.15**
Loin Width	**4.39**
Width at Pin Bones	**6.76**
Chest Width	**8.20**

It will be noticed that the increases are very gradual until the last three measurements are reached. Those three are very distinctly more variable than the others. There are three distinct sources of the variation which is summed up in these standard deviations. In the first place there is the error in taking the measurement itself. In the second place some steers gained a smaller amount than other steers in the same lot and this would cause some variation in the percentage increase or decrease in the relative measurement. In the third place two steers gaining the same amount may not have put the gain on the same parts of the body. For instance, one might increase more in paunch girth and less in heart girth than another steer in the same lot and gain the same amount. In other words, the change in shape during fattening may really be different in different steers. It is this third source of variation in which we are interested and about which we wish to know. The second source of variation should be of almost equal importance in the case of all the different measurements. Therefore, increased variation of the changes in one measurement as compared to another must be due to differences in the first or third sources of variation or both. Much of it is attributable to the first source,—that is, to differences between the true weight or the true measurement and the observed weight or the observed measurement. If we were justified in assuming that the errors of measurement were the same for these steers as the figures given in Table 2, the errors of measurement could be eliminated in a rough way from these standard deviations. When such an assumption is made the standard deviations all become less. Muzzle circumference seems to have been taken more accurately on the steers than on the dairy cows. All the other measurements, except the widths of chest, loin, and pin bones, tend to approach more closely a uniform standard deviation of about 2.0 per cent (extremes: width at eyes 1.3 per cent and paunch girth 2.7 per cent). The three widths mentioned remain very distinctly more variable than any of the other measurements. This can mean either that the steers really do vary extremely in the way they change their loin, chest, and pin-bone widths during fattening or that the errors in taking these three measurements are very much greater on fat steers than they were on the dairy cows. On the basis of our observations we are inclined to believe that the latter explanation is the more important, although it seems quite likely that the steers really would vary somewhat more in the way they changed their shape in these three measurements which directly reflect increases in fatness than they would in measurements of parts which are much more muscular or skeletal in nature.

The various measurements which were taken on all nineteen lots of cattle rank as follows in the average percentage change which they made during the fattening process:

Chest Width	**+ 9.29**
Loin Width	**+ 5.18**
Heart Girth	**+ 1.55**
Flank Girth	**+ .97**
Paunch Girth	**— .35**
Depth of Chest	**—1.95**
Length of Body	**— 3.53**
Height over Withers	**—5.68**

The average changes in the nine measurements which were not studied on all nineteen groups rank as follows when compared with the other measurements on corresponding groups:

1. Width at hooks is almost equal to flank girth
2. Pelvis width is almost equal to paunch girth
3. Length of pelvis is practically equal to depth of chest
4 and 5. Cannon circumference and width at pin bones make practically the same change as length of body
6. Muzzle circumference decreases almost as much as height over withers
7. Length of head decreases more than height over withers and almost as much as height over hips
8. Height over hips decreases more than height over withers, especially where younger groups of cattle are concerned
9. Width at eyes shows the most extreme decrease of all, a decrease which would have averaged nearly 7.8% if it had been taken on all the groups and had maintained the same ratio to height over withers as it did in the groups on which it was taken.

In general, we may say that measurements of *width* increased distinctly, particularly those involving the width of soft fleshy parts. Except for the almost totally unreliable width at pin bones, width at eyes was the only width which decreased at all relative to weight and it was almost purely a skeletal measurement. Measurements of *girth* or *circumference* made a moderate increase if they involved soft fleshy parts of the body and a moderate decrease relative to weight if they involved only non-fleshy parts, such as the muzzle or cannon bone. Measurements of *length* decreased relative to weight without exception but the decrease was smaller for lengths involving the main part of the body such as pelvis length and chest depth and body length than it was for the lengths which were more purely skeletal, such as head length and height over hips or withers. In general, the soft fleshy parts of the body increased very greatly in absolute measurements while the skeletal parts grew slowly and thus decreased relative to weight. Of the various skeletal parts, the head grew the most slowly with the leg bones next. The pelvis showed a surprisingly large growth relative to other skeletal parts. Except for the loin and flank the various cuts of the hind quarters seemed to enlarge during fattening much less than most of the cuts of the fore quarters. This seems to emphasize a point which is frequently misunderstood about the fattening of cattle. The object of fattening is much less a matter of increasing the proportion of the desirable cuts in the carcass (if indeed that proportion is actually increased by fattening) than it is to improve the grade and market desirability of the whole carcass and to increase the proportion of carcass to live weight.

