THE ASSOCIATION OF WEIGHT AND BREED TYPE WITH ADJUSTED ^{40}K COUNT AND CERTAIN INDICES OF CARCASS COMPOSITION IN BEEF STEERS

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CHAPTER I

INTRODUCTION

The continuing demand for an increase in the quantity of consumer acceptable lean beef and rising production costs only emphasize the importance of learning more about the growth and development of meat animals. The growth phenomenon is the heart of the livestock and meat industry and a basic understanding of growth has potential for direct application to many problems that confront world food production (Hedrick, 1975).

It is important, therefore, to establish relative indexes that accurately and precisely identify composition differences among animals. These indices should be objective, easily obtained, repeatable and applicable to a wide based population of cattle. Many such attempts are recorded in the literature. Of particular interest are the possibilities of non-destructive methods of live evaluation that could be adapted to selection programs as well as to market animals. One such non-destructive method of live animal evaluation employed for estimating differences in body composition that has received considerable study is the ^{40}K whole-body counter. However, the value of ^{40}K counters depends on how precisely they estimate fat-free lean, and the accuracy with which sources causing variation in counting data can be identified and controlled.

The relationships between various carcass measurements and composition have been studied by numerous researchers. These indices vary considerably in their worth and validity; and furthermore, they vary as to the particular population of animals from which they are derived.

However, an understanding of how these relationships change or are affected by changes in weight has received very little study. Also with the advent of centralized processing, muscle boning and boxed beef, there is a need to study the relationships between certain individual muscles and total carcass lean, which might well provide a rapid and reliable index as to total lean differences among carcasses.

The objectives of this study were:

1. To determine the feasibility of accounting for variations in whole-body counting efficiency attributable to differences in mass by counting standard references (phantoms) weighing 500, 700, 900 and 1100 pounds, which approximated the dimensions of similar weight beef steers.
2. To establish the relationship between live adjusted count and empty body weight for cattle differing in breed type and slaughtered at four different weights; and to establish the relationship between adjusted count and certain composition components for these steers.
3. To observe weight changes in growth patterns with respect to fat-free lean, total body fat and bone for Hereford and crossbred steers slaughtered at 500, 700, 900 and 1100 pounds; and determine weight group trends in the association between certain easily obtainable carcass measurements and carcass composition.
4. To study weight changes and growth patterns for certain individual muscles and muscle groups in relation to slaughter weight changes for these steers, and to establish the associations between carcass closely trimmed lean and these individual muscle weights.

CHAPTER II

REVIEW OF LITERATURE

Introduction

The search for a rapid, non-destructive measure of leanness which will give precise information concerning the live animal has occupied the thoughts and time of animal scientists for the past century. One such instrument, the ^{40}K whole-body counter, is currently being used and evaluated at the Oklahoma State Live Animal Evaluation Center. Traditionally, the only accurate measurement of body composition required rendering the carcass into a form which was unsaleable or at least had decreased value via total tissue dissection and chemical analysis. The practical value of this alone as well as the labor cost involved necessitates the search for indices of composition with respect to the carcass as well as the live animal.

This review of literature will concern itself with previous research generally concerning the bovine in the general areas of (1) whole-body counting and sources of variation; (2) general comments concerning growth and development; and (3) indices of carcass composition (specific gravity and individual muscles).

Principles of Whole-body Counting

Two basic principles have been fundamental in developing whole-body counters for estimating the body composition of live animals; (1) a high proportion and relatively constant amount of the total body potassium is contained in the intracellular, non-fat phase of body tissues (Kulwich et al., 1958; Talso et al., 1960; Kirton et al., 1961; Forbes, 1963; Kirton et al., 1963; Pfau et al., 1963). That is, a majority of the potassium is associated with the muscle mass; and (2) all naturally occurring potassium has associated with it a radioactive nuclide ^{40}K which makes up a constant fraction (.0119 ± .000056%) of the total potassium (Vinogradov, 1957; Anderson, 1959; Forbes, 1963; Ward et al., 1967). The natural isotope ^{40}K emits approximately 11 percent of its radiation as high energy (1.46 MEV) gamma radiation. This high energy level of radiation is associated with a high probability that the gamma rays will penetrate the body tissues; therefore, the gamma radiation can be counted providing a suitable detection system has been established.

Other properties of ^{40}K that confer a unique value for estimating total potassium are: (1) potassium is the only major element found in body tissue in significant amounts that has predictive value for estimating body composition (Brozek, 1965; Ward, 1968); (2) and the specific activity of ^{40}K is virtually constant because the half-life has been determined to be 3×10^9 years. Therefore, based on these properties and the above principles, it has been postulated that total body potassium could be estimated from whole-body count and subsequently converted to an estimate of lean mass.

Concentration, Constancy and Distribution of ^{40}K as Influenced by Breed, Weight and Age

The usefulness of whole-body counting for predicting body composition depends on the constancy of potassium relative to other components (Clark et al., 1972) as well as the tissue distribution of potassium. The question of concentration, constancy and distribution of potassium in the whole-body, carcass and component parts (i.e. lean, fat, bone, organs, viscera, etc.) has been debated more than the other principles upon which whole-body counting has been founded. Biological variability of potassium content in animal tissues has been implicated as an important source of error in the use of ^{40}K whole-body counting (Kirton et al., 1961; Lawrie and Pomeroy, 1963; Gillett et al., 1965; Gillett et al., 1967; Gillett et al., 1968; Stant et al., 1969).

Concentration and Constancy of Potassium in Muscle

Several workers (Kirton and Pearson, 1963; Pfau and Kallistratos, 1963; Pfau, 1965; Stant et al., 1969; Carr, 1975) have reported values for potassium concentration in the musculature of swine ranging from 69 percent of total body potassium to 84 percent of the carcass potassium. Blaxter and Rook (1956), and Kirton and Pearson (1963) reported sheep muscle potassium concentrations of 296 to 300 mg/g of muscle and 2.98 to 3.16 g/kg of muscle, respectively, and Lohman et al., (1965) observed that the percentage of whole-body potassium in lamb carcasses was 21 percent.

Mitteldorf and Landon (1952) reported that the potassium content of raw beef rib eye ranged from 0.29 to 0.34 percent potassium in seven composite samples from cattle differing appreciably in composition and maturity. Swift and Berman (1959) using flame photometry, determined potassium content to range from 297 to 451 mg/100g of muscle in eight muscles from two cows, a bull and a heifer. Van Dilla et al. (1961) pooled data from three Nevada test site locations and reported a range in the potassium content of cattle muscle of 3.8 to 4.7 g/kg. Kulwich and coworkers (1961) used a gamma counter with plastic scintillation detectors to estimate the percentage potassium in the round fat-free separable lean from six bull, six steer and four heifer carcasses. The mean percentage potassium was estimated to be 0.375 ± .015 with a coefficient of variation of 4.0 percent. Green et al. (1961) determined whole-body potassium concentration in five calves to be 0.21 percent of the whole-body. Clark et al. (1972) reported a range of 0.290 to 0.297 percent for muscle potassium levels in 99 beef carcasses when potassium was expressed on a fat-free basis.

The validity of the constancy relationship between potassium and muscle was questioned in data reported by Lawrie and Pomeroy (1963). Differences in potassium concentration as great as 30 percent were found by these workers to occur among five muscles from pigs representing three weight groups (150, 200, and 250 pounds). The constancy of potassium concentration has also been questioned in a series of three studies conducted to determine the variation in potassium concentration in different muscles from swine, cattle and sheep, respectively (Gillett et al., 1965; Gillett et al., 1967; Gillett et al., 1968).

Gillett et al. (1967) reported significant ($P<.05$) differences in the potassium concentration per unit muscle weight in eight muscles excised from steers slaughtered at weights ranging from 232.2 to 344.3 kg. These differences in concentration were apparent when expressed either on a wet, fat-free, moisture-free or protein-free basis. Variations among muscle potassium mean concentration ranged as high as 12.91 percent where means of the potassium concentration in muscle were compared. These workers suggested that variation in the potassium concentration among muscles of the same animal may be an important source of error in the ^{40}K method of estimating body composition via whole-body counting. McLellan (1970) noted that these differences amounted to only approximately 5 grams of total body potassium and therefore, it is doubtful whether the ^{40}K counter would be sensitive to such small muscle to muscle variations. When muscle, breed, and muscle-breed interaction effects were removed, the mean squares revealed significant breed differences in the potassium concentration of the various muscles studied between Angus and Herefords. Although breed differences were found, the percent difference was small and it was concluded that variation between breeds was of little significance to the potassium-muscle relationship in this study.

Using a sodium iodide crystal for gamma radiation detection, Duggleby and Seebeck (1967) measured 152 samples of muscle, fat and bone from seven steers to estimate potassium concentration. Highly significant differences were observed between muscle groups and between muscles. In contrast, Green et al. (1961) reported data in which the potassium concentration in the whole-body of calves and pigs was found to be reasonably constant.

In 1967 Ward et al. attempted, by means of gamma-ray spectrometry, to determine if there was a difference in the potassium concentration of eight wholesale cuts from five cow carcasses. Significant differences were found in potassium concentration among cows on a fat-free basis but no differences were found among wholesale cuts within animals. Coefficients of variation for the potassium content of 9.0 and 14.7 percent were reported when expressed on a fat-free and fat-free dry matter basis, respectively. It should be pointed out that because of the limited numbers of animals involved in this study (a one-year-old Hereford heifer, three four-year-old Holstein cows, and a fat seven-year-old Guernsey) the results are somewhat questionable and inconclusive.

Bennink and coworkers (1968) provided additional data supporting the constancy of potassium. The concentration of potassium was determined on 36 ground meat samples representing composites from sides of 12 beef steers, and eight wholesale cuts from each of three mature dairy cows. The potassium concentrations were not significantly different among the wholesale cuts from the three cows or among cows, nor were differences found among ground beef samples from different steers.

Lohman _et_ _al_. (1970b) evaluated the biological sources of variability of lean potassium concentration in beef cuts from data obtained from Lohman and Norton (1968). The steers were of Holstein, Angus-Holstein, Charolais-Angus and Angus breeding and were fed either a high or low roughage diet. The steers were slaughtered in four predetermined weight groups (306, 385, 465, and 544 kg). The lowest average potassium concentration (fat-free dry matter basis) was found to occur in the rib, 13.72 g/kg, (11.9%, coefficient of variation), the highest in the round, 15.27 g/kg, (9.1%, coefficient of variation). The difference in the potassium concentrations and the coefficients of variation were attributed to the high fat content of the rib (25.65%) compared to the round (6.49%). Studies by Kirton and Pearson (1963), Ward and coworkers (1967) and Clark _et_ _al_. (1972) have also suggested that the proportion of fat in the tissue can have a marked influence on concentration of potassium.

Lohman and coworkers (1970b) also found a significant association between weight group and potassium (fat-free dry matter basis) determined by atomic absorption spectrometry, but not when determined by gamma ray spectrometry (Lohman and Norton, 1968). Both methods of analysis indicated a slight breed effect on potassium concentration, with Angus and Charolais-Angus steers having significantly higher concentrations than either the Holstein or the Angus-Holstein crosses. The total coefficient of variation (biological plus technical) associated with the average potassium estimate for each steer by atomic absorption spectrometry was 6.4 percent. After accounting for technical error differences (3.6%) among breed types and treatments, the remaining variation, 3.0 percent, was considered to be an estimate of biological variation of potassium per kilogram fat-free dry matter muscle in these steers. Similarly, Lohman and Norton (1968) estimated biological variation of the ratio of carcass potassium per unit of lean to be less than 3.0 percent as estimated by ^{40}K carcass count.

Additional work by Lohman <u>et</u> <u>al</u>. (1970a) examined the technical variation in the measurement of potassium in seven cuts constituting the entire boneless right side from the same 98 steers (Lohman and Norton, 1968). It was found that 13 percent of the error variance was associated with duplicate samples and the coefficient of variation was 9.6 percent. Such data suggest serious limitations in estimating potassium to using atomic absorption spectrometry. Similar conclusions have been drawn by Johnson <u>et</u> <u>al</u>. (1972). This worker concluded that measurement variation was a large source of variation in determining potassium content of muscle samples taken from the <u>longissimus</u> muscle of 36 cross-bred Angus-Hereford steers when using atomic absorption techniques. It can be postulated from these conclusions that much of the inconsistency in the data reported concerning muscle potassium variation could be attributed to variation associated with the method used to determine potassium concentration.

In recent tests to determine the level and distribution of potassium in 99 beef carcasses, Clark <u>et</u> <u>al</u>. (1972) found significant differences in wet tissue potassium level for different retail cuts among the weight groups tested (227, 341, and 454 kg live weight). However, expressing these data on a fat-free basis provided more consistent results. When the data were analyzed on a within group basis, significant differences in retail cut potassium concentration were reported regardless of how these data were expressed (wet, fat-free, or fat-free, moisture-free basis). Differences in total carcass potassium were also dependent upon the method of expressing the data. However, no differences in total carcass potassium were observed between weight groups when these data were expressed on a fat-free basis.

More recently, Sims and Wellington (1976) studied the influence of breed, sex, energy intake, age and weight on potassium concentration.

These workers reported potassium levels (atomic absorption spectroscopy) measured in six muscle categories comprising the entire musculature of 36 cattle consisting of equal numbers of Angus and Holstein bulls, steers and heifers. Because the six muscle categories formed different proportions of total muscle, a weighted total muscle potassium concentration was calculated. Tissue potassium concentration (mg/g) was computed as wet potassium, fat-free wet potassium, fat-free dry matter potassium, dry matter potassium and potassium: protein ratio. Animal to animal variation was found for all five methods of expressing potassium concentration ($P < .01$). Among muscles, variations in potassium concentration (mg/g) were also observed regardless of method of expression. The least variability in potassium content among muscles was found when these data were expressed on a fat-free wet basis. The coefficient of variation of the weighted mean total muscle fat-free wet potassium for all 36 animals was 2.43 percent. Other coefficients of variation ranged from 3.13 to 7.30 percent depending on method of expressing potassium content. The coefficients of variation for muscle categories within animals ranged from 3.80 to 10.10 percent with a mean of 6 percent compared to a range of 2.80 to 4.71 percent and a mean value of 3.48 among animals within muscles. These workers suggested that this supports Lohman's _et al_. (1970b) hypothesis, muscle to muscle variation within animals is greater than muscle animal to animal variation. No breed x muscle interactions were observed in this study; although, Holsteins were noted to generally contain higher potassium concentration than Angus. A large reduction in breed potassium concentration differences occurred when potassium was expressed as fat-free wet potassium. Sex did not account for a significant proportion of the total variation in potassium concentration.

Limited work concerning variations in potassium concentration as influenced by age has been published, especially with regard to the bovine. Lowry _et al_. (1942) studied the relationship between age and the potassium concentration in the thigh muscle of rats. A small decrease in potassium concentration of fat-free muscle was noted with increasing age. This decrease represented a 5.6 percent change in muscle potassium concentration from the youngest to the oldest. Gradual changes were observed to occur in rats of intermediate age. In

1950, Spray and Widdowson noted an increase of 80 mg k/100g fat-free body tissue in swine, from birth to 259 days of age. This is in agreement with work reported by Cheek and West (1955) in which it was observed that young rats had a lower potassium concentration per unit lean body mass than adults. Barlow and Manery (1954) concluded that at 3 to 4 weeks of age, potassium concentration in breast muscle of young chicks was relatively stable. Blaxter and Rook (1956) found no significant effects of age upon muscle potassium levels in eight Ayrshire cattle ranging from 1 to 300 weeks in age, however, large variability in the potassium content of the muscle samples was found (13.1%, coefficient of variation). Allen _et al_. (1960) observed the ratio of potassium (as determined by gamma activity) and body water of 38 human subjects ranging in age from 16 to 51 years to be both a function of age and sex.

Stant _et al_. (1969) slaughtered 48 barrows at five different weights (23, 46, 68, and 91 kg). Potassium content of the live pig (determined by whole-body counting) and of the carcass and offal (determined chemically) increased with an increase in weight. However, the rate of increase in potassium content occurred at a slower rate relative to the increase in live animal, carcass and offal weight.

Sim and Wellington (1976) reported correlations of weighted mean total muscle potassium concentration (five methods of expression) with shrunk body weight and age. All of the correlations for mean potassium of total muscle with shrunk body weight were negative ($P<.05$). Correlations with age and weighed total muscle potassium were significant ($P<.05$) and ranged from -.318 to -.620, dependent upon method of expression. It was concluded that age was more strongly associated with the decline in potassium than was shrunk body weight.

Distribution of Whole-body Potassium

Lohman and Norton (1968) in an extensive study involving 90 steers attempted to describe the distribution of potassium among the four breeds and four weight groups studied as well as the influence of biological, environmental, and "experimental factors" on the variability of potassium in several body components. The percentage distribution of whole-body potassium based on major component parts (table 1) was

TABLE 1. POTASSIUM CONCENTRATION AS A PERCENTAGE OF SIX BODY COMPONENTS[a]

Component	g K[b]/kg	% K	Coefficient of variation
Standard trimmed lean	3.32	53.4	5.7
Carcass bone	3.07	12.4	14.3
GI tract	2.71	16.4	33.6
Head and Organs	2.39	7.7	9.6
Blood, mesenteric fat and feet	0.66	2.7	21.2
Adipose tissue	0.77	3.8	24.7

[a] Lohman and Norton (1968).