Evidence for a breed difference in the changes in body shape during fattening appears to be strong only in the case of flank girth and paunch girth. In both flank girth and paunch girth the Herefords increased the most or decreased the least and the difference was large enough and consistent enough to be at least on the borderline of statistical significance. Both these differences also agree with the visual impressions one gets of these animals and with slaughter data; namely, that the Herefords develop much larger middles than the Brahmans during heavy feeding but are less well developed in the flanks when thin. However, neither of these breed differences is nearly distinct enough to permit a steer to be identified objectively as Brahman or Hereford from the records of his change during fattening. Therefore, it would be exceedingly difficult, if not absolutely impossible to study the inheritance of differences in the rate of change of flank or paunch girth during fattening.

In not a single one of the seventeen measurements was the population homogeneous with respect to the average change shown by the different groups. However, in most of the measurements the observed heterogeneity is to be explained as entirely due to the groups of steers being of different ages and making different total gains. In flank and paunch girth, breed differences contribute to group heterogeneity. In several measurements no explanation is offered for the unusually large or unusually small changes made by certain groups. The 1923 purchased Brahmans differed greatly from the other groups in several cases. They were also visibly quite different in the way they changed during the fattening period. They gained a rather small amount and tended to grow rather than to fatten. Whether this was due to their different early environment, to individual heritable peculiarities of their immediate ancestors, or to some other cause is not known.

RATIOS OF ONE MEASUREMENT TO ANOTHER

The usefulness of ratios of measurements to the cube roots of the weights in estimating fatness is quite limited, according to the results of this investigation. Measurements of soft parts which would reflect the degree of fatness were quite inaccurate. This was particularly true in the case of chest width. On the other hand the accurate measurements for the most part either increased at the same rate as the cube root of weight did or increased much more slowly and thereby only reflected increasing fatness in a negative way by decreasing relative to weight. Since the fat steer is clearly *less* tall and *less* long but *more* wide in proportion to weight than the thin one, it seemed reasonable to suppose that if one desired merely an objective indicator of fatness a more reliable indicator might be found in the ratios of a measurement of height or length to a measurement of width than in a ratio involving weight. Eight such ratios, which seemed promising on the basis of what the weight ratios had shown, were studied. They were the three ratios of chest width to chest depth, to heart girth, and to height over withers; the three ratios of loin width to chest depth, to heart girth, and to height over withers; and the two ratios of heart girth to chest depth and to height over withers.

The summary of the data showing the changes in the ratio of chest width to heart girth is given in Table 22.

Table 22. Summary of Changes in Chest Width Relative to Heart Girth during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	+10.0	5.9
1921 Brahmans	10	+12.2	13.3
1922 Herefords	14	+13.1	7.1
1922 Brahmans	8	+14.1	10.2
1923 Herefords	10	+ 6.5	8.2
1923 Brahmans	5	+11.8	7.2
1923 Purchased Brahmans	5	— 1.6	6.9
1924 Herefords	10	+16.0	8.5
1924 Brahmans	14	+ 1.6	4.9
1924 Back-crosses	4	+ 6.3	.5
1925 Herefords	10	+ 6.2	4.5
1925 Brahmans	14	+ 7.5	6.3
1925 Back-crosses	4	+ 4.7	8.8
1926 Herefords	13	+ 7.1	7.1
1926 Brahmans	17	+ 9.7	9.4
1926 Back-crosses	5	+11.5	4.4
SMS Ground heads	10	+ .9	3.9
SMS Ground ration	10	— 1.2	7.3
SMS Unground ration	9	+ 3.7	6.0
Total	185		
Weighted average		+7.58 ± .37%	7.49%

The change is positive in all but two groups and the average change is large. However, the standard deviation is also large—so large as to preclude the practical use of changes in this ratio as indicators of changes in the fatness of individual animals. Group heterogeneity is quite evident, Z being nearly three times as large as it is at the limit beyond which the probability of homogeneity falls below .05.

The summary of the data showing the changes in the ratio of chest width to chest depth is given in Table 23.

Table 23. Summary of Changes in Chest Width Relative to Chest Depth during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	+15.9	6.1
1921 Brahmans	10	+18.6	15.7
1922 Herefords	14	+19.8	7.6
1922 Brahmans	8	+20.9	12.6
1923 Herefords	10	+10.0	8.8
1923 Brahmans	5	+15.8	8.2
1923 Purchased Brahmans	5	+ 3.3	8.4
1924 Herefords	10	+23.0	8.3
1924 Brahmans	14	+ 6.8	5.0
1924 Back-crosses	4	+11.2	2.7
1925 Herefords	10	+ 9.6	5.7
1925 Brahmans	14	+ 9.6	7.7
1925 Back-crosses	4	+ 6.0	11.8
1926 Herefords	13	+ 9.8	8.4
1926 Brahmans	17	+12.2	8.9
1926 Back-crosses	5	+13.0	2.9
SMS Ground heads	10	+ 2.6	5.2
SMS Ground ration	10	+ .4	8.6
SMS Unground ration	9	+ 4.2	6.6
Total	185		
Weighted average		+11.49±.42%	8.37%