[b] K = potassium.

estimated from ^{40}K measurements. Standard trimmed lean accounted for the major proportion of the total potassium, 53.4 percent and had a coefficient of variation of 5.7 percent. Carcass bone and gastrointestinal tract contents contributed 12.4 percent and 16.4 percent of the total potassium, respectively, and had the greatest animal to animal variability (coefficients of variation of 14.3% and 33.6%, respectively). These workers noted a decrease in potassium concentration as body mass increased in all of the body components studied, with the exception of bone and gastrointestinal potassium which decreased slightly, suggesting weight may be an important source of variation in ^{40}K estimates of fat-free lean. A tendency for the potassium concentration to increase in muscle, bone and organs, and to decrease in other components as the proportion of beef-breeding increased was also observed.

Breidenstein (1964) presented data to demonstrate the importance of non-lean sources of potassium in beef. In this work lean accounted for 40 to 60 percent (diet dependent), fat 12 percent and bone 3 percent of the total variation.

The mean potassium content of the internal organs of cattle was observed to approximate that of the meat, although considerably more variation was noted among the organs than among meat samples studied (Bennink <u>et</u> <u>al</u>., 1968).

Findings of other research concerning potassium distribution in other species also report that the majority of the total body potassium is associated with the muscle tissue. Kirton <u>et</u> <u>al</u>. (1961) employed ^{40}K counting to study potassium distribution in 10 sheep and observed 2.98 mg K/kg weight in separable lean compared to 0.70 for separable fat and 1.41 for separable bone. Counting errors for these estimates were observed to be 5.35, 66.41 and 34.85 percent for the lean, fat and bone, respectively. The large counting errors associated with fat and bone indicate that these estimates were relatively inaccurate, whereas the relatively low counting error associated with lean indicates that the proportion of potassium in this tissue is relatively constant. It was found that the non-carcass components (hide, feet, head, blood and internal organs and their contents) contained 1.78 g K/kg weight on the average and had a counting error of 6.56 percent.

Stant et al. (1969) investigated changes in potassium distribution associated with maturation of the pig. Potassium contents of 24 Yorkshire-Duroc crossbred barrows and 24 Yorkshire-Chester White crossbred barrows representing four weight groups (23, 46, 68 and 91 kg) were estimated by both whole-body counting and chemical methods. Averaged across weight group, the carcass contained approximately 73.0 percent of the total potassium. Chemical estimates of the total potassium in the lean, fat and bone represented approximately 79.1, 6.2 and 14.6 percent of the total carcass potassium, respectively, when averaged across weight groups.

Summarizing the literature concerning concentration, constancy and distribution it appears that there are variations in potassium content and distribution within and among tissues. These coupled with variations caused by differences in gastrointestinal fill, breed, weight and age could be important sources for error in whole-body counting. However, because the major proportion of total potassium associated with the musculature and animal to animal variation is less than within animal variation, whole-body counting appears to have potential as an estimator of whole-body composition, if error inherent to the instrumentation can be controlled.

Relationship between ^{40}K and Leanness

Most of the initial work involving the ^{40}K whole-body counting technique and its relationship to body composition has dealt with humans and indirect measures of body composition. Woodward et al. (1956) determined ^{40}K count on 13 human subjects in a 4-pi gamma ray detector. The results correlated well with the lean body mass as estimated by trituim dilution. Zobrisky et al. (1959) were among the first to study ^{40}K as a quantitative measure of the composition of large animals. Their results indicated that the ^{40}K technique had possibilities of being used as a rapid non-destructive method of determining composition ratios in livestock and meat.

Much research has been published concerning ^{40}K estimates (live, carcass, and wholesale parts) and the physical and chemical composition of beef, pork and lamb since the 1950's. Correlations ranging from

0.58 to 0.95 between whole-body ^{40}K count (live and carcass) and lamb carcass lean or "edible portion" have been noted in the literature (Kirton _et_ _al_., 1961; Judge _et_ _al_., 1963; Lohman _et_ _al_., 1965; Bridenstein _et_ _al_., 1965a). Similarly, considerable work relating whole-body count and total body potassium in swine to leanness in individual wholesale cuts, lean cuts, percent ham, percent ham and loin, total carcass lean, as well as ether-extract data has been reported (Kulwich _et_ _al_., 1958; Breinstein _et_ _al_., 1965b; Kirton _et_ _al_., 1963; Mullins _et_ _al_., 1969; Moser, 1970; Addison, 1973; Schmidt _et_ _al_., 1974; Carr, 1975).

In an early study (Kulwich _et_ _al_., 1961), 16 beef rounds were counted for a period of 42 to 51 minutes and the gamma ray emission data were related to their physical and chemical composition. The correlation between pounds of separable lean and ^{40}K count was .975, and was increased to .982 when adjustments were made for differences in efficiency due to differences in round weight. Fat-free lean and ^{40}K count were also highly correlated ($r = .983$). Also of importance was the highly significant correlation between ^{40}K net count and percent fat ($r = -.87$). However, it should be pointed out that this study consisted of a limited number of observations and the rounds used varied considerably in weight and composition.

Lohman _et_ _al_. (1964) observed that fat-free lean from 29 steers was significantly related to live weight and ^{40}K evaluation ($r = .95$ and .98, respectively). In an extensive study involving 21 steers in each of two years, Lohman _et_ _al_. (1966) reported that whole-body potassium (determined via ^{40}K counting) accounted for 51 percent of the total variation in carcass lean with a standard error of estimate of 22.4 pounds or 9.0 percent of the mean carcass lean. When both live weight and whole-body potassium were fitted to a linear model, the standard error of the estimate for carcass lean was not significantly reduced below that obtained with whole-body potassium alone. Carcass ^{40}K measurement of the right side accounted for 88 percent of the variation in carcass lean with a standard error of estimate of 11.0 pounds or 4.4 percent of the mean carcass lean. Carcass count and weight fitted together significantly ($P < .01$) reduced the standard error of the estimate to 7.3 pounds (2.4%) of carcass lean. In the second year of this work a low radioactive diet of oats was fed to the steers on test in an attempt to control the contribution of the gastrointestinal tract to the count. In this trial 88 percent of the variation in carcass lean was accounted for by whole-body potassium and the use of ^{40}K carcass count in a prediction equation with carcass weight compared to carcass weight alone significantly reduced the standard error for carcass lean by 5.5 pounds from 15.2 pounds to 9.7 pounds. Day to day variation in counting was found to be less than 3 percent.

Smith et al. (1965) found that live weight and live ^{40}K count accounted for 86.7 percent and 42.6 percent, respectively, of the total variation in fat-free lean in 46 steers ranging in weight from 650 to 1200 pounds. Together, live weight and live ^{40}K count removed 90.6 percent of the total variation in fat-free lean.

McLellan (1970), in a study involving 31 steers and heifers of uniform weight, found that live weight accounted for 21 percent of the variation in pounds fat-free lean, while the average of two counts (after 24 hours shrink) was associated with 64 percent of the variation in fat-free lean.

Frahm et al. (1971) evaluated 40 bulls over four slaughter-weight groups. They reported a pooled-within group correlation of 0.87 between the average of two ^{40}K counts, after 24 hours shrink, and pounds of fat-free lean. Standard errors for regression of fat-free lean on ^{40}K count were as low as 3.8 kg (2.8% of the mean). By design, these bulls were of similar breeding, as well as body type and weight. The standard deviation in live weight of all 40 bulls (weight, taken after 24 hours shrink) was 15.6 pounds and accounted for only 4 to 10 percent of the variation in fat-free lean. These workers concluded prediction equations utilizing count and weight were no more accurate in predicting fat-free lean than those based on ^{40}K count alone, when developed using animals of similar type and weight.

More recently the body composition of 56 steers ranging in weight from 183 to 574 kg was estimated from whole-body ^{40}K counting, as reported by Clark et al. (1976). The use of ^{40}K and live weight together to predict fat-free body weight accounted for 97 percent of the total variation. Live weight and ^{40}K live accounted for 95 percent and 94 percent of the variation in fat-free body weight, respectively. The combination of live weight and ^{40}K live resulted in a 14 percent reduction in the average miss to 11.06 kg compared to 12.60 kg. When the lean weight of the carcass was used as the dependent variable and live weight and ^{40}K live as the independent variable, the variation accounted for was found to be 87 percent and the standard error of estimate was 8.16 kg. The conclusiveness of this study to determine the effectiveness of whole-body count as a predictor of lean is questionable because of the very extreme range in weight and the influence of weight on count and body composition.

In summary, research involving the evaluation of leanness in beef cattle using the ^{40}K whole-body counting technique has produced relatively consistant results and supports the concept of a close relation between whole-body potassium and lean weight, fat-free lean and fat-free body weight.

Sources of Variation and Factors Influencing Counting Efficiency in ^{40}K Whole-body Counters

Although preliminary research has tended to verify the assumptions underlying the technique of estimating leanness from gamma radiation emitted from the isotope ^{40}K, there are sources of variation that are inherent both to the animal and to the instrumentation, that must be recognized. Smith (1964) discussed several of these sources of variation (table 2).

Referred to earlier in this review are citations of the effects of weight, size, breed and age on potassium concentration in muscle and the relationship of non-carcass components to total body potassium. It has been suggested that the variation in potassium concentration among muscles within the same animal as well as the animal to animal variation may be important sources of error in whole-body counting. However, these causes of variation may be of little significance in the whole-body count because of a lack of sensitivity to the magnitude of these differences. This relationship has not been fully evaluated.

TABLE 2. SOURCES OF VARIATION IN WHOLE-BODY COUNTING[a]

I. Variation due to Contamination
    A. External Contaminants of hair or wool
    B. Internal Contaminants of Gastrointestinal Tract
    C. Tissue Absorption of Radioactive Nuclides other than ^{40}K

II. Variations Inherent to the Animal
    A. Size or Mass of Animal
    B. Conformation or Shape of Animal
    C. Muscle Distribution
    D. Variation in size and K content of Non-Carcass Body Components
    E. Variation in the K content of muscle
    F. Changes in Sample Geometry
    G. Self-absorption by Sample
    H. Background Depression

III. Variations Inherent to Instrumentation
    A. Background Fluctuations
    B. Instrument Instability
    C. Errors in Routine Balancing of Electronics

[a] Smith (1964).

External and Internal Contamination

External contamination of the animal by natural and artificial radioactivity and internal contamination of the animal by those radioactive nuclides which are either absorbed (Anderson et al., 1957) into the body tissue or which are associated with the "gastrointestinal fill" at the time of counting are potential sources of variation. Since 1945 there has been an increase in the radioactive materials in the atmosphere. These artificial radio-nuclides (radioactive fall-out) are found primarily as surface contaminants and could contribute to external contamination.

Kirton et al. (1961) demonstrated the importance of washing to removing external radiation contamination in the wool of sheep. Washing the lambs reduced potassium content by 0.94 g of potassium per kg live weight, or approximately 35 percent as estimated by whole-body counting. Potassium was reported to be the primary contaminant removed by shearing and washing.

Twardock and coworkers (1966) studied the effect of washing using eight steers that were measured for radioactivity before washing, after one wash and then after a second wash. The first wash reduced the ^{40}K count rate by 4.8 percent ($P < .01$), but the second wash had a non-significant effect (1.1%). Cesium^{137} which is found distributed throughout the animal tissues similarly to potassium and is considered to be the primary interferring radio-nuclide with a sufficient gamma-ray energy to overlap with ^{40}K was reduced by 18 percent on the first wash and 1.6 percent further after the second wash.

Anderson et al. (1957) reported the presence of minute amounts of ^{137}Cs in many foods including beef, lamb and pork. The presence of radioactive emitters with energies similar to that of ^{40}K could contribute to the total error involved in ^{40}K evaluation, unless they occur in proportional amounts and in similar distributions to that of ^{40}K.

The presence of radioactivity in the gastrointestinal tract has been implicated as an important source of variation, particularly for the ruminant whose tract contents may vary from as little as 10 percent to as much as 30 percent of the animal's weight. Radioactive fallout was found in unusually high amounts in rumen contents of cattle consuming roughage near a Nevada nuclear test site, while rumen contents from cattle 75 and 300 miles from this site had only about 1/10th as much fallout (Van Dilla et al., 1961). The radionuclides present were identified as Zr-Nb^{95}, Ce-Pr^{144}, and Ru-Rh^{106}.

Research by Lohman and others (1966) indicated the importance of diet in controlling the radioactivity of the gastrointestinal contents. In this work steers fed the high roughage diet averaged 3 percent higher whole-body potassium than those fed a low roughage diet, but had 5 percent less carcass lean. Steers fed the high roughage diets averaged twice as much radioactivity in the gastrointestinal tract and contents as those fed the low roughage diet. To further verify this source of variation these workers attempted to assess the contributions of body components to whole-body ^{40}K count using components of six steers. On the average 21 percent (ranging from 10 to 30%) of the whole-body count originated from the gastrointestinal tract and contents. In the second phase of this study (Lohman et al., 1966) the steers were fed an oat diet low in radioactivity (Twardock et al., 1966) for one week prior to counting in an effort to minimize the variation of total body potassium attributable to gastrointestinal differences. Reconstruction of the steer components (carcass and non-carcass) revealed a 7 percent contribution from the gastrointestinal tract and contents compared to 21 percent in phase I (normal diet). The variation in carcass lean accounted for by whole-body potassium increased from phase I (51%) to phase II (88%).

Lohman and Norton (1968) found gastrointestinal tract and contents to account for 16.4 percent of the whole-body potassium and was the most variable source of potassium in the body (33.6%, coefficient of variation). These results concur with values presented by Kirton (1963) and Breidenstein (1964).

Johnson et al. (1972) studied the influence of dietary potassium level on ^{40}K, blood serum and muscle tissue potassium using 36 crossbred Angus-Hereford steers. Their data indicated that animal to animal variation in potassium concentration was a possible source of variation and that the primary influence of dietary potassium to ^{40}K is the effect on potassium content of the gastrointestinal tract content.

The variability of the contents of the gastrointestinal tract can be controlled, in part, by subjecting the animal to a shrink period prior to counting. McLellan (1970) studied the influence of shrink time on 31 steers and heifers of four slaughter weight groups. He reported no detectable difference in ^{40}K count-fat-free lean associations between the 24-hour and 72-hour shrinkage period. However, Johnson (1972) reported the regression of ^{40}K net count on live weight was similar for unshrunk and shrunk cattle. This worker suggested feeding a standard diet of known potassium content two weeks prior to counting.

Counting Efficiency

The detection efficiency of a whole body counting system is a function of sample mass (at a constant density) and sample to counter geometry (Twardock et al., 1966). According to Anderson (1959), sample mass has two important effects on the net count from a given sample. First, an increase in the sample mass lowers the total count by absorbing a fraction of the background radiation, which in the absence of a sample would pass into a detector and be registered. This physical phenomenon is called background depression and results in lowering the background radiation reaching the detectors below that actually present in the atmosphere at a rate of about 10 percent of the net whole-body count (Anderson, 1959).

Twardock et al. (1966) reported this same phenomenon and described their efforts to determine background depression of large-volume phantoms. By introducing distilled water phantoms, ranging from less than 200 kg to approximately 450 kg into the counter and measuring the background depression these workers found that for every 100 kg increase in weight background count was depressed by 228 counts.

Forbes (1968) plotted percent of background (4-pi plastic scintillation detector arrangement) against successive additions of one-liter plastic bottles filled with double distilled water. The results indicated that for every liter of water introduced into the counting chamber, percent background was decreased by .292 percent. This value extrapolated to weight is approximately 1.3 percent decrease for every 10 pounds increase in weight.

The decrease in the background count rate due to absorption by the sample was measured by Lohman (1968) by placing non-radioactive samples of various sizes into the counter. The background count rates were measured with and without balloon filled boxes (containing 3.6 kg distilled water/balloon). A linear relation was found between sample mass and background depression between 182 and 454 kg of weight. The variation in background count rate accounted for by sample mass was 97 percent.

The second effect sample mass has on the count of a given sample referred to by Anderson (1959) is the phenomenon of self-absorption of radiation emitted by the sample; that is, there is a higher probability that as sample size increases a gamma ray will lose part or all of its energy before leaving the sample. Anderson found that the greater the sample mass, the lower the counting efficiency. It was stated by Anderson (1968) that gamma radiation is significantly scattered and absorbed by any sample whose mass exceeds a few kilograms, and that there is a need to establish counting rates as a function of sample mass. He also pointed out the need to consider variations in sample shape and the distribution of radioactivity within the sample. Miller and Remenchik (1963), also considered the influence of distribution of potassium and noted that standards possessing a uniform distribution of radioactivity would not provide a sufficiently accurate calibration curve.

Twardock and coworkers (1966) conducted a study to determine the influence of sample size and sample to detector geometry on detection efficiency. Five phantoms (KCl in distilled water, constant density) weighing 200, 392, 488 and 585 kg, respectively, were used. Each phantom was constructed to simulate the approximate dimensions of a live steer of similar weight. The regression of weight on percent gamma detection indicated that there was a loss in counting efficiency of .0056 percent for every kilogram increase in phantom weight. Deviations in the actual self-absorption of an animal and that predicted from this study was considered to be dependent on the extent to which the phantoms did not reproduce geometry, self-absorption and ^{40}K distribution of the animal being referenced.