Table 24. Summary of Changes in Chest Width Relative to Height at Withers during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	+24.7	7.4
1921 Brahmans	10	+27.6	17.0
1922 Herefords	14	+26.9	9.5
1922 Brahmans	8	+25.8	10.7
1923 Herefords	10	+16.4	9.8
1923 Brahmans	5	+16.4	9.3
1923 Purchased Brahmans	5	+ 7.8	7.7
1924 Herefords	10	+28.6	11.8
1924 Brahmans	14	+11.2	7.5
1924 Back-crosses	4	+17.6	2.0
1925 Herefords	10	+15.0	6.0
1925 Brahmans	14	+15.4	8.9
1925 Back-crosses	4	+10.8	11.6
1926 Herefords	13	+12.2	8.0
1926 Brahmans	17	+14.0	11.9
1926 Back-crosses	5	+14.3	4.2
SMS Ground heads	10	+ 3.8	4.5
SMS Ground ration	10	+ 3.3	9.7
SMS Unground ration	9	+ 5.1	8.1
Total	185		
Weighted average		+16.07±.47%	9.46%

The change is positive in all groups and is large but varies widely in amount and has a large standard deviation. Group heterogeneity is very marked. This ratio would be a more useful indicator of fatness than the preceding one but is still extremely erratic in its apparent changes.

The summary of the data showing the changes in the ratio of chest width to height at withers is given in Table 24.

The changes are all positive and very large. However, group heterogeneity is extreme and variation within the groups is very large. This ratio would be a better indicator of fatness than either of the preceding ones but is even more erratic than they are.

The summary of the data showing the changes in the ratio of loin width to heart girth is given in Table 25.

Table 25. Summary of Changes in Loin Width Relative to Heart Girth during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	+ 4.2	4.7
1921 Brahmans	9	+ 4.1	7.0
1922 Herefords	14	+ 2.0	6.0
1922 Brahmans	8	— .3	6.0
1923 Herefords	10	+ 3.8	4.5
1923 Brahmans	5	— 3.8	3.5
1923 Purchased Brahmans	5	— 4.0	2.4
1924 Herefords	10	+ .3	4.2
1924 Brahmans	14	— .7	4.9
1924 Back-crosses	4	+ 1.0	4.6
1925 Herefords	10	— .4	3.9
1925 Brahmans	14	+ 1.2	3.9
1925 Back-crosses	4	+ 3.5	2.6
1926 Herefords	13	+ 8.7	3.6
1926 Brahmans	17	+ 6.4	4.6
1926 Back-crosses	5	+ 6.5	4.8
SMS Ground heads	10	+10.2	4.5
SMS Ground ration	10	+ 9.0	2.6
SMS Unground ration	9	+ 9.4	3.2
Total	184		
Weighted average		+ 3.64 ±.23%	4.55%

Table 26. Summary of Changes in Loin Width Relative to Chest Depth during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	+ 9.9	5.1
1921 Brahmans	9	+ 9.7	7.5
1922 Herefords	14	+ 8.0	6.1
1922 Brahmans	8	+ 5.5	5.8
1923 Herefords	10	+ 7.2	4.8
1923 Brahmans	5	— .4	4.4
1923 Purchased Brahmans	5	+ .7	4.6
1924 Herefords	10	+ 6.3	4.4
1924 Brahmans	14	+ 4.4	5.4
1924 Back-crosses	4	+ 5.7	5.2
1925 Herefords	10	+ 2.8	3.6
1925 Brahmans	14	+ 3.0	3.6
1925 Back-crosses	4	+ 4.6	3.7
1926 Herefords	13	+11.4	4.1
1926 Brahmans	17	+ 9.0	6.6
1926 Back-crosses	5	+ 7.8	4.8
SMS Ground heads	10	+11.8	4.5
SMS Ground ration	10	+10.8	1.9
SMS Unground ration	9	+ 9.8	2.0
Total	184		
Weighted average		+ 7.27 ±.25%	4.94%

The changes are predominantly positive but are negative in five groups. The average change is small and the coefficient of variation is large. Group heterogeneity is very evident. These results seem to show that this ratio is not a highly accurate expression of fatness.

The summary of the data showing the changes in the ratio of loin width to chest depth is given in Table 26.

Except for one group all average changes are positive and fairly large, especially in comparison with the standard deviation. This ratio is distinctly superior to the previous one as an indicator of fatness but still admits of very wide variation between individual steers. Group heterogeneity is unmistakable.

The summary of the data showing the changes in the ratio of loin width to height at withers is given in Table 27.

Table 27. Summary of Changes in Loin Width Relative to Height at Withers during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	+18.3	6.7
1921 Brahmans	9	+18.4	9.7
1922 Herefords	14	+14.4	8.0
1922 Brahmans	8	+10.0	6.7
1923 Herefords	10	+13.3	6.0
1923 Brahmans	5	+ .1	2.1
1923 Purchased Brahmans	5	+ 5.1	3.2
1924 Herefords	10	+11.1	6.6
1924 Brahmans	14	+ 8.6	5.2
1924 Back-crosses	4	+11.8	6.6
1925 Herefords	10	+ 7.9	4.0
1925 Brahmans	14	+ 8.4	4.5
1925 Back-crosses	4	+ 9.4	2.5
1926 Herefords	13	+13.8	4.8
1926 Brahmans	17	+10.4	5.6
1926 Back-crosses	5	+ 9.1	4.6
SMS Ground heads	10	+13.3	5.1
SMS Ground ration	10	+13.9	4.0
SMS Unground ration	9	+10.9	3.6
Total	184		
Weighted average		+11.57±.29%	5.74%

The change is positive for all groups and the average change is quite large. However, the variation is fairly large and group heterogeneity is very evident. As an indicator of fatness this ratio is evidently superior to the other two ratios involving loin width but exhibits an even larger standard deviation of individual changes.

The summary of the data showing the changes in the ratio of heart girth to chest depth is given in Table 28.

The average change is positive in all groups but is small. The standard deviation is quite small, which is probably a result of the fact that the two measurements concerned are among the most accurate taken and are but slightly affected by the animal's position. Heterogeneity of the groups is quite evident but this is very largely caused by the last nine groups of cattle, which were younger than the rest and which made considerable growth in chest depth during the fattening period. On account of the smallness of the average change this ratio does not seem to be a highly useful indicator of fatness even though its variation is small.

Table 28. Summary of Changes in Heart Girth Relative to Chest Depth during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	+5.5	2.8
1921 Brahmans	10	+5.6	3.5
1922 Herefords	14	+6.0	2.2
1922 Brahmans	8	+5.8	1.8
1923 Herefords	10	+3.2	1.7
1923 Brahmans	5	+3.6	3.5
1923 Purchased Brahmans	5	+4.9	2.9
1924 Herefords	10	+6.0	2.1
1924 Brahmans	14	+5.1	1.4
1924 Back-crosses	4	+4.7	2.9
1925 Herefords	10	+3.2	2.4
1925 Brahmans	14	+1.9	2.4
1925 Back-crosses	4	+1.1	3.3
1926 Herefords	13	+2.5	1.9
1926 Brahmans	17	+2.4	2.3
1926 Back-crosses	5	+1.3	2.1
SMS Ground heads	10	+1.5	1.3
SMS Ground ration	10	+1.7	2.0
SMS Unground ration	9	+ .5	1.7
Total	185		
Weighted average		+3.58±.11%	2.30%

The summary of the data showing the changes in the ratio of heart girth to height at withers is given in Table 29.

Table 29. Summary of Changes in Heart Girth Relative to Height at Withers during Fattening.

Group	Number of Steers Included	Average Change	Standard Deviation
1921 Herefords	13	+13.5	4.1
1921 Brahmans	10	+13.6	5.4
1922 Herefords	14	+12.2	3.6
1922 Brahmans	8	+10.4	3.6
1923 Herefords	10	+ 9.2	2.4
1923 Brahmans	5	+ 4.1	2.8
1923 Purchased Brahmans	5	+ 9.5	1.6
1924 Herefords	10	+10.8	4.2
1924 Brahmans	14	+ 9.3	3.3
1924 Back-crosses	4	+10.7	2.0
1925 Herefords	10	+ 8.3	2.0
1925 Brahmans	14	+ 7.2	4.3
1925 Back-crosses	4	+ 5.8	4.7
1926 Herefords	13	+ 4.7	2.0
1926 Brahmans	17	+ 3.8	3.9
1926 Back-crosses	5	+ 2.5	1.5
SMS Ground heads	10	+ 2.8	1.2
SMS Ground ration	10	+ 4.5	3.4
SMS Unground ration	9	+ 1.4	2.4
Total	185		
Weighted average		+ 7.77±.17%	3.42%

The average change is positive for every group. The change is medium in size, being exceeded by the change in two of the three ratios involving chest width and one of the ratios involving loin width. However, the standard deviation of this change is very distinctly smaller than that for the three ratios which show larger average changes. The change in the ratio of heart girth to height at withers shows extreme group heterogeneity, which seems to be caused by age and conditions peculiar to each feeding season. Thus all six groups fed during the last season show moderate changes and, in both the second and the third feeding seasons, the three younger groups show smaller changes than the older groups fed at the same time.