Martin et al. (1968) investigated the effects of weight and length of sample on counting efficiency, as well as ^{40}K activity of the sample. The experiment involved a 3 x 3 x 3 factorial design of treatments utilizing cylinders of three lengths (60, 113, and 166 cm) occurring at each of three weights (13.6, 40.9, and 68.2 kg) at each of three activities (100, 150, and 200 g KCl). Length, weight and activity level each affected efficiency of detection. The effects of weight were curvilinear, with an increase in weight being associated with a decrease in efficiency of gamma detection. The total effects of activity were considered negligible, and the interaction observed between length and weight suggested that weight and length should both be considered in establishing efficiency curves for correcting counting data.

Lohman (1968) studied the relation between detection efficiency and sample mass using phantoms containing known quantities of potassium chloride in distilled water and by injecting ^{42}K into cattle of selected body weights (Twardock et al., 1966). Four phantoms were constructed out of wood, to contain 181, 272, 363 or 454 kg of water and to approximate the dimensions of steers of similar mass. In general, a linear relation was found between steer or phantom mass and counting efficiency. An increase in mass on the average was associated with a decrease in counting efficiency. Variation in detection efficiency accounted for by weight was greater than 99 percent and the standard error of estimate was determined to be .09 percent. These workers further stated that the detection efficiency of large phantoms was influenced more by electronic instrument drift than a smaller sample. This is in agreement with discussion provided by Twardock et al. (1966).

Several researchers have found that sample to detector geometry (space-distance relationship between the animal and the counter detector) also influence the detection efficiency of a ^{40}K whole-body counter. Twardock et al. (1966) observed that a small sample was more effectively surrounded by the detector position in counting cattle and found that the close-fitting detector was 20 percent more efficient than the loose-fitting detector. However, because of the relative high count rates of cattle, precise measurements were also readily attained at the lower counting efficiency. Lohman et al. (1966) reported that position effect could contribute to whole-body counting error and effect the precision of estimated whole-body potassium. Moser (1970) found a lower association between count and measures of leanness in hogs of lighter weights than was found with heavier weight hogs. He concluded that positioning of the animals in the counter and the ratio of pig to detector volume may have been responsible for the lower correlations of the lighter weight pigs. The smaller pigs occupied a relatively smaller portion of the total counter volume, therefore, allowing a lesser chance for the gamma radiation emitted from animals to reach the detector. Another possible explanation for the low association at lighter weights is that the variation in animal composition is considerably less at lighter weights and therefore, more sensitivity would be required to detect these small differences.

Variation Inherent to Instrumentation

Included in sources of variation due to instrumentation are background fluctuation, instrument instability and errors in routine balancing of the electronics. Accurate measurements of an animal's ^{40}K count rate depend upon a very stable background count rate during the time that the measurement is made. Twardock _et_ _al_. (1966) stated that the instruments' electronic stability should be such that repeated measurements of background or of a single radioactive sample during a 60 to 120 minute interval should have a statistical variation almost the same as the nuclear decay standard deviation. Correlations for long term drift are made by measuring standards and background at regular intervals. Such long term fluctuations in detection efficiency were attributed to: (1) changes in photomultiplier tube performance; (2) oxygen absorption in the scintillator (liquid scintillation) causing attenuation of scintillation light; and (3) changes in performance of electronic components other than the photomultiplier tubes. According to Anderson (1968), the best method for quantitative evaluation of instrument stability is the frequent measurement of stable, inanimate reference samples that resemble the experimental objects to a reasonable approximation.

Growth and Development

The major tissues (bone, muscle and fat) grow and develop at relative different rates post-natally (Hammond, 1933) and the individual changes in form and composition due to a differential growth of their constituent parts (Palsson, 1955). The processes of growth and development consist of more than a simple increase in size and weight and cannot be clearly defined separate and apart from each other. Changes in body proportions are brought about by different tissues, within different body parts, growing at different rates (Hammond, 1932; Huxley, 1932; Zinn, 1967; Berg, 1968). It is generally accepted that the order of tissue growth follows subsequent trends starting with tissues comprising vital organs and performing special physiological processes followed by bone and tendon growth, muscle and lastly fat deposition (Palsson and Verges, 1952; McMeekan, 1959; Butterfield and Berg, 1966a; Zinn, 1967). Bone is relatively slow growing, muscle tends to grow at a more rapid rate and fat deposition is initially slow but then exceeds muscle growth at later stages of development (Haecker, 1920; Callow, 1948; and Berg and Butterfield, 1968; Mukhotz and Berg, 1971). Early maturing animals enter the fattening phase of growth at lighter weights than the late maturing animals and have a higher proportion of fat at similar weights. It is possible to control the rate at which different tissues and parts of the body grow and develop by altering the genetic makeup of the animal via selection and the environment (changes in nutritional level and selecting the time at which the nutritional level is altered) to which the animal is exposed (Hedrick, 1975). Therefore, there should be an optimum stage of growth and development at which an animal could be slaughtered for maximum yields of edible meat in comparison with efficiency and cost of production (Hedrick, 1975).

Muscle, which by weight is the major body tissue, appears to make up a reasonably constant proportion of body weight at a given weight for beef animals of diverse genotypes and produced in variable environmental conditions (Elsley _et al_., 1964; Butterfield, 1965b; Mukhotz and Berg, 1973). Although, individual muscles vary widely in their growth patterns (Butterfield and Berg, 1966a; Berg, 1968) the major differential growth within the musculature takes place soon after birth (prior to 3 months of age); therefore, growth differentials between muscles play a minor role in affecting the composition of animals of normal slaughter weight (Berg and Butterfield, 1968; Butterfield and Johnson, 1971).

Quantitatively, fat is the most variable constituent in the body and in muscle (Tulloh, 1963; Berg and Butterfield, 1968) and the major changes in composition of the animal body depends on the level of fatness (Callow, 1948; Callow, 1949; Callow, 1962). The accretion of fat in the body during post-natal growth and development is the result of animals being fed for extended periods of time at levels in excess of their maintenance requirements. Breed, sex condition, caloric intake, and physiological age are some of the primary factors that influence fat deposition in muscle and in the body (Hedrich, 1975). Fat is deposited at widely varying rates in different parts of the body, which results in marked variation in the proportion of fat found in different parts of the body (Hankins and Titus, 1939). Deposition of fat, like muscle and bone, follow definite growth patterns. In younger animals fat is deposited around the viscera and kidney. With an increase in age and adequate caloric intake, fat deposition occurs intermuscularly, subcutaneously and, lastly, in the form of intramuscular fat (Callow, 1948; Andrews, 1958; Zinn, 1967).

Most data indicate that weight and stage of fattening have a greater effect on physical composition of the carcass than does age (Winchester and Howe, 1955; Winchester and Ellis, 1957; Butterfield, 1965b; Butterfield and Johnson, 1971). The current trend to market beef animals at a younger age has reduced the age effect on composition and increased that of weight (Zinn, 1967; Dinkel et al., 1969).

Butterfield (1965a) indicated that age had no important effect on the proportion of "expensive" muscle, suggesting that there is no optimum age of slaughter at which the most expensive muscles will be in relative higher proportion to total muscle. It was also observed that when fatness increased above 20 percent of dissectible fat, the proportion of "expensive" muscle was depressed markedly.

Butterfield and Johnson (1971) reported data indicating widely divergent growth rates used to produce age differences at slaughter appear to have only a minor effect in producing different relative growth rates of individual muscles. It was concluded that even with wide differences in growth rate, similar weight relationships were maintained between muscles.

Indices of Carcass Composition

Specific Gravity

A number of workers have studied specific gravity as a measure of body composition. Garrett (1968) and Pearson (1968) reviewed and discussed this technique. Behnke et al. (1942) reported that variations in fat appeared to be the chief determinant of body specific gravity.

Initial work by Kraybill et al. (1952) related specific gravity to separable fat from the 9-10-11 rib cut. The thirty cattle used in this study ranged in fatness from 13.6 to 39.5 percent (coefficient of variation 6.0%) and a coefficient of determination of .91 was found for these two variables. In other studies (Orme et al., 1958; Cole et al., 1960b; Bieber, 1961; Cobb and Overjerd, 1965) involving certain carcass parts, such as a specific muscle or cut or ground samples of certain carcass cuts, specific gravity has been only a mediocre predictor of the fat concentration. Most of the variations accounted for by specific gravity were between 0.55 and 0.65, with an overall range of 0.12 to 0.83.

Research findings have shown a strong relation between chemically determined carcass fat and carcass fat estimated from specific gravity data (Guenther et al., 1967; and Garrett et al., 1968). Guenther et al. (1967) used fifty-one, half sib Hereford steers ranging in age from 14 to 18 months and in live weight from 372.9 to 464.9 kg to study this relationship. Fat content ranged from 29.9 to 50.1 kg (per side), and a correlation of 0.928 was obtained between total carcass fat and fat as predicted from specific gravity. When the equation developed by these workers was applied to a different group of 18 beef carcasses of known specific gravity and fat content (ranging in age from 12 to 18 months and 10.2 to 44.3 kg in fat/side) the correlation between the actual fat content and that calculated from the specific gravity data was 0.995. Garrett's work with 48 steers indicated that specific gravity accounted for 92 percent of the variation in total fat. The standard error of estimate for this regression was calculated to be 7.0 percent of the mean value of the measured fat.

In one of the most extensive investigations involving the specific gravity technique, Kelly et al. (1968) determined specific gravity on right side wholesale cuts and left 9-10-11 rib and physically separated carcasses from 156 steers, which had been exposed to various nutritional regimes for various periods of time and were slaughtered at various ages. As a consequence, the meat separated from the bone contained from 2.5 to 50 percent fat. The predictability of fat from specific gravity determined in 128 carcasses in which the meat contained from 10.0 to 30.0 percent fat was very low (R^2 ranged from 0.04 to 0.32). However, when fat content of the meat ranged from 30 to 50 percent, the standard error of estimate expressed as a percent of the mean fat was less than 10.7, and reached 3.9 percent when fat was greater than 40 to 50 percent and coefficients of determination ranged from 25 to 63 percent.

Gil et al. (1970), using 18 Hereford cattle ranging from 5 to 18 months of age, studied the relationship between specific gravity and chemically determined fat on 59 quartered carcasses. The data were divided into six groups according to percent fat. Significant correlation between specific gravity and percent fat were obtained for high percent fat groups (30 to 34.9 and 35 to 42.0%). These authors suggested density was more closely associated with bone growth than other tissues in younger animals.

Powell and Huffman (1973) investigating possibilities of predicting chemical composition from easily obtainable carcass variables, reported correlations coefficients of -.92 and -.92, respectively between carcass specific gravity and chemically determined percent fat for two groups of carcasses. Group I consisted of 15 steers selected to give three 280 kg ± 7 kg carcasses closely grouped in the lower end of each of the five U.S.D.A. yield grades. Group II included the 15 in Group I plus an additional 26 carcasses differing class, weight and finish. It should be noted that this sample constituted an illegitimate correlation study.

Garrett and Hinman (1969) found very strong relationship between carcass body composition and carcass density in beef cattle and these relationships were not appreciably influenced by breed-type or sex (Garrett et al., 1971).

Preston _et al_. (1974) studied the relationship between the specific gravity of the carcass and its chemical composition and the possible relationship between proportion of bone and the predictability of specific gravity measurement using 36 steers which differed considerably in weight and degrees of fatness. Specific gravity was highly related to fat (-.96). Bone proportionality with the range included in the study (11.7 to 18.6% separable bone) did not alter the relationship between carcass specific gravity and carcass composition.

More recently Clark _et al_. (1976) presented data which related right side specific gravity measurement obtained from 56 steers ranging in weight from 183 to 574 kg. The specific gravity (independent variable) was related to fat-free body weight, percentage fat of the carcass, percentage fat-free carcass weight (dependent variables). Variation in the dependent variables accounted for by the specific gravity ranged from 56 to 88 percent. Specific gravity accounted for the least amount of variation in lean weight of the carcass, fat-free carcass weight, and fat-free body weight (56, 68 and 69%, respectively) and the largest amount of variation in percentage carcass fat (87%) and percentage fat-free body (88%).

In conclusion, these data in general support the use of specific gravity as a means of estimating the tissue composition of mature animals or those in a later stage of growth and development. Research by Rathbun and Pace (1945), Bray _et al_. (1959), Cole _et al_. (1960b), Wedgwood (1963) and Kelley _et al_. (1968) have observed that specific gravity is of little or no use in the estimation of body composition of carcasses from young animals or where the carcass fat content is low. The most recent research young animal with a low-fat content was conducted by Waldman _et al_. (1969) in which specific gravity and subsequent physical separation determined on the left side of 14 Holstein calves. Two of the 14 calves were slaughtered at birth, four at 91 kg and eight at 277 kg live weight. Correlations of specific gravity with carcass fat, bone, and muscle weight (0.37, 0.53 and 0.40, respectively) were not statistically significant. Regression analysis found specific gravity contributed very little to the estimation of composition. The poor relationship of specific gravity with carcass composition found in this study was in agreement with earlier reports.

Individual Muscles and Muscle Groups

Considerable work has indicated the relationship of wholesale cuts and closely trimmed cuts to total carcass muscle. However, with the advances in processing and merchandising of boneless meat and the variation of intermuscular and intramuscular fat, and bone there is a need to study the relationship between individual muscles or muscle group and total carcass lean. Butterfield and May (1965) and Berg and Butterfield (1968) observed that after three months of age, each muscle in the carcass constituted a remarkably constant proportion of the total musculature. It has been suggested that a greater degree of accuracy and repeatability is attained in the prediction of total muscle weight by proper anatomical dissection than by either dissection of lean from commercial cuts or the gross separation of lean from fat and bone (Butterfield, 1962; Mukhotz and Berg, 1973).

Topel *et al*. (1965) studied the relationship of weight of certain whole porcine muscles from the ham and loin, to carcass muscling. Partial correlation coefficients, adjusted for differences in side weight, between the five muscles studied and weight of lean cuts were found to be highly significant ($P < .01$), with the *longissimus dorsi* muscle having the highest correlation (0.70). Pooling the five muscles into one muscle group resulted in a highly significant partial correlation coefficient of 0.75 when related to the weight of lean cuts. This was the highest association found among all parameters studied (i.e. *Longissimus dorsi* area, carcass length, and backfat thickness).

Carr (1975) removed the *biceps femoris* and *semimembranosus* muscles from 100 market barrows, representing two breeds, slaughtered in groups of 20 at 100, 150, 200, 250 and 300 pounds, in an effort to characterize muscle growth and determine the validity of using muscle weights to predict total carcass lean. Correlation coefficients between these muscles and parameters of carcass lean (fat-free lean, lean cuts, etc.) were found to be significant ($P < .05$) for both breeds. However, the total variability accounted for ranged from 9 to 36 percent of the variation associated with the parameters studied; therefore, it was concluded that neither *biceps femoris* nor *semimembranosus* weights would serve as a reliable predictor of fat-free lean in these heavily muscled pigs.

Butterfield (1962) presented data indicating that the heterogeneity (breed, age and shape) of the 35 steers dissected had a non-significant influence on the prediction of total muscle by individual muscle weights. Highly significant associations were reported between total muscle weight and the individual muscles studied, with the biceps femoris muscle having the highest predictive index (r = .99 and S.E. of 2.330 g), whereas, the semitendinosis had the least predictive index (r = .96 and S.E. of 5.106 g).

One of the few American studies reported in the literature in which individual muscles were utilized as predictors of lean was reported by Orme et al. (1960). In this study six muscles and two muscle groups were excised from carcasses of 43 mature (8½-11 years) Hereford cows, ranging in weight from 191 to 405 pounds and U.S.D.A. quality grade from high cutter to high commercial. The longissimus muscle represented the heaviest muscle studied comprising 6.83 percent of the total separable lean; whereas, the psoas major represented the lightest muscle (2.77%). All simple correlation coefficients between individual muscles and muscle groups were highly significant and the weights of certain of the muscles studied accounted for 64 to 92 percent of the variation in total separable carcass lean. The four heavier muscles (longissimus, biceps femoris, semimembranosus and adductor, semitendinosis and quadraceps complex) appeared to be the best estimators, but the four lighter muscles (rectus femoris, psoas major, triceps brachii and infraspinatus) also accounted for a large fraction of the total variation in lean. When these data were adjusted for slaughter and carcass weight, by regression analysis, the partial correlation coefficients obtained were somewhat less but still significantly associated with total lean. This author suggested that the relationships between individual muscles and total lean were sufficiently high to warrant their use for predictive purposes. They stated that the relationships found with these mature cattle, which were quite variable in composition, age, size, etc., are suggestive of similar relationships for immature cattle which vary greatly in their amount of muscling.

This worker further attempted to predict total carcass lean from the weights of various muscle combinations. Seventy-seven to 94 percent of the variation in total carcass lean was found to be associated with weights of two or more of the individual muscles studied.