CORRELATION BETWEEN RATIOS AND ESTIMATED FATNESS

To test further which of these ratios was most closely related to fatness, the fatness of each individual steer was estimated on the basis of its dressing per cent and its percentage of caul fat to final feedlot live weight by using the prediction equation developed in an earlier study(11) (estimated % of fat in entire live animal = 9.073 times per cent of caul fat + 0.936 times dressing per cent — 44.96%). This estimated fatness was then correlated with each of the eight ratios just discussed, using the measurements taken just before the fattened steers were shipped to market. Each correlation was calculated separately for each group of steers (so as to eliminate heterogeneity of group means) and then all correlations between estimated fatness and each ratio were averaged together using the method described by Fisher on pages 168 and 169 of his book(6). The first two groups of steers had to be omitted from this calculation because individual caul fat weights were not obtained when they were slaughtered. Three degrees of freedom were lost for each group of steers in the process of averaging and the resulting average correlations are the statistical equivalent of a single correlation calculated upon a single group of 113 steers, except that this average being based upon different groups, fed at different times and in different ways, is probably more reliable as a basis for generalization because unnoticed differences in the methods of taking the measurements or other unsuspected and accidental conditions which might influence the size of the correlation in a single group or for a single season, would not be apt to affect these average correlations noticeably.

These correlation coefficients between estimated fatness and each of these eight ratios, together with the rank of the changes in the ratios during fattening according to mean size, to standard deviation, and to mean size divided by standard deviation are given in Table 30.

Even a casual study of Table 30 shows that the last four ratios have little claim to further serious consideration as indicators of fatness. They rank low in all three aspects of the change during the fattening process. All four correlations are low, the last one being only a little larger than its probable error, and the two next to the last ones being only a little more than three times their probable errors. In a statistical sense the correlation between estimated fatness and the chest width—chest depth ratio is probably significant since it differs from zero by about three times its standard deviation. Nevertheless, this correlation is small and therefore not of much practical use even though it does indicate that, as a general rule, a wide chest relative to chest depth is associated with a high degree of fatness.

Table 30. Summary of Average Data Bearing upon the Usefulness of Eight Measurement Ratios as Indicators of Fatness.

Ratio	Correlation between Final Ratio and Estimated Fatness	Rank According to large Average Change During Fattening	Rank According to Smallness of Deviation of Change During Fattening	Rank According to Largeness of Ratio: Average Change to Standard Deviation
Heart Girth: Height at Withers	+.563	4	2	1
Heart Girth: Chest Depth	+.464	8	1	4
Chest Width: Height at Withers	+.414	1	8	3
Loin Width: Heigth at Withers	+.323	2	5	2
Chest Width: Chest Depth	+.294	3	7	6
Loin Width: Chest Depth	+.226	6	4	5
Chest Width: Heart Girth	+.207	5	6	7
Loin Width: Heart Girth	+.076	7	3	8

The ratios involving chest width as compared with the corresponding ratios involving loin width show (1) higher correlations, (2) larger average changes, and (3) larger standard deviations of the changes. This and other circumstances connected with the measuring seems to indicate that width of chest is more closely related to fatness than width of loin is, but was not measured quite as accurately. Continuing this comparison in the same way, it will be noted that the ratios having heart girth for the numerator as compared to the corresponding ratios having loin width or chest width as numerators show (1) higher correlations, (2) smaller average changes, (3) smaller standard deviations of the changes. This is interpreted to mean that chest width responds more to fattening than the other two measurements do but is most difficult to measure accurately. Heart girth responds less to increasing fatness than the other two measurements but is very much more accurately measured than either of the others.

Turning now to look at the denominators it will be observed that both ratios having heart girth for a denominator rank at or very near the bottom of the list in all four columns of Table 29. It seems clear that heart girth as an indicator of fatness belongs in the group with chest width and loin width, and not in the group with chest depth and height at withers. The ratios involving wither height when compared with the corresponding ratios involving chest depth show in every case (1) higher correlations, (2) larger average increases during fattening, and (3) larger standard deviations of the increases. This is interpreted to mean that wither height is less influenced by increasing fatness (and also by the normal growth incident to steers of the ages used in these experiments) than chest depth is, but is more difficult to measure accurately on steers as wild as these.

GENERAL DISCUSSION

Underlying the question of whether a given body measurement is well adapted for use in the accurate description of beef cattle, there are three important questions. The first question is: to what extent does the measurement reflect increasing fatness, as distinct from the changes of normal growth? The second question is: how does the measurement change with the normal growth incident to cattle of any given age? The third question is: how accurately can the measurement be taken in spite of changes in the animal's position and in the tenseness of its muscles and in spite of partly unavoidable errors in the technique of the operator? Not one of the measurements studied in these experiments was completely satisfactory in all three of these points.

From most practical points of view the measurements naturally fall into two groups: first, those which increase with increasing fatness more rapidly than weight does and which therefore reflect fatness in a positive way; and second, those which increase less rapidly than weight does during fattening and therefore reflect fatness in a negative or passive way.

Only four of the measurements included in this study belong in the first group. They are: chest width, loin width, heart girth, and flank girth. Width at hooks also increased faster than weight did on these steers, but the evidence indicates strongly that this was caused by the normal growth of steers as young as many of these were and would not have occurred in an experiment confined to mature or nearly mature steers. Of the other four measurements paunch girth seems to have no advantage over heart girth. Its average increase is less and the unavoidable error in its measurement is distinctly greater than in the case of heart girth. It may therefore very well be dropped from further consideration. Heart girth is very distinctly more accurate than either chest width or loin width but on the other hand does not increase nearly so much during fattening. Unquestionably either chest width or loin width would be a more useful measurement than heart girth for describing in objective terms the fatness of a steer if it could be taken as accurately as heart girth. Can they be taken thus accurately? Unquestionably they were not in these data, but most of these steers were wild and difficult to pose. Also our measuring calipers had rather small contact surfaces and it seems reasonable to suppose that there would be less error on the part of the operator if the calipers used had contact surfaces several square inches in area. This would be of especial importance on very fat steers, which usually have quite soft flesh on the sides of their chests and loins. It seems to us highly probable that with gentle steers which could be posed as show steers are, and with calipers having very large contact surfaces, the measurements of chest width and loin width can be made much more accurate than they were under the conditions of this study and probably can be made so accurate that they will be distinctly superior to heart girth as indicators of fatness even though they can never be measured quite as accurately as heart girth. Whether or not this opinion is fully justified can only be ascertained by further experiments. An increase in the accuracy of the measurements or in the accuracy of the method of estimating fatness would of course increase the size of the correlations shown in Table 30(18). But if we leave out of consideration the possibility of improving the accuracy of these measurements it would seem that in these data heart girth was actually more valuable as an indicator of fatness than was chest width or loin width. The latter two showed greater increases during fattening but were more variable and less highly correlated with estimated fatness than heart girth was. Loin width was probably a little less valuable than chest width although somewhat more accurately measured. Doubtless all three of these measurements deserve further consideration as indicators of fatness.

The measurements which reflect fatness only in a passive or negative way naturally fall into four main groups: head measurements, pelvis measurements, height measurements, and trunk measurements such as chest depth and body length. The head measurements are of minor importance since they do not measure a part of the body directly important from the standpoint of meat production. Moreover, they are influenced by sex condition and also approach their mature value at a very early age. Pelvis measurements increase normally with age at peculiar rates. Compared with other skeletal measurements, they are quite slow in approaching their mature values. Here, too, important sex differences are present. Width at pin bones is highly inaccurate on real fat steers.

Height at withers and height at hips appear to duplicate each other almost exactly except that young cattle are relatively higher over the hips than at the withers. Wither height increases a little more during normal growth, also wither height appears to have been a trifle less accurately measured on these steers, so many of which were wild. However, wither height has been much more widely used in other studies as a standard to which all other measurements are compared. For this last reason wither height seems slightly more useful than hip height and, since the two measurements so nearly duplicate each other, it does not seem worth while to include both in future studies. Chest depth is probably the most accurate of the trunk measurements and is of practical importance in that it measures directly one of the components of the idea of low-setness or blockiness of form. It is only slightly affected by fatness but is relatively slow to approach its mature value. Body length is relatively inaccurate among the measurements which are only slightly affected by fatness, but does measure a very important dimension of the steer and is an important part of our conception of ranginess of type as contrasted with blockiness or compactness.

Our conclusion in regard to the general usefulness of the various measurements is that unless there exists some special reason to investigate some special detail of conformation (such as paunchiness or pelvis shape or relative head width or length), the measurements taken should include one or two or possibly three measurements which reflect to the fullest extent the effects of fatness and two or three measurements which reflect as fully as possible the extent of normal growth free from the influence of fatness or thinness. In our experience heart girth has been the most desirable of the measurements which reflect fatness directly, although we are of the opinion that refinement of the methods of measuring, especially upon very gentle steers, might very easily make chest width or loin width more desirable for this purpose. In our experience height over withers and height over hips have been outstandingly the most desirable measurements which reflect growth independent of fatness. Hip height has perhaps been slightly more desirable than wither height for this purpose, but out of deference for the more widely established custom of expressing other measurements as relative to wither height we do not believe the advantages of height over hips justify recommending the use of hip height to the exclusion of wither height. As a fairly close second to these two in usefulness stands depth of chest. Body length is a poor third.