Butterfield (1965b) reported findings from a study involving 29 British breed beef steers representing a more homogenous population than in previous studies by this worker. Highly significant correlation coefficients were found between the seven individual muscles dissected and total muscle; accounting for 76 to 98 percent of the variation in total muscle. However, special interest was expressed in the applicability of the "shin" muscle group studied as a predictor of total muscle because of its readily accessible nature and low economic value. Regression equations utilizing "shin" muscle group weight and certain estimates of carcass fat and carcass weight were presented and accounted for a significant proportion of the total carcass muscle variation (98%).

CHAPTER III

A STUDY OF THE RELATIONSHIP BETWEEN ^{40}K COUNTING EFFICIENCY OF A SMALL STANDARD SOURCE AND FOUR PHANTOMS WEIGHING 500, 700, 900 AND 1100 POUNDS

Summary

The relationship between the counting efficiency of a small standard source (619.03 g potassium chloride) and four phantoms (constant density and .33% potassium chloride by weight) weighing 500, 700, 900 and 1100 pounds was studied. The counting efficiencies of the phantoms decreased as weight increased, while the small standard source counting efficiency remained reasonably constant. The counting efficiencies of the 500, 700, 900 and 1100 pound phantoms were 7.61, 8.04, 8.31 and 8.57 percent less than the respective small standard source efficiencies. The slight change from 700 to 900 pounds was confounded by a change in the detector configuration and re-calibration of the counter. Prediction equations were developed for each phantom weight. The variation in phantom counting efficiency accounted for by standard source counting efficiency ranged from 98.4 to 99.9 percent, suggesting a strong and essentially linear relationship between these variables. It can be concluded that phantoms provide an effective means of correcting count data for differences in counting efficiency attributed to mass, and data obtained using a small standard source can be used to predict phantom counting efficiency with a high degree of accuracy.

Introduction

The potential usefulness of ^{40}K whole-body counting is dependent upon the accuracy with which sources causing variation in the counting data can be identified and controlled. One such source of variation is day to day fluctuations in counting efficiencies caused by instrument drift (Twardock _et al_., 1966). Instrument instability coupled with changes in routine balancing of the counter electronics can be important sources of error in whole-body counting. Such error can be controlled by counting a standard reference sample containing a known quantity of potassium to determine counting efficiency and adjusting sample count data to a standard base efficiency. However, certain characteristics inherent to the sample such as mass and shape (Twardock _et al_., 1966; Lohman, 1968) and the whole-body distribution of potassium (Miller and Remenchik, 1963) influence relative counting efficiencies. Also, changes in the sample to detector geometry may influence counting efficiency (Twardock _et al_., 1966; Moser, 1970). The decrease in counting efficiency associated with an increase in sample mass (Anderson, 1959; Twardock _et al_., 1966; Anderson, 1968; Lohman, 1968; Martin, _et al_., 1968) has been attributed to the scattering and absorbing of radiation originating within a sample (self-absorption) and to the absorption of environmental gamma radiation by the sample (background depression).

Twardock _et al_. (1966) concluded that counting rate of a small sample was influenced to a lesser degree by instrument drift than that of a larger sample. Therefore, frequent measurement of reference standards (phantoms) that resemble the samples (animals) to a reasonable approximation would be expected to provide a more accurate estimate of day to day fluctuations in counting efficiency than a small standard reference source.

This experiment was designed to study the relationship between the counting efficiency of a small standard potassium source containing 619.03 grams of potassium chloride and the counting efficiency of four phantoms weighing 500, 700, 900, and 1100 pounds, respectively. Also, developed were prediction equations that could be used to predict counting efficiency of the four weight phantoms from standard source counting efficiency and to use the predicted phantom efficiencies to adjust counting data obtained on 96 steers representing two breed types and four weights.

Materials and Methods

Whole-body Counter

The O.S.U. ^{40}K whole-body counter (with plastic scintillation detector logs) which is housed at the Live Animal Evaluation Center on the Oklahoma State University campus has previously been described by Moser (1970), McLellan (1970), Carr (1975) and in considerable detail by Frahm, et al. (1971). Modifications were made in the detector system in an effort to maintain a uniform sample to detector geometry over a wide range in sample weight. A "small configuration" was designed for the purpose of counting samples weighing 700 pounds and under, and a "large configuration" was designed to accommodate samples weighing 900 to 1100 pounds. Each detector system was constructed using the same seven plastic scintillation detectors placed in the same respective position on a "horse-shoe like" steel frame. Both configurations enveloped the top and sides of the samples to be counted, and approximated a 3-pi arrangement of the detector logs. The difference between the two systems were the size of sample that the configuration could accommodate, and an increase in the spacing between detector logs for the "large configuration".

Phantoms

One gallon plastic containers (6 in^3) were filled with a distilled water solution of known density (1.13 g/ml) and potassium chloride concentration (.33% by weight). The density of the solution and potassium concentration were chosen to approximate the whole-body density and concentration of a "typical" slaughter weight beef steer (Lohman and Norton, 1968). The desired density was obtained by adding 199.8 grams of sodium chloride per liter of distilled water and the acquired density was checked with a hydrometer.

The four phantoms weighing 500, 700, 900 and 1100 pounds, respectively were constructed by arranging the filled containers in multiple layers placed on a mobile dolly (figure 1). The dimensions of each phantom were selected to approximate length, width and height measurements of similar weight beef steers.

In order to establish the relationship between counting efficiency (CE) of a sealed standard source (STDS) and counting efficiency of the phantom at each of the four weights, a series of 6 standard source net counts and 6 phantom net counts were obtained at 4 different settings (window width) of the discriminator in the pulse height analyzer for each detector configuration. Twenty-four standard source net counts and 24 phantom net counts were obtained at each of the four weights (table 3). A 500 milliliter plastic bottle containing 619.03 grams of potassium chloride was used as the small standard source. Changing the window width on the counter influenced the portion of radiation detected from a given source and allowed the standard source and phantoms to be counted over a range of efficiencies. The four window widths (table 3) were set in order for the standard source to be counted at approximately 9, 11, 13 and 15 percent counting efficiency. Because the plastic scintillation detector logs had to be electronically rebalanced using a Ortec Multi-Channel Analyzer (Model 6220) and the standard source to detector geometry was changed when the detector system was converted from the "small configuration" to the "large configuration", the window width settings differed slightly between the two detector systems.

The 500 and 700 pound phantoms were counted in the "small configuration" whereas, the 900 and 1100 pound phantoms were counted in the "large configuration". The total count data for the standard source and the 500 and 700 pound phantoms were obtained for each of the four window widths before converting the counter detector system to accommodate the 900 and 1100 pound phantoms. Furthermore, the count data were obtained on both the 500 and 700 pound phantoms at each window width prior to re-calibrating the counter to obtain the next desired counting efficiency.

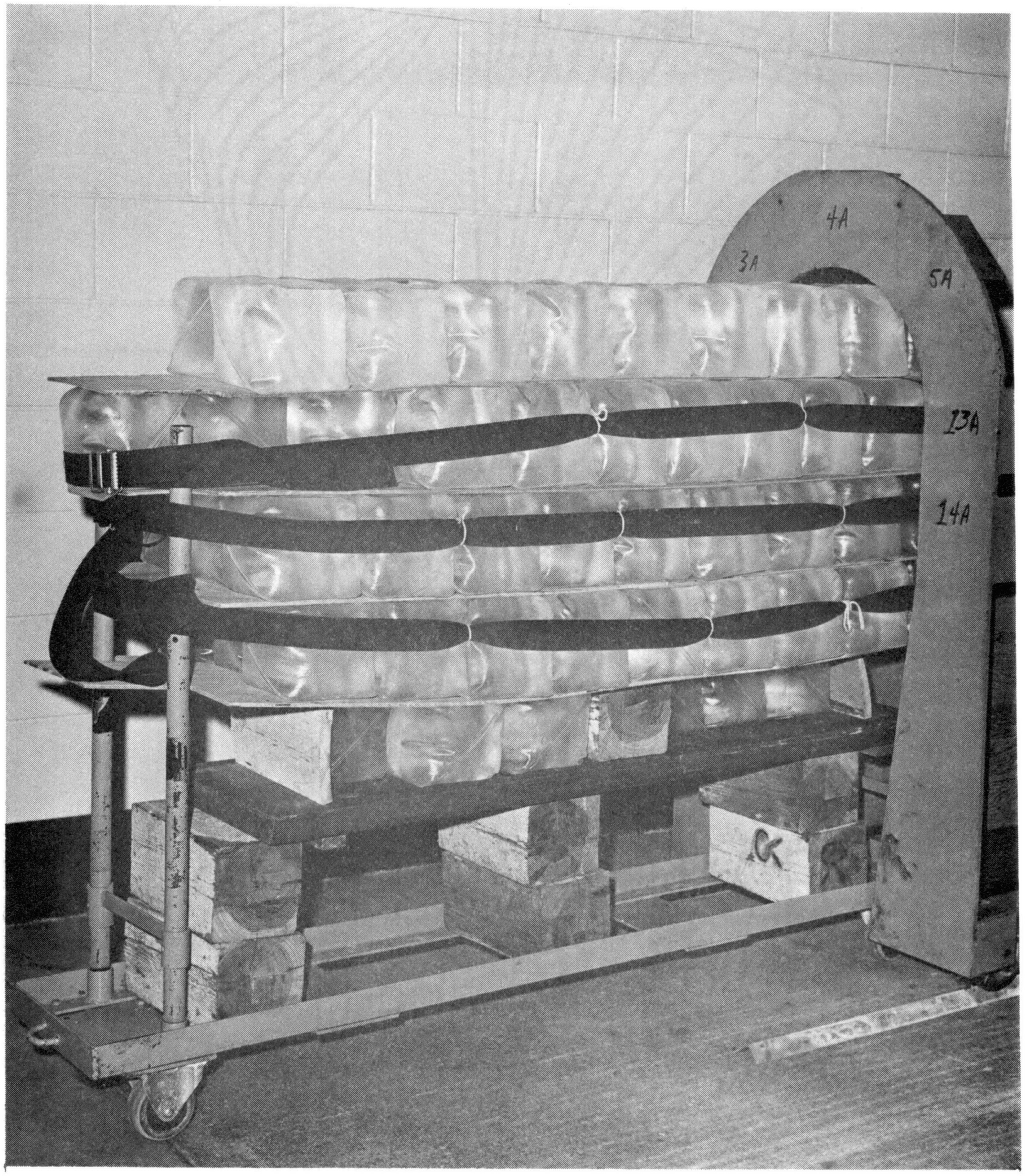

Figure 1. 1100 Pound Phantom System

TABLE 3. COUNTING DESIGN AND WINDOW WIDTH SETTING, BY DETECTOR CONFIGURATIONS, FOR STANDARD SOURCE AND FOUR PHANTOMS

	Small configuration					Large configuration			
Window width[a]	STDS[b]	500 pound phantom	STDS[b]	700 pound phantom	Window width[a]	STDS[b]	900 pound phantom	STDS[b]	1100 pound phantom
EMN 1.10					EMN 1.00				
EMX 1.60	6	6	6	6	EMX 1.60	6	6	6	6
EMN 1.00					EMN 1.00				
EMX 1.62	6	6	6	6	EMX 1.77	6	6	6	6
EMN 1.00					EMN .90				
EMX 1.75	6	6	6	6	EMX 1.87	6	6	6	6
EMN 1.00					EMN .80				
EMX 1.95	6	6	6	6	EMX 1.90	6	6	6	6
Total net counts	24	24	24	24		24	24	24	24

[a] Window width represents the minimum energy pulse count (EMN) and the maximum energy pulse count (EMX) in Million electron volts.

[b] Small standard source, 619.03 grams potassium.

The counting procedure for this experiment was to obtain 5 consecutive one-minute initial background (BG) counts (counting chamber empty), followed by 5 consecutive one-minute counts with the standard source placed in a designated position in the counting chamber, and then a subsequent set of 5 consecutive one-minute background counts were taken. Immediately following the preceding background count, 5 consecutive one-minute counts were obtained with one of the respective phantoms positioned in the counting chamber, followed by 5 consecutive one-minute background counts. The above counting procedure was repeated 5 additional times for each window width. Net count per minute (NCPM) for both the standard source and the phantoms were calculated by removing that portion of the detectable radiation attributed to the environment (background) using the following formula:

$$\text{NCPM} = \text{Mean sample count} - \text{Mean BG count}$$

Mean sample count was the average of the 5 counts obtained for either the standard source or the phantoms. The mean background count was the average value for the 5 backgrounds obtained prior to and the 5 backgrounds obtained after the counting of the standard source or of the phantom. It should be noted that the second series of backgrounds acquired following counting either the standard source or a particular phantom was designated as the first series of background count for calculating the net count per minute of the standard source or phantom that followed rather than obtaining a separate set of backgrounds.

The net count data for both the standard source and the phantoms were expressed as a percent of the total gamma disintegrations emitted per minute (TDPM), counting efficiency, as determined from the potassium concentration of the standard source and the four respective phantoms (table 4). The total disintegrations per gram of potassium were estimated, based on 204 gamma events occurring per minute for one gram of stable potassium (Overman, 1967).

The percent counting efficiency for these data was determined by the following formula:

$$\text{CE} = \frac{\text{NCPM (STDS or phantom)}}{\text{TDPM (STDS or phantom)}} \times 100.$$

TABLE 4. GRAMS OF POTASSIUM CHLORIDE AND GAMMA DISINTEGRATIONS PER MINUTE FOR THE STANDARD SOURCE AND THE FOUR PHANTOMS

Item	Standard source	Phantom weight (lbs)			
		500	700	900	1100
Grams of potassium chloride	619.03	746.3	1044.8	1263.4	1543.7
Gamma dpm[a]	6.63×10^4	7.08×10^4	9.91×10^4	1.39×10^5	1.69×10^5

[a] Disintegrations per minute.

Statistical Analyses

Means and standard deviations were determined according to methods outlined by Steel and Torrie (1960) sections 2.7 and 2.8. The prediction equations for each of the four weights were estimated as described by Steel and Torrie (1960) sections 9.2, 9.7 and 9.8. Homogeneity of regression coefficients was tested as outlined by Steel and Torrie (1960) section 15.9.

Results and Discussion

The mean percent counting efficiencies for the standard source and four phantoms counted at each of the window widths used for the two detector systems are presented in table 5. The window width setting generally provided standard source efficiencies near the desired efficiencies (9, 11, 13 and 15%) and provided an effective method of obtaining a range in percent counting efficiency expected to be encountered in a study encompassing several months or longer. On the average, the counting efficiencies of the 500 and 700 pound phantoms were 7.61 and 8.04 percent less than the respective counting efficiencies for the standard source. The 900 and 1100 pound phantoms were counted at 8.31 and 8.57 of the efficiency of the standard source. A smaller reduction in counting efficiency was noted as weight increased from 700 to 900 pounds than when weight increased from 500 to 700 or 900 to 1100 pounds. The change in weight from 700 to 900 pounds was accompanied by a change in detector configuration as well as a re-balancing of the detector logs. It is believed that the similar counting efficiency reduction is associated with re-establishment of a more effective phantom-to-detector geometry with the 900 pound phantom in the "large configuration".

The prediction equations obtained for each weight when phantom counting efficiency was regressed on standard source counting efficiency are presented in table 6. Each equation is based on 24 pairs of observations across the four window widths for each detector system. Each of the four regression coefficients were found to be significantly different from zero ($P < .01$). The homogeneity of the regression coefficients was tested in an effort to pool the regression coefficients;

TABLE 5. MEANS[a] AND STANDARD DEVIATIONS[b] FOR THE STANDARD SOURCE AND FOUR PHANTOMS COUNTING EFFICIENCIES

	Small configuration				Large configuration			
Window width[c]	Standard source (%)	500 pound phantom (%)	Standard source (%)	700 pound phantom (%)	Standard source (%)	900 pound phantom (%)	Standard source (%)	1100 pound phantom (%)
Window width I	9.13 (.105)	3.23 (.046)	9.10 (.108)	2.87 (.036)	8.97 (.074)	2.83 (.039)	8.77 (.040)	2.52 (.020)
Window width 2	10.82 (.100)	3.96 (.033)	10.89 (.110)	3.46 (.030)	11.00 (.102)	3.38 (.017)	10.96 (.069)	3.10 (.026)
Window width 3	12.64 (.176)	4.55 (.105)	12.49 (.065)	3.92 (.046)	13.09 (.154)	4.07 (.068)	13.14 (.151)	3.75 (.035)
Window width 4	14.86 (.092)	5.26 (.102)	14.41 (.196)	4.48 (.084)	15.21 (.106)	4.76 (.071)	15.20 (.168)	4.41 (.022)

[a] Six observations per mean.

[b] Standard deviations of the mean in parenthesis.

[c] Window width differed from the small counter to the large counter (see table 3).

TABLE 6. PREDICTION EQUATIONS, r^2 AND STANDARD ERRORS OF ESTIMATE FOR THE REGRESSION OF PHANTOM COUNTING EFFICIENCY ON STANDARD SOURCE COUNTING EFFICIENCY

Configuration	Phantom weight	Prediction equation[a,b,c]	r^2	Standard error of estimate
Small	500	$Y = .1199 + .3484^{**} (X_1)$	.984	.038
configuration	700	$Y = .1474 + .3015^{**} (X_1)$	.992	.021
Large	900	$Y = .0044 + .3113^{**} (X_1)$	.999	.019
configuration	1100	$Y = -.0857 + .2939^{**} (X_1)$	.999	.010

[a] Prediction equations are based on 24 pairs of observations.