The dimension-weight index proposed by Yapp (20) as a general index of body build in cattle is:

$$\frac{\text{Body Length}}{\sqrt[3]{\text{Weight}}} \times \left(\frac{\text{Height over Withers}}{\sqrt[3]{\text{Weight}}}\right)^2 \times \frac{1}{475.8}$$

when the component ratios are separated into the forms in which they were studied in this Bulletin. The third factor is a constant introduced by Yapp to express in cubic centimeters the volume of a pound of flesh and need not concern us further here where we are interested only in variations and changes in these ratios or indices. Since both these ratios which are combined in Yapp's index show negative changes during fattening, such a combination of them as in Yapp's index will show a still larger negative change during fattening. Thus the average change in the ratio, $\frac{\text{Body Length}}{\sqrt[3]{\text{Weight}}}$, among these 185 steers during fattening was — 3.53% and the average change in the ratio, $\frac{\text{Height over Withers}}{\sqrt[3]{\text{Weight}}}$, was — 5.68%. Therefore, the average change in Yapp's index would have been approximately — 14.2% (or possibly a little larger on account of a correlation between the two ratios). This index would therefore express the changes on a larger scale and to that extent is desirable, although its standard deviation would also be somewhat larger than that of either ratio alone. Some such combination as this is also desirable in that it embodies more than one measurement and thereby tends to make errors of measurement less important. From this point of view, this index would be still further improved if it included the ratio of one more measurement, such as chest depth, instead of giving double weight to height at withers. Squaring height at withers allows errors in the measurement of wither height to retain considerable importance. Other indexes embodying various combinations of measurements will doubtless suggest themselves to the reader as worthy of consideration. Certainly such combinations are *more complete* descriptions of the animal form than one measurement is, either by itself or relative to weight. However, the changes of these combinations cannot be so readily analyzed as those of the simpler ratios of a single measurement to live weight, and, therefore, we have confined the analysis in this Bulletin to the simpler ratios. The index proposed by Yapp is clearly very strongly influenced by fatness, and yet it probably is also very much influenced by variations in body shape independent of fatness. There is still a real need in this connection for an index which shall express only the fat-free body-build in objective terms as well as for an index which shall more perfectly serve as an indicator of fatness.

The question of whether *any* measurement is sufficiently informative to be worth taking in general feeding experiments remains a debatable one, and probably depends chiefly upon the cost of taking the measurements and upon one's assurance that there would be opportunity to calculate and analyze the results. In the geometrical sense the animal body is of such a complicated shape that any one or few measurements could approximate a description of it in only the crudest way. Moreover, the details of that shape change with every movement of the muscles of the body. Furthermore, many of the points which are of considerable importance in determining the commercial worth of a steer are difficult or impossible to measure. For example, a smooth sleek coat undoubtedly has its value in the market place but would be impossible to measure by a tapeline or rule and would be difficult to measure objectively even by the use of a carefully prepared set of artificial grades of sleekness. Again, the angle at which a steer's ribs appear to spring from his backbone undoubtedly has much to do with his market desirability but would be difficult in the extreme to measure, especially since only curved surfaces are involved. Certainly no one measurement or small group of measurements can approach weight in completeness as a description or in economic importance. Nevertheless, if one is going to take the weights anyhow, a few of the most important measurements discussed in this Bulletin may give very helpful supplementary information and may very well prove to be worth more than the cost of taking the measurements and the cost and trouble of analyzing the data. The information yielded by measurements should be regarded as supplementary to and confirmative of the inferences drawn from weight changes rather than as a substitute for the information gained from studying the weights alone.

SUMMARY

As an incidental part of various cattle feeding experiments, certain body measurements were taken on 185 steers divided among 19 different lots. These measurements were taken at the beginning of the feeding period when the steers were thin and again at the close of the feeding period when the steers were fat. The changes in the measurements of each steer during fattening were studied to determine in an objective way how the animal's shape or conformation changed during the fattening process.