[b] Beta values were tested for homogeneity and found to be significantly different ($P < .01$) from each other with the exception of the 700 and 1100 pound b values.

[c] X_1 = Standard source counting efficiency.

** $P < .01$ that $b = 0$.

thereby, increasing the precision of the estimate. However, significant ($P<.01$) differences were found between the regression coefficients with the exception of those obtained with count data from the 700 and 1100 pound phantoms. The variations in phantom counting efficiency accounted for by standard source counting efficiency were 98.4, 99.2, 99.9 and 99.9 percent for phantoms weighing 500, 700, 900 and 1100 pounds, respectively (table 6). These data suggest a strong and essentially linear relationship between standard source counting efficiency and phantom counting efficiency within the range of window widths used. The small standard errors of estimate associated with each of the four prediction equations suggest that phantom counting efficiency can be predicted from standard source efficiency with a high degree of precision. From these data it appears that standard source counting efficiency could be used to predict counting efficiency of samples similar in weight to the phantoms used in this study. This would provide a means of more effectively correcting data obtained using the standard source as a standard reference for differences in counting efficiencies attributed to weight (mass) as well as day to day variation in counting efficiencies.

To provide an example of the influence of phantom mass on counting efficiency using the four established prediction equations, a standard source efficiency of 12 percent was used to estimate phantom counting efficiency. Twelve percent represents an intermediate counting efficiency and the range that might be encountered during a study involving several months. The respective predicted counting efficiencies for the four phantom weights and by the two detection systems, based on a 12 percent standard source counting efficiency were 4.30 and 3.76 percent for the 500 and 700 pound phantoms counted in the "small configuration" and 3.74 and 3.44 percent for the 900 and 1100 pound phantoms counted in the "large configuration". A 12.44 percent reduction in percent counting efficiency was noted as phantom weight increased from 500 to 700 pounds. Similarly, a reduction of 7.99 percent was observed as phantom weight increased from 900 to 1100 pounds. However, counting efficiency decreased only slightly (.30) as phantom weight increased from 700 to 900 pounds. These data are presented graphically in figure 2. If self-absorption and background depression

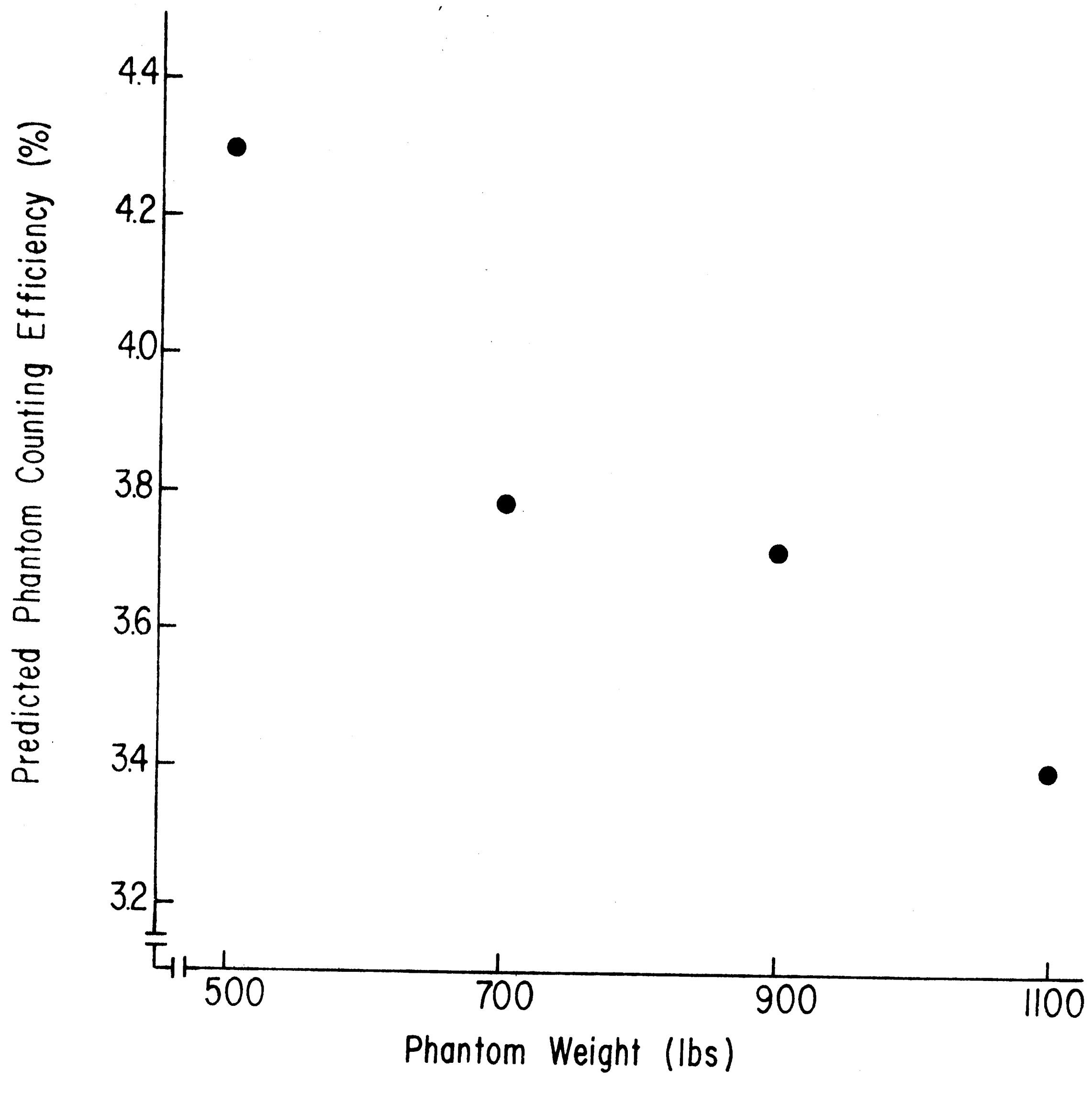

Figure 2. Predicted phantom counting efficiencies based on regression equations (Table 6), using 12 percent standard source efficiency

were the only two factors influencing the reduction in counting efficiency, as weight increased, a more uniform decrease would be expected to occur across the weight groups. This appeared to be the situation within the "small configuration" (500 to 700 pounds) and within the "large configuration" (900 to 1100 pounds), but not for the reduction in counting efficiency when the detector system was changed (700 to 900 pounds). Converting the counter to the "large" detector system appears to have influenced the phantom to detector geometry; therefore, offsetting a portion of the reduction in counting efficiency attributed to self-absorption and background depression. It is also possible that the re-balancing of the electronics could have influenced the counting rate. The latter appears to be doubtful because the standard source counting efficiency did not change appreciably between the two counters (table 5). The general tendency for counting efficiency to decrease with an increase in mass is in agreement with data reported by Anderson (1959), Twardock *et al*. (1966), and Lohman (1968).

CHAPTER IV

THE RELATIONSHIP BETWEEN LIVE ADJUSTED ^{40}K COUNT AND CARCASS COMPOSITION OF STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

Summary

The relationship between adjusted ^{40}K count and carcass composition was studied using 48 Hereford and 48 crossbred steers counted and slaughtered at four different weights. Two counts, obtained on the same animal on the same day, were found to be reasonably repeatable (.916 to .970). Analysis of variance indicated significant breed type and weight group differences for adjusted count and the ratio of adjusted count to empty body weight. The crossbred steers were observed to have larger adjusted counts than the Hereford steers, at similar weights. Tests for linearity suggested that the major proportion of weight group sum of squares associated with adjusted count could be attributed to linear effects. However, there was a tendency for the increase in adjusted count to decrease as slaughter weight changed from 500 to 1100 pounds. This was especially noticeable with respect to the Hereford steers.

The relationship between mean adjusted count and mean weight of fat-free lean generally showed a reasonably linear response across the four slaughter weight groups and for the respective breed types. However, considerable within slaughter weight group variation was observed for both the Herefords and the crossbreds. The relationship between mean adjusted count and mean pounds total body fat appeared to be some-

what curvilinear in nature. Simple within slaughter weight correlations were positive and for the most part, significant at the $P < .05$ level. Also, the within weight group associations between adjusted count and pounds of fat-free lean were generally found to be stronger than associations between empty-body weight and pounds of fat-free lean. Negative, but generally non-significant ($P > .10$) associations between adjusted count and weight of total body fat were observed. Associations between empty body weight and pounds of total body fat were inconsistent. Pooled within slaughter weight group correlations between adjusted count and pounds of fat-free lean were positive ($P < .05$) and accounted for 22.4 and 33.8 percent of the variation in fat-free lean for the Herefords and crossbreds, respectively. Similar associations between adjusted count and weight of total body fat were observed when these data were pooled within slaughter weight groups. Little or no association ($P > .10$) between adjusted count and hide weight or mean hide thickness was observed. Adjusted count data obtained at weights other than the designated slaughter weight proved to be no more predictive of weight of fat-free lean and total body fat than the adjusted count obtained at slaughter, regardless of breed type.

Prediction equations developed from these data suggests that within narrow weight range groups such as those used in this study, fat-free lean could generally be more precisely predicted from adjusted count than from empty body weight. However, the combination of these two variables generally provided the smallest standard errors, although exceptions were noted. The weight of fat-free lean was more closely estimated from regression analysis than was total body fat using adjusted count, empty body weight, or both, as the independent variables. Ignoring slaughter weight group, adjusted count accounted for 90.9 and 85.7 percent of the variation associated with pounds of fat-free lean for Herefords and crossbreds, respectively. Whereas, empty-body weight accounted for 94.1 and 92.6 percent of the variation in pounds of fat-free lean for the Hereford and crossbred steers, respectively. When these two variables were fitted simultaneously in the prediction equation an increase in the variation in fat-free lean accounted for was observed, but more important was the significant reduction in the standard errors of estimate. A reduction in the standard error of estimate of 19.2 percent was noted for the crossbred steers when both variables were fitted, compared to empty body weight alone. Similar results, but a somewhat smaller reduction (9.4%) was observed for the Herefords. When total body fat was regressed on adjusted count, empty body weight or both these variables, across weight groups, empty body weight accounted for considerably more variation in total body fat than adjusted count. Reductions in the standard errors of estimate as large as 26.69 percent was observed when both variables were fitted to the model.

Introduction

Estimating the body composition of live animals by ^{40}K whole-body counting is feasible only because of the direct relation of potassium to lean body mass and its indirect relation to fat (Ward, 1968). However, the research findings concerning the relationship between whole-body count and fat-free lean have been somewhat variable. For carcasses and live animals Kirton _et al_. (1961, 1963), Kirton and Pearson (1963), Judge _et al_. (1963) and Martin _et al_. (1968), and Carr (1975) observed that whole-body counting may be of limited use as an indicator of carcass composition of sheep, pigs or calves, in narrow weight ranges. In contrast, Lohman _et al_. (1966), McLellan (1970) and Frahm, _et al_. (1971) found strong associations between whole-body count data and estimates of weight of carcass composition, of cattle similar in weight. Likewise, Schmidt _et al_. (1974), Carr (1975) and Clark _et al_. (1976) observed strong relationship between whole-body count data and amount of fat-free lean over a large divergence in weight.

The purpose of this study was to evaluate the relationship between live ^{40}K adjusted count and body composition in growing and fattening beef steers of four weight groups representing two different breed types.

Materials and Methods

Experimental Design

Forty-eight Hereford and 48 Charolais crossbred steers, representing two biological types ("conventional", early maturing and "growthy", later maturing) and four slaughter weight groups of 500, 700, 900 and 1100 pounds were used in this study. Three replications of 16 Herefords and 16 Charolais x Angus or Charolais x Hereford crossbred steers were placed on feed in the fall of 1972, 1973 and 1974. Within each replication, four steers of each breed were randomly allotted to one of the four slaughter weight groups (table 7). One Charolais-crossbred steer was lost from the 1100 pound slaughter weight group during the first replication and the missing data for this steer was estimated as described in the section on statistical analysis.

Description of Animals and Handling Procedures

The calves, weighing approximately 425 pounds, were received, weighed, ear tagged and randomly allotted to feeding pens where they received feed and water *ad libitum* until reaching their randomly assigned slaughter weight. The calves were initially fed a starter ration (table 8) containing 14.5 percent crude protein. The protein content of the ration was reduced to 13.4 percent after the cattle gained approximately 100 pounds. Subsequent reductions in the protein in the ration were made for each 100 pound increase in live weight by altering its composition.

Unshrunk weights, to the nearest 5 pounds, were obtained for each steer on a weekly basis. Upon reaching the first specified weight (500 pounds), each steer was taken off feed and water for a 24-hour shrinkage period and then evaluated by the ^{40}K whole-body counting technique. Those steers allotted to the 500 pound slaughter group were transported to the OSU Meat Laboratory for slaughter following live evaluation, whereas those steers assigned to one of the other three slaughter weight groups were returned to the feeding pens. Upon reaching the next weight, the steers were again removed from feed and water, shrunk and counted with those animals allotted to the 700 pound slaughter

TABLE 7. EXPERIMENTAL DESIGN AND DISTRIBUTION OF STEERS BY BREED, REPLICATION AND SLAUGHTER WEIGHT GROUPS

		Slaughter weight group (lbs)				
Breed	Replication	500	700	900	1100	
Hereford steers	1	4	4	4	4	
	2	4	4	4	4	
	3	4	4	4	4	
		12	12	12	12	48
Crossbred steers	1	4	4	4	4[a]	
	2	4	4	4	4	
	3	4	4	4	4	
		12	12	12	12	48

[a] One steer from this sub-cell was lost and missing values were estimated.

TABLE 8. COMPOSITION OF FINISHING RATION[a]

Ingredients	%	lbs
Dehydrated alfalfa pellet[b]	4.40	88.0
Cottonseed hull	9.75	195.0
Barley, rolled	30.58	611.5
No. 2 yellow corn[b]	39.03	780.8
Molasses, liquid	4.70	94.0
Cottonseed meal[b]	10.05	201.2
Limestone	0.58	11.5
Salt	0.24	4.5
Trace mineral mix	0.02	0.4
Urea (45% N)	0.65	13.0
	100.00	2000.0

[a] Initial ration, crude protein 14.5 percent.

[b] Ration ingredients that were altered to decrease crude protein level following each 100 pound gain.

weight group being slaughtered. A similar process was followed for the 900 and 1100 evaluation weight groups. Therefore, those steers designated as the 1100 pound slaughter group were counted at 500, 700, 900 and 1100 pounds prior to slaughter. Steers allotted to the 900, 700 and 500 slaughter groups were counted at 500, 700 and 900; 500 and 700; and 500 pounds, respectively.

Whole-body Counter

The OSU whole-body counter (plastic scintillation detector logs) which is housed at the Live Animal Evaluation Center on the Oklahoma State University campus has been described by Moser (1970), McLellan (1970), Carr (1975) and in considerable detail by Frahm *et al*. (1971). However, for the purpose of this study two different detector systems were designed in an effort to maintain a uniform animal to detector geometry over the range in steer weights. A "small configuration" was designed for the purpose of counting steers weighing 700 pounds and under, and a "large configuration" was designed to accommodate steers weighing 900 to 1100 pounds. Each detector system was constructed using the same seven plastic scintillation detectors with each detector placed in the same respective position on a "horseshoe like" steel frame. Both configurations enveloped the back and sides of the steer being counted and approximated a 3-pi arrangement of the detector logs. The differences between the two systems were the size of the steer that could be accommodated and an increase in the spacing between detector logs for the "large configuration".

^{40}K Counting Procedure

As the steers reached one of the pre-designated ^{40}K live evaluation weights (500, 700, 900 and 1100 pounds) and/or their respective slaughter weight, they were taken off-feed for 24 hours, and thoroughly washed using a low potassium soap (Proctor-Gamble, Orvis-W.A. Paste) to remove possible radioactive contamination in the hair and on the skin. Shrunk live weights (count weight) were recorded on each steer prior to counting. The mean count weight for each evaluation, and mean slaughter weights for each group are presented in table 9.

TABLE 9. MEAN WEIGHT AND RANGE FOR EACH EVALUATION AND SLAUGHTER WEIGHT BY BREED TYPE

Breed	Weight (lbs)	No. Animals	Mean (lbs)	Range (lbs)
Hereford steers	500			
	Evaluation[a]	48	510	472-546
	Slaughter	12	507	488-538
	700			
	Evaluation	36	701	685-743
	Slaughter	12	703	690-743
	900			
	Evaluation	24	901	880-928
	Slaughter	12	903	885-928
	1100[b]			
	Evaluation	12	1095	1071-1117
Crossbred steers	500			
	Evaluation[a]	48	515	489-573
	Slaughter	12	525	497-568
	700			
	Evaluation	36	706	684-748
	Slaughter	12	700	684-720
	900			
	Evaluation	24	901	883-921
	Slaughter	12	902	883-921
	1100[b]			
	Evaluation	12	1095	1081-1119

[a] Evaluated by ^{40}K whole-body counter.

[b] 1100 pound evaluation weight was also slaughter weight.

In order to correct the ^{40}K counting data for day to day fluctuations in counting efficiency, daily tests on instrument efficiency and stability were obtained throughout the duration of this study by counting a sealed small standard source (STDS) containing 619.03 grams of potassium chloride. Prior to and following each counting of the standard source, 5 consecutive two-minute background counts (BG) were obtained with the counting chamber empty to measure that portion of the total count attributable to detectable environmental radiation. The standard source was then placed in a designated position and 5 consecutive two-minute counts were taken. Net count per minute (NCPM) for the standard source was calculated by subtracting the mean of 10 background counts (5 before and 5 after) from the mean of the 5 standard source counts and the difference was then divided by two and expressed on a per minute basis (two minute counting time). The standard source was counted during each counting period just prior to the first steer and immediately following counting the last steer for that day. In the event that the counting period involved an entire day, a mid-day count was taken on the standard source.

Counting efficiency (CE) was expressed as the percent of the total disintegrations emitted from the standard source and calculated using the following formula, $CE = \frac{\text{STDS NCPM}}{66{,}300 \text{ dpm}} \times 100$. The value "66,300" disintegrations per minute represents the estimated number of gamma events occurring per minute from 619.03 grams of potassium chloride. The total disintegrations per gram of potassium were estimated based on 204 gamma events occurring per minute for one gram of potassium (Overman, 1967). The counting efficiency for a particular day was determined from the average of the two or three efficiencies determined that day. The range in percent counting efficiency during the three year duration of this study was from 8.75 to 14.6 percent.

The steers were positioned for counting by backing them into the counting chamber. One or more one-inch wooden planks were placed on the counting chamber floor in order to maintain a comparable space relationship between the sacral vertebrae, for the different types and the different weight animals, and the center detector of each of the two detector systems.

Net ^{40}K count per minute for each steer was obtained as follows: 5 consecutive two-minute initial background counts were recorded, followed by 5 consecutive two-minute counts with the steer positioned in the counting chamber, and 5 subsequent two-minute background counts following removal of the steer from the counting chamber. The mean of 10 background counts (5 before and 5 after the steer count) were subtracted from the average of the 5 steer counts. The net count was then divided by two in order to express the data as net count per minute. It should be noted that when more than one steer was counted on a given day, the background count immediately following the first steer was designated as the initial background count of the steer to follow, and so on. Two random net counts (COUNT I and COUNT II) were obtained on each steer during a particular counting period. The two net counts were averaged to provide a mean net count referred to simply as count. The 500 and 700 pound count data were obtained using the "small configuration" and the 900 and 1100 pound count data were obtained using the "large configuration".

Adjusted Net Count

Twardock *et al.* (1966) discussed errors involved in using a small standard source to evaluate detection efficiency when counting large samples. These workers concluded that counting efficiency of standard sources more nearly representing the size and geometry of the samples being counted were more representative of variation in instrument efficiency as it affects counting rate for individual steers.

At the time of the live animal and carcass evaluation of the 96 steers used in this study an adequate and inexpensive means of developing a phantom system with the flexibility to represent the range in weight of the cattle was unavailable. Therefore, the count data from the small sealed standard source (500 ml plastic bottle) containing 619.03 grams of potassium chloride was used to monitor changes in counter efficiency and stability, and subsequently to provide a means of adjustment of steer count data for day to day variation in counting efficiency. However, in the fall of 1975, a phantom system was developed, tested and used to adjust the count data of individual steers not only to a common efficiency, but also for differences in counting efficiency attributable to body mass (Chapter III).

Four regression equations, one for each slaughter weight group, were developed by regressing standard source counting efficiency on counting efficiency of four phantoms (500, 700, 900 and 1100 pounds) of constant density and containing quantitated amounts of potassium (Chapter III). Data from the phantom study (Chapter III) indicated that counting efficiency decreased with an increase in size and mass. The standard errors of estimate associated with the four respective regression equations suggested that phantom counting efficiencies could be predicted from counting efficiencies determined on the standard source with a high degree of precision. Therefore, it was decided that count data obtained on individual steers would be adjusted to a common counting efficiency based on predicted phantom counting efficiencies. This would allow adjustments in the data for day to day instrument fluctuations as well as correction for at least part of the decrease in counting rate associated with increased size and mass to be made.

To accomplish this count data obtained on 500 pound steers were adjusted with efficiencies predicted from the equation developed from data obtained on the 500 pound phantom. Likewise, 700, 900 and 1100 pound steer count data were adjusted based on efficiencies predicted from equations developed with 700, 900 and 1100 pound phantoms, respectively. Phantom efficiencies were predicted using standard source counting efficiencies, calculated from count data obtained on the standard source during the three replications of the cattle study, as the independent variable. For example, the 900 pound count data for steer No. 935 was obtained on May 23, 1973. The standard source counting efficiency for that day was 11.34 percent. Using the prediction equation developed for the 900 pound phantom, and 11.34 as the independent variable the predicted counting efficiency used to adjust the count data for that steer was generated. Similarly, all individual steer count data were adjusted using standard source efficiencies obtained on a particular day as the independent variable and the respective prediction equation comparable to the steers evaluation weight.

The adjusted count data (ADCT) were developed using the following formula: $\text{ADCT} = \frac{\text{Mean NCPM}}{\text{Predicted \% efficiency}} \times 100$. The mean net count per minute represents the average of the two randomly obtained net counts per steer per counting period. All count data will be discussed in terms of adjusted count, with the exception of repeatability.

Slaughter Procedure

Upon reaching the pre-determined slaughter weight and following whole-body evaluation, steers were transported to the OSU Meat Laboratory for slaughter the following day. Post slaughter weights were obtained on the hide (HWT), and the full and empty stomach. Empty body weight (EBWT) was determined by subtracting the difference between the full and empty stomach weights from the slaughter weight (i.e. EBWT = Slaughter weight - (Full stomach wt. - Empty stomach wt)). Hide thickness (HTHK) was recorded as the average of 3 measurements made on the dorsal midline of the hide using a No. 102 MG/National Micrometer. The hide was folded (flesh sides flush) and one measurement was made approximately 12 inches from the anterior (head) end, one approximately in the center of the back, and the last measurement was obtained approximately 12 inches from the posterior (tail) end of the hide. The hot carcass (HTCWT) was weighed and placed in a chill cooler (approximately 4° to 6°C) for 48 hours.

Carcass Measurements

All carcass measurements were determined on the right side of each carcass and included chilled carcass weight (lbs), a single fat thickness measurement (in), and an average of 3 fat thickness measurements (in). The single fat thickness measurement (SFAT) was made at a point 3/4 of the distance from the dorsal process of the 12th thoracic vertebra and perpendicular to the long axis of the *longissimus* muscle. Three fat thickness measurements (AVFAT) were made at points 1/4, 1/2, and 3/4 of the distance from the dorsal process of the 12th thoracic vertebra and on the long axis of the *longissimus* muscle and perpendicular to the fat were used to compute the average fat thickness.

Physical Separation

To arrive at the lean, fat and bone composition of the carcass, the right side of each carcass was separated into wholesale cuts using standard beef carcass cutting procedures (A.M.S.A., 1967). The kidney, heart and pelvic fats (KHP) were removed and weighed. Weights were recorded for the untrimmed round, loin, rib, chuck, and "thin cuts" which included the fore-shank, brisket, plate and flank. The physical separation was made on a wholesale cut basis using a muscle systems technique in an effort to effectively remove as much intermuscular fat as possible and thereby, obtain a more precise estimate of the closely trimmed lean (CTL) of the particular wholesale cut. Damp cover cloths were used to reduce dehydration of those wholesale cuts awaiting separation. Weights for separable fat (SF), bone (B) and closely trimmed lean (CTL) were recorded on each wholesale cut and the "thin cuts" to the nearest tenth of a pound. These values were doubled in order to equate the data to the whole carcass.

Fat-free Lean and Total Body Fat

Following separation and weighing, the closely trimmed lean from the respective wholesale cuts and "thin cuts" was thoroughly mixed and allowed to chill prior to grinding and sampling. The procedure used to sample the closely trimmed lean involved one coarse grind (3/8 in plate) and two fine grinds (1/8 in plate) with subsequent intermediate blending as described by Munson et al. (1966) and Carr (1975).

Fifteen "grab samples" were taken at uniform intervals during the final grinding period in an effort to obtain samples as representative, as possible, of the entire carcass. Three of five sub-samples, each composed of three initial "grab samples" were chosen at random, thoroughly mixed by hand and designated as an A, B or C sample, respectively. An exception to this procedure occurred in the first replication (16 Herefords and 15 Charolais crossbreds) when only A and B samples were designated. Approximately 70 gram portions of these sub-samples were placed in three plastic "whirl pac bags" and labeled. The top portion of the bag was compressed before sealing to remove as much air as possible. The samples were then wrapped in laminated freezer paper and stored at (-18°to -20°C) for later chemical analysis.

Preparation of the sub-samples involved thawing at 1.7°C. temperature overnight and homogenization at 20°C using a Sorvall Omni-Mixer. Moisture and ether-extract analysis were conducted on a 5 gram sub-sample. Moisture (MOIST) determinations were conducted on the total lean sub-samples as outlined by A.O.A.C. (1965). A Thelco Model 29 drying oven with a vacuum attachment was used to dry all sub-samples. Percent ether-extract (EE) was determined using the Soxhlet Method (A.O.A.C., 1965). The percent ether-extract from the sub-samples were averaged to estimate the fat content of the total closely trimmed lean. The analysis of variance mean squares for the chemical procedures are presented in table 47 of the Appendix. Animal to animal variation accounted for 96.4 and 95.62 percent of the variation associated with ether-extract and moisture analysis, respectively (table 48, Appendix). The remaining variation was attributed to determination errors.

Fat-free lean (FFL) was determined by subtracting the total ether-extractable weight (CTL x % EE) from the weight of the carcass closely trimmed lean. Total body fat (TBFAT) was estimated by adding the total ether-extractable weight (CTL x % EE) to the total separable fat weight and the kidney, heart and pelvic fat weight. Both the fat-free lean and total body fat values were doubled to represent the whole body.

Statistical Analyses

The data were arranged in a randomized complete block design with a 2 x 4 factorial arrangement of treatments (Breed and weight group). Each block (replication) represented 4 steers per treatment combination (table 7). The data were analyzed using the computer program entitled Statistical Analysis System (SAS) developed by Barr and Goodnight (1972).

One steer was lost from the Charolais crossbred 1100 pound weight group in the first replication. In order for the data to be balanced and complete, all observed values for this missing steer were estimated by using the mean value, for those data considered, of the remaining 3 steers in that particular sub-cell for that replication. The estimated values were treated as normal data. However, the residual degrees of freedom in the analyses of variance were reduced by one.

Means and standard deviations, analyses of variance for chemical analysis (nested design), orthogonal comparisons among weight group totals, correlations and regression analyses were computed using SAS procedures. All data were pooled within replication (year).

Results and Discussion

Repeatability

The knowledge of whether independent estimates made on the same animal on the same day have a strong relationship with one another is very important in determining the precision of an evaluation technique such as whole-body counting. Repeatability of the O.S.U. whole-body counter was determined by counting each animal twice (Count I and Count II) on a given day. If the first count and second count were equal for each individual steer, the repeatability would be 1.0, and the technique would be completely repeatable.

The pooled correlation coefficients (repeatability) between ^{40}K Count I and Count II measured on the same animal on the same day are presented in table 10. The number of animals per correlation decreased as weight increased from 500 to 1100 pounds as a result of those animals assigned to the lighter weight groups being slaughtered.

Pooled correlation coefficients ($P < .001$) of .956, .916, .937 and .970 were determined for those animals counted at 500, 700, 900 and 1100 pounds, respectively. The coefficients of determination (r^2) ranged from 82.9 percent for the 700 pound weight group to 94.1 percent for the 1100 pound weight group, indicating generally that a high proportion of the variation in Count I was accounted for by Count II.

There appeared to be no trend for counts obtained in either the "small" or "large" configuration to be more repeatable than counts obtained in the other. Also counts obtained on steers representing different weight groups counted within the same detector system were not

TABLE 10. POOLED[a] CORRELATIONS OF ^{40}K COUNT I WITH COUNT II FOR THE FOUR SLAUGHTER WEIGHT GROUPS[b]

	Slaughter weight group			
	500	700	900	1100[c]
Number of Observations	95	71	47	23
r	.956***	.916***	.937***	.970***

[a] Pooled within breed type.

[b] Unadjusted count data were used.

[c] Missing data estimates not used.

*** $P < .001$.

observed to have a particular pattern.

In general these positive correlations indicate that there was a strong association between Count I and Count II and that the O.S.U. whole-body counter was repeating itself reasonably well during the duration of this study. Correlations of a similar magnitude have been reported by McLellan (1970) and Frahm et al. (1970) in studies with beef cattle.

Relationship between Count Data and Weight

The means and standard deviations for slaughter weight, empty body weight, adjusted count and adjusted count expressed as a ratio of empty body weight and as a ratio of pounds of fat-free lean are presented in table 11 for both the Herefords and crossbred steers. The mean values and relative small standard deviations for the four respective weight groups suggest that these cattle were slaughtered reasonably close to the designated slaughter weights and the variation within slaughter weight groups was reasonably small. It also appears that the variation associated with empty body weight was approximately the same as observed for slaughter weight. The variation associated with adjusted count appeared to be somewhat greater for the crossbreds than the Herefords.

Analysis of variance (table 12) revealed significant differences ($P<.01$) between breed type and weight group effects for these count data with the exception of the ratio of adjusted count to pounds of fat-free lean ($P>.50$). Generally, few significant interactions were found and where significances were detected, the particular interactions constituted only a small portion of the total variation.

It can be noted, by comparing the data in table 11, that at similar slaughter weights the crossbreds had significantly higher ($P<.01$) adjusted counts (1191, 1436, 1642 and 1822 cpm) than the Herefords (1010, 1234, 1493 and 1650 cpm). This relationship is more easily seen in figure 3. Increases in adjusted count of 224, 259 and 157 cpm were observed for the Herefords as slaughter weight increased from 500 to 700, 700 to 900 and 900 to 1100 pounds, respectively (table 13). For similar changes in slaughter weight, adjusted count

TABLE 11. MEANS AND STANDARD DEVIATIONS[a] FOR SLAUGHTER WEIGHT, EMPTY BODY WEIGHT AND COUNT DATA FOR HEREFORDS(H) AND CROSSBRED (X) STEERS BY SLAUGHTER WEIGHT GROUPS

		Slaughter weight group (lbs)							
Item	Breed type	500		700		900		1100	
No. of steers		12		12		12		12	
Slaughter weight	H	506.9	(15.0)	703.0	(14.4)	903.1	(14.3)	1095.4	(12.2)
	X	525.0	(23.8)	699.5	(10.2)	901.7	(12.5)	1095.4	(12.4)
Empty body weight[b] (lbs)	H	482.8	(17.5)	673.0	(14.4)	878.7	(14.2)	1069.0	(9.8)
	X	494.5	(26.0)	671.3	(8.0)	867.3	(19.8)	1065.0	(16.0)
Adjusted count[c] (cpm)	H	1010	(6.9)	1234	(7.1)	1493	(9.6)	1650	(11.5)
	X	1191	(9.2)	1436	(14.6)	1642	(10.9)	1822	(15.2)
Ratio ADCT/EBWT	H	2.09	(.12)	1.83	(.10)	1.70	(.10)	1.54	(.10)
	X	2.41	(.18)	2.14	(.23)	1.89	(.12)	1.71	(.16)
Ratio ADCT/FFL[d]	H	6.03	(.43)	5.72	(.44)	5.54	(.26)	5.39	(.37)
	X	6.11	(.53)	5.93	(.48)	5.63	(.39)	5.26	(.30)

[a] Standard deviations of the mean are in parenthesis.

[b] Empty body weight (EBWT) = Slaughter weight - (Full stomach wt - empty stomach wt).

[c] Adjusted count (ADCT).

[d] Fat-free lean, pounds.

TABLE 12. ANALYSIS OF VARIANCE FOR ADJUSTED COUNT AND OTHER COUNT DATA FOR HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

		Mean square		
Source	d.f.	Adjusted count	Ratio ADCT/EBWT[b]	Ratio ADCT/FFL[c]
Total	94	...	...	...
Replication(R)	2	11918.51	.00031	.19849
Breed type(BT)	1	741840.86**	1.46337**	.09780
R x BT	2	4336.72	.01086	.13416
Weight group(WG)	3	1842001.20**	1.72458**	2.43395**
R x WG	6	34349.79	.07313	.76402**
BT x WG	3	2749.34	.03529	.11734
R x BT x WG	6	17676.80	.01655*	.08232
Residual[a]	71	9941.16	.06778	.12775

[a] The residual d.f. was reduced by 1, because of missing data estimation for one sub-cell.

[b] Ratio of adjusted count to empty body weight.

[c] Ratio of adjusted count to fat-free lean.

* $P < .05$.