The measurements which were taken on all the steers showed the following percentage increase or decrease relative to live weight during the fattening process:

Chest Width	**+ 9.29%**
Loin Width	**+ 5.18%**
Chest Girth	**+ 1.55%**
Flank Girth	**+ .97%**
Paunch Girth	**— .35%**
Depth of Chest	**— 1.95%**
Length of Body	**— 3.53%**
Height over Withers	**— 5.68%**

The nine measurements, which were studied on only part of the steers, rank as follows when compared with the other measurements on the same steers:

Width at hooks changes at approximately the same rate as flank girth
Width of pelvis changes at approximately the same rate as paunch girth
Length of pelvis changes at approximately the same rate as depth of chest
Cannon circumference and width at pin bones make practically the same change as length of body
Muzzle circumference shows almost as large a decrease relative to weight as height over withers does
Length of head decreases more than height over withers and almost as much as height over hips
Height over hips decreases more than height over withers, especially on the younger groups of cattle
Width at eyes shows the most extreme decrease of all, a change which would have averaged nearly — 7.8% if it had maintained the same ratio to height over withers in all the groups of steers as it did in the groups on which width at eyes was actually studied.

Much variation was shown in the amount of change made by different individual steers. The standard deviation of the percentage change in the various measurements (relative to weight) varied by small steps from 1.78% for cannon circumference to 3.15% for length of body. Three of the measurements had standard deviations far outside this range. They were: loin width 4.39%, width at pin bones 6.76%, and chest width

8.20%. Much of this variation, especially in the last three measurements, is due to errors in taking the measurements but a small part of it is probably caused by the steers not all changing their shape in exactly the same way with increasing fatness.

In general, steers increase much more in *width* during fattening than they do in *length* or *depth* of body, and least of all in *height* and *head measurements.* In general, the soft parts of the body increase most rapidly and the only bony measurements which even approximately keep up with the increase in live weight are the pelvis measurements.

Evidence for a breed difference in the way body conformation changed with fattening was strong only in the case of flank girth and paunch girth, in both of which the Herefords increased more or decreased less relative to live weight than the Brahmans did. However, both these observed average differences were practically on the borderline of statistical significance. Therefore, there was very much overlapping of the individual steers of the two breeds and it would appear impossible to identify and study the inheritance of different rates of changing flank girth and paunch girth. The observed differences probably were genuine breed differences but were so slight that averages of fairly large numbers of steers were required to demonstrate their existence. Under those circumstances a highly correct classification of individual animals with respect to these characteristics appears impossible and an impracticably large number of animals would require to be fattened to permit the discovery of the mode of inheritance of this characteristic even if it were really inherited in the simplest monohybrid manner,—a hypothesis which is probably unjustifiably simple.

Evidence of age differences are unmistakable for many measurements. This is particularly true of the pelvis measurements, which were the slowest of all the measurements of bony parts to approach their mature dimensions. Measurements which, like the head measurements, approached their mature dimensions at a very early age did not show nearly so much influence of age upon their rates of change.

In not one of the seventeen measurements studied was the population surely homogeneous with respect to the average change shown by the different groups. This heterogeneity was in most cases caused by some common factor which affected alike all the groups fed in a single season and which probably was the amount of gain made or some peculiarity in taking the measurements at that time. Age differences contributed much to this heterogeneity. Breed differences played a part in at least two measurements. In some cases no cause for the heterogeneity was apparent.

The most generally useful single measurement among those which increase rapidly with increasing fatness seems to be chest girth, although chest width and loin width could be more useful if the errors in taking those measurements could be made as small as the errors in most of the other measurements.

The most generally useful measurement among those which increase at a less rapid rate than weight seems to be either height at withers or height over hips, with the former deserving a slight preference on account of being so generally used as a standard in other measurement studies. Depth of chest seems to stand next to these two measurements in general usefulness, while length of body also deserves consideration.

The most generally useful ratio studied seems to be the ratio of chest girth to wither height, but the ratios of chest width and loin width to wither height would be still more useful if chest width and loin width could be determined more accurately, and the ratio of chest girth to chest depth also deserves consideration.

Throughout the whole question of using body measurements to supplement studies of weight changes in cattle there runs as an undertone the question of how accurate body measurements can be as objective descriptions of animal form. In general, great accuracy is attained only in the measurement of rigid, bony structures, such as: head length, cannon circumference, or width at eyes. However, these parts of the animal body are usually of very slight direct commercial importance. The details of conformation which have a direct commercial importance are for the most part concerned with soft structures which have curved surfaces and are joined together by movable joints. They are therefore difficult or impossible to describe in a mathematical sense with anything like completeness. It seems to us from our experience in this study that body measurements should be regarded as of minor importance compared with weight changes, and that in most cases a system of artificial grades, standardized either by the use of models or of pictures, might more satisfactorily describe important details of conformation than simple linear measurements alone can. Linear measurements should be regarded as supplementary to other means of description rather than as a substitute for those other means. The great advantage of linear measurements is their high degree of objectivity, which advantage they share with body weight.

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