** $P < .01$.

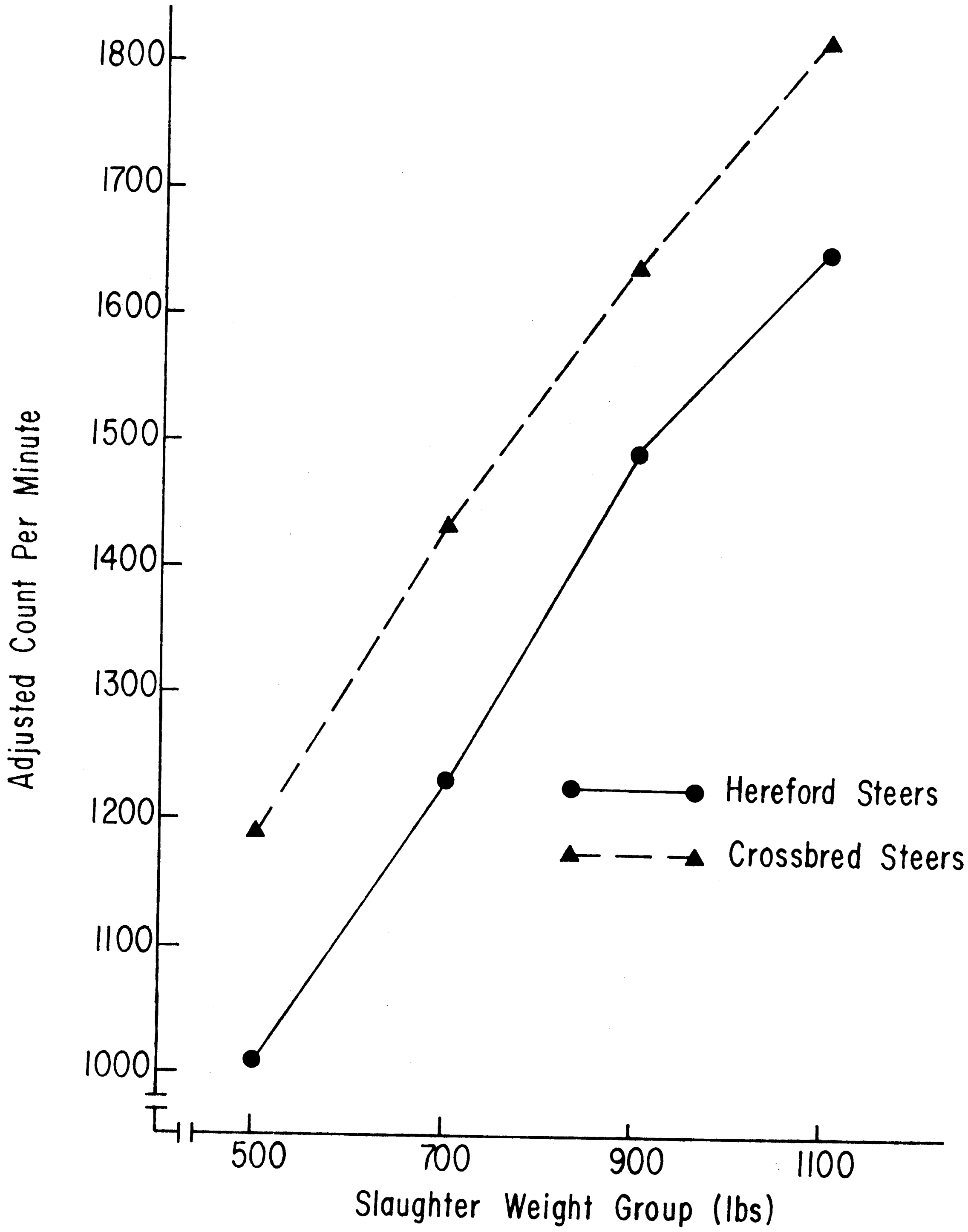

Figure 3. Mean adjusted count per minute for Hereford and Crossbred steers slaughtered at four different weights

TABLE 13. CHANGES IN COUNT DATA FOR EACH 200 POUND CHANGE IN SLAUGHTER WEIGHT

Item	Breed[a] type	Slaughter weight groups (lbs) 500 to 700	 700 to 900	 900 to 1100
Adjusted	H	224	259	157
count (CPM)	X	245	206	180
Ratio[b]	H	-.26	-.13	-.16
ADCT/EBWT	X	-.27	-.25	-.18
Ratio[c]	H	-.31	-.18	-.15
ADCT/FFL	X	-.18	-.30	-.37

[a] Herefords = H, Crossbred = X.

[b] Ratio of adjusted count (ADCT) to empty body weight (EBWT).

[c] Ratio of adjusted count (ADCT) to pounds of fat-free lean (FFL).

increases of 245, 206 and 180 cpm were observed for the crossbreds (table 13). Orthogonal comparisons were used to characterize the nature of the response curve of a certain variable associated with changes in slaughter weight. If the sum of squares associated with the test for linear effects accounts for the majority of the sum of squares associated with the weight group effects, an essentially linear relationship between the trait or characteristic in question and weight is suggested. Whereas, a significant quadratic test suggests that there is strong evidence of a non-linear relationship in at least some portion of the weight range studied. That proportion of the weight group sum of squares accounted for by linear, quadratic and cubic sums of squares, respectively, is presented in table 14. Presented in the Appendix (table 49) are the actual sum of squares associated with these effects as well as the error mean square used to determine the level of significance.

With regard to adjusted count, linearity ($P<.01$) accounted for 99.4 percent of the weight group sum of squares. These data suggest that although there was a tendency for the increase in adjusted count to decrease as slaughter weight increased, the change was not significantly non-linear ($P>.50$).

When the adjusted count data were expressed as a ratio of empty body weight, the count rate per unit of body weight appeared to decrease as slaughter weight increased from 500 to 1100 pounds, regardless of breed type (table 13). The decrease in this ratio remained reasonably constant, thus a significant ($P<.01$) linear weight group effect was observed, with the linear sum of squares accounting for greater than 98 percent of the weight group sum of squares. The relationship of this ratio (ADCT/EBWT) to slaughter weight is presented in figure 4. Expressing adjusted count as a ratio of pounds of fat-free lean also indicated that although both pounds of fat-free lean and adjusted count increased with weight, the adjusted count per unit of fat-free lean decreased. This relationship is also presented in figure 4. The change in the ratio of ADCT/FFL was found to be reasonably constant and quadratic and cubic effects were non-significant ($P>.50$).

TABLE 14. PROPORTION OF WEIGHT GROUP SUM OF SQUARES ASSOCIATED WITH LINEAR, QUADRATIC OR CUBIC EFFECTS FOR HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

	Proportion weight group SS		
Item	Linear	Quadratic	Cubic
Adjusted count	99.44**	.470	.000
Ratio ADCT/EBWT	98.80**	.015	.005
Ratio ADCT/FFL	99.90**	.060	.040

** $P < .01$.

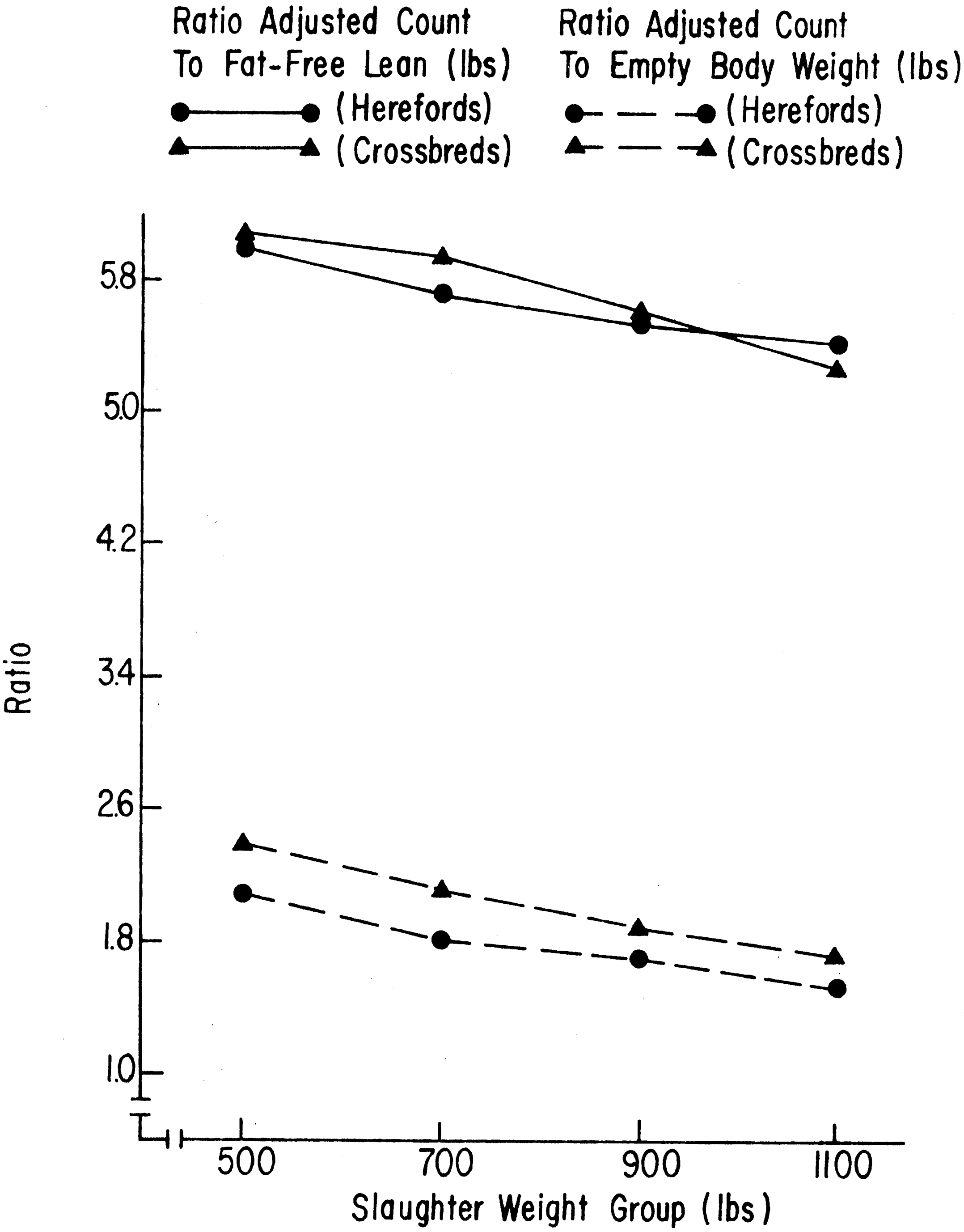

Figure 4. Mean ratio of adjusted count to pounds of fat-free lean and mean ratio of adjusted count to empty body weight for Hereford and Crossbred steers slaughtered at four different weights

Relationship between Count Data and Composition

Means, standard deviations and mean squares for fat-free lean and total body fat on a weight basis are presented in table 15. Significant ($P < .01$) breed type and weight group effects were observed for these data (table 15). It is apparent that the crossbred steers were considerably leaner and had deposited less total body fat at similar weights than the Hereford steers.

Figure 5 presents the plot of the individual observations for the count data (unadjusted for differences in counting efficiency attributed to size and mass) and pounds of fat-free lean. Although there was a tendency for an increase in unadjusted count to be associated with an increase in fat-free lean, it was apparent from the lines connecting the slaughter weight group means of these observations that there was considerable variation associated with this tendency. The means and standard deviations for the unadjusted count data were 4280 ± 309, 4593 ± 302, 5620 ± 542 and 5586 ± 857 for the Herefords and 5074 ± 516, 5217 ± 414, 6097 ± 464 and 6386 ± 739 for the crossbreds.

A small proportion of the variation observed in this plot can be attributed to the day to day variation associated with instrumentation whereas the major contributing source of variation appears to be attributable to a decrease in counting efficiency associated with an increase in body weight. Twardock _et_ _al_. (1966) attributed the change in counting efficiency associated with increases in mass to self-absorption and background depression.

In order to correct for differences in efficiency associated with the increase in weight from 500 to 1100 pounds, all count data were adjusted as described in the materials and methods based on predicted phantom counting efficiencies. The plot of the individual observations and mean values for the adjusted count data and pounds fat-free lean are presented in figure 6. These data suggest that the adjustments made were quite effective in reducing the variation within slaughter weight groups and aligning the data in a reasonably linear fashion, regardless of breed type. At similar fat-free lean weights, however, it does appear that on the average crossbred steers counted higher than Hereford steers and therefore, development of prediction

TABLE 15. MEANS, STANDARD DEVIATIONS[a] AND MEAN SQUARES FOR FAT-FREE LEAN AND TOTAL BODY FAT FOR HEREFORDS (H) AND CROSSBREDS (X) BY SLAUGHTER WEIGHT GROUPS

		Slaughter weight group (lbs)				Mean squares[b]						
Item	Breed type	500	700	900	1100	Breed type	RxBT	Weight group	RxWG	BTxWG	RxBTxWG	Residual[c]
No. of steers		12	12	12	12							
Degree of freedom						1	2	3	6	3	6	71
Fat-free lean (lbs)	H	168.1 (11.9)	216.4 (14.5)	269.8 (13.4)	306.5 (17.6)	20208.1**	530.5	93918.8**	617.0	323.1	278.3	246.5
	X	195.9 (18.9)	242.4 (19.1)	292.4 (18.8)	346.0 (17.3)							
Total body fat (lbs)	H	62.4 (17.0)	124.2 (12.4)	202.2 (17.6)	303.2 (25.0)	4288.0**	188.6	57589.1**	293.3*	224.3	77.1	84.0
	X	46.8 (7.4)	103.2 (16.1)	175.8 (20.8)	259.2 (33.1)							

[a] Standard deviations of mean are in parenthesis.

[b] Replication mean squares not presented, $(P > .10)$.

[c] The residual d.f. was reduced by 1, because of missing data estimation for one sub-cell.

* $P < .05$.

** $P < .01$.

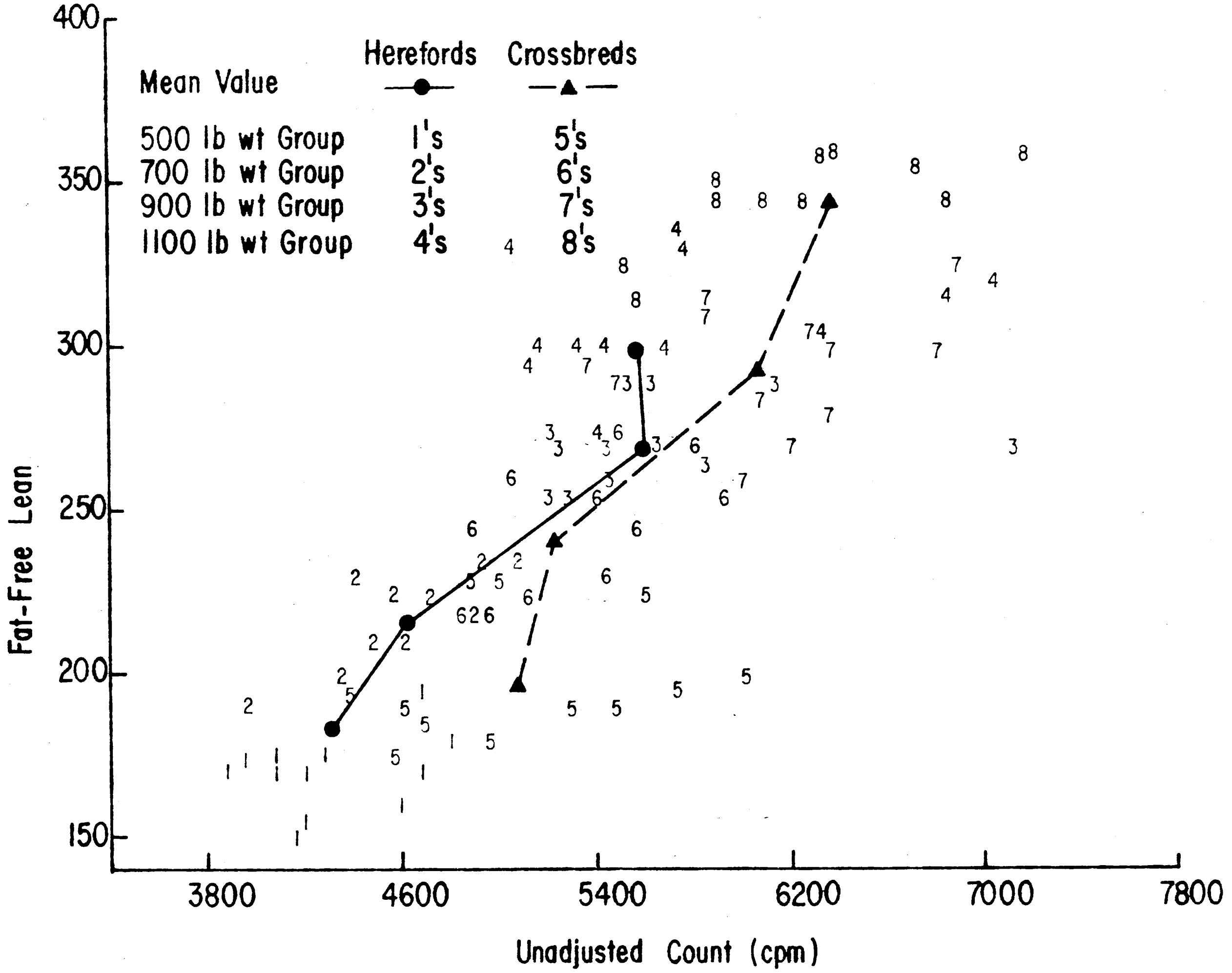

Figure 5. Plot of count data and pounds of fat-free lean prior to adjustments based on predicted phantom counting efficiencies

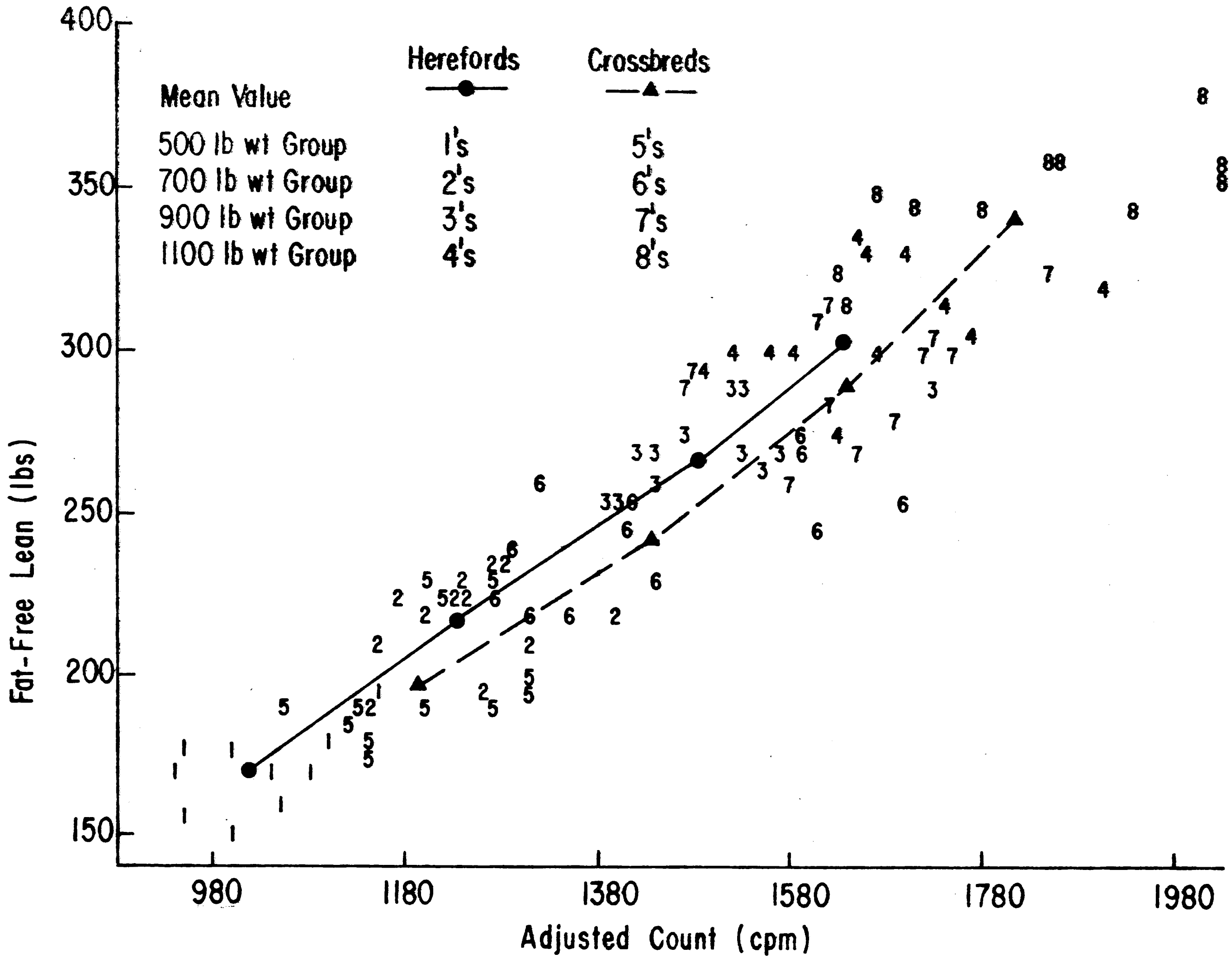

Figure 6. Plot of adjusted count data and fat-free lean for all steers

equations should take into consideration breed type differences.

The relationship between total body fat and adjusted count for the Herefords and crossbreds is presented in figure 7. This relationship suggests that on the average as these steers deposited greater quantities of total body fat, adjusted count increased but at a decreasing rate. It can be theorized that this phenomena is the result of self-absorption or even a "shielding" effect of the external fat not accounted for by the phantom adjustments.

Correlations

The correlation between adjusted count and certain estimates of leanness and fatness as well as the association between empty body weight and these traits are presented in tables 16 and 17 for the Hereford and crossbred steers, respectively. These correlation coefficients are based on the assumption that there is a linear response between adjusted count and these composition components. The validity of pooling these correlations within slaughter weight groups is dependent on the assumption that the within weight group correlations are estimating the same rho value. Since the respective slaughter weight group correlations are based on observations from only 12 animals, it should be kept in mind that an "extreme" observation can have a marked effect on the magnitude of the correlation.

For either the Herefords or crossbreds, the within slaughter weight group correlations between adjusted count and fat-free lean were positive and for the most part significant ($P < .05$) or at least approaching significance. The exceptions to this were correlations between adjusted count and fat-free lean of .114 and .205 for the 1100 pound Herefords and the 700 pound crossbreds, respectively. Furthermore, adjusted count was generally more strongly associated with fat-free lean than was empty body weight on a within slaughter weight group basis. Exceptions to this trend were observed for the 1100 pound Hereford and the 500 pound crossbred steers.

Negative, but generally non-significant ($P > .10$) within slaughter weight group correlations were observed between adjusted count and total body fat. No consistent trend in these correlations was noted as

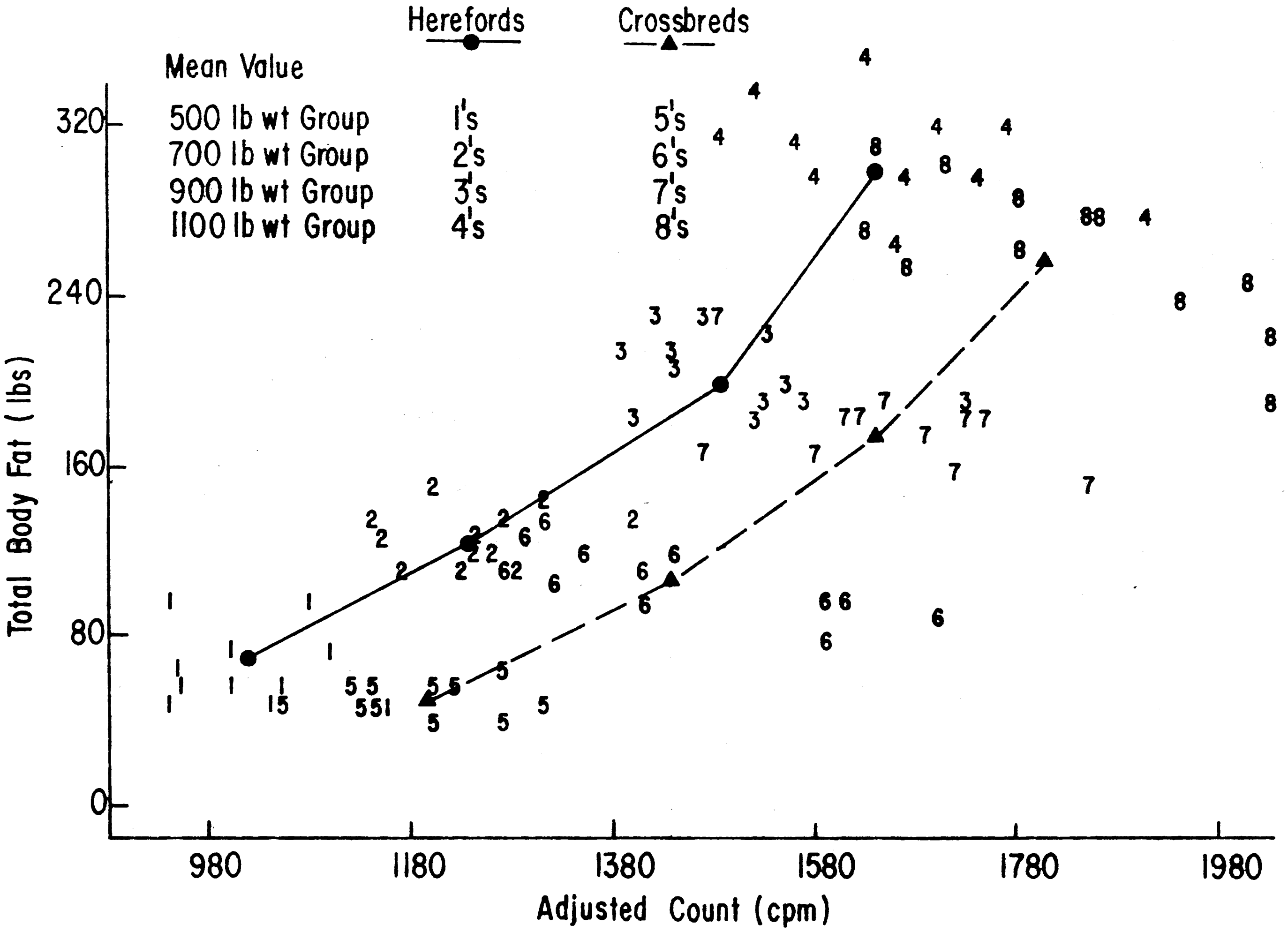

Figure 7. Plot of adjusted count data and total body fat for all steers

TABLE 16. SIMPLE AND POOLED CORRELATIONS BETWEEN LIVE ESTIMATES AND CERTAIN ESTIMATES OF CARCASS COMPOSITION FOR HEREFORD STEERS

Slaughter weight group[a] (lbs)	Adjusted count (cpm)		Empty body weight (lbs)	
	Fat-free lean (lbs)	Total body fat (lbs)	Fat-free lean (lbs)	Total body fat (lbs)
500	.748*	-.326	.663	-.122
700	.490	-.273	.259	.119
900	.703*	-.495	.528	.625*
1100	.114	-.445	.319	.087
Pooled[b] correlation	.473**	-.388*	.397*	.184

[a] 12 observations per weight group, d.f. = 9.

[b] Pooled within slaughter weight groups, d.f. = 36.

* $P < .05$.

** $P < .01$.

TABLE 17. SIMPLE AND POOLED CORRELATIONS BETWEEN LIVE ESTIMATES AND CERTAIN ESTIMATES OF BODY COMPOSITION FOR CROSSBRED STEERS

Slaughter weight group[a] (lbs)	Adjusted count (cpm)		Empty body weight (lbs)	
	Fat-free lean (lbs)	Total body fat (lbs)	Fat-free lean (lbs)	Total body fat (lbs)
500	.681*	-.369	.850**	.084
700	.205	-.735**	.125	-.308
900	.567	-.400	.125	.666*
1100	.751**	-.772**	-.019	.596
Pooled correlation[b]	.581**	-.629**	.374*	.345*

[a] 12 observations per weight group, d.f. = 9.

[b] Pooled within slaughter weight groups, d.f. = 36.

* $P < .05$.

** $P < .01$.

slaughter weight increased from 500 to 1100 pounds, regardless of breed type. The within weight group associations between empty body weight and total body fat suggested that at the lighter weights (500 and 700 pounds) there were little or no association between these two variables. However, as empty body weight increased, a significant ($P<.05$) and positive association developed with the exception of the 1100 pound Hereford steers. This may be explained by the fact that the observed variation in empty body weight within this weight group was very small, whereas the variation in total body fat was quite large.

The pooled within slaughter weight correlations between adjusted count and fat-free lean were all positive and determined to be significant at the $P<.05$ percent level. The proportion of the variation in fat-free lean accounted for by adjusted count was 22.4 and 33.8 percent for the Herefords and crossbreds, respectively. Although the pooled correlations between empty body weight were also significant ($P<.05$), the magnitude of this association was somewhat less than that observed for adjusted count and fat-free lean. This suggests that within a narrow weight range adjusted count would provide a stronger estimate of differences in fat-free lean than empty body weight. These data are in agreement with data reported by McLellan (1970) and Frahm et al. (1971) in which it was concluded that there was a stronger relationship between ^{40}K count and fat-free lean than between live weight and fat-free lean when studying sampled populations with relative small deviations in slaughter weight. However, it should be pointed out that these researchers found the association between ^{40}K count and fat-free lean to be considerably stronger in magnitude (.80 to .87) than was observed in this study.

The pooled correlations between adjusted count and total body fat were also found to be significant ($P<.05$) for both the Hereford and crossbred steers. For the Hereford steers, adjusted count accounted for 15.0 percent of the variation in total body fat compared to 39.6 percent for the crossbreds. Very little data concerning the relationship between fat and ^{40}K count are available in the literature. However, the total fat composition of cattle has been suggested to be an important source of variation in whole-body counting (Breidenstein et al., 1964;

Lohman and Norton, 1966).

The correlation analyses of the adjusted count data indicate that there are real and positive associations between adjusted count and fat-free lean and that within a narrow range of weight this association is stronger than the association between empty body weight and fat-free lean. However, due to the small number of steers per weight group used in this study, a reliable estimate of this association was unattainable.

The pooled within slaughter weight correlation coefficients between adjusted count and empty body weight, and body composition expressed as a percent of empty body weight and as a percent of hot carcass weight are presented in table 51 of the Appendix.

Pooled within slaughter weight correlations between adjusted count and certain traits which may have an influence on counting rate are presented in table 18. These traits are generally thought to have either a "shielding" or "depression" effect on the number of gamma emissions interacting with the detector. However, these associations were non-significant ($P > .10$) and did not follow any particular trends, regardless of breed type. The relationship between adjusted count and linear measures of external fat thickness were negative and among the strongest obtained. For the Herefords a significant ($P < .05$) correlation of -.366 was observed between adjusted count and average fat thickness. This association was in agreement with trends observed between adjusted count and total body fat.

The association between adjusted count and hide weight and adjusted count and hide thickness were non-significant ($P > .10$). These results are in agreement with data reported by McLellan (1970). This worker studied several sources of variation in whole-body counting using a multiple linear regression model to analyze the amount of variation in count associated with each particular variable. It was concluded that neither hide weight nor hide thickness significantly reduced the total sum of squares and therefore were of little or no use in increasing the precision of the estimate.

Also of interest was the association between adjusted count data obtained at live evaluation weights other than the pre-designated slaughter weight groups and carcass composition at time of slaughter. These

TABLE 18. POOLED[a] CORRELATIONS BETWEEN ADJUSTED COUNT AND HIDE WEIGHT, HIDE THICKNESS AND MEASURES OF FAT THICKNESS FOR STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

	Adjusted count (cpm)	
Trait	Hereford	Crossbred
Hide weight (lbs)	-.027	.003
Hide thickness (µm)	-.285	.000
Single fat thickness (in)	-.306	-.332*
Average fat thickness (in)	-.366*	-.189

[a] Pooled within slaughter weight group, d.f. = 36.

* $P < .05$.

correlations are presented in tables 19 and 20 for Hereford and crossbred steers, respectively. Again it should be emphasized that these correlations are based on limited numbers of observation and therefore may not provide good estimates with regard to the true rho value of the population(s) of inference.

Generally, the correlation of adjusted counts obtained at evaluation weights other than the slaughter weight were no more strongly associated with fat-free lean than the adjusted count obtained at the time of slaughter, in fact several negative, but non-significant associations were observed.

With regard to the association of adjusted count obtained at different live evaluation weights and total body fat at time of slaughter, there appears to be a definite negative relationship between these two variables. Also, there was a tendency for the strength of this relationship to increase with an increase in weight, regardless of breed type. It was also observed that the negative associations were more consistent from weight group to weight group than the associations between adjusted count and fat-free lean.

Prediction Equations

Since the purpose of this study was to evaluate the ^{40}K whole-body counter as a predictor of body composition, adjusted count and empty body weight data were used as independent variables and either fat-free lean or total body fat on a weight basis were selected as the dependent variable. Each of the independent variables were first considered separately and then they were both fitted simultaneously in the prediction equation to arrive at the respective standard errors of estimate associated with each regression. The respective standard errors of estimate for these regressions are presented in table 21 by breed type and slaughter weight groups. The regression coefficients for these data are presented in table 52 of the Appendix.

The standard errors of estimate were consistently lower for the regression of fat-free lean on adjusted count than for the regression of fat-free lean on empty body weight. The exception occurring in the Hereford 1100 weight group, where a standard error of estimate of 17.3

TABLE 19. SIMPLE CORRELATIONS BETWEEN COUNT DATA, OBTAINED AT FOUR COUNTING WEIGHTS, AND INDICES OF CARCASS COMPOSITION FOR HEREFORD STEERS[a]

	Slaughter weight group (lbs)							
	500		700		900		1100	
Count[b]	FFL[c]	TBFAT[d]	FFL	TBFAT	FFL	TBFAT	FFL	TBFAT
ADCT-500	.748**	-.326	.606*	-.094	-.364	-.824**	.646*	-.390
ADCT-700	...	...	.490	-.273	-.158	-.435	.586	-.275
ADCT-900	...	...	...	...	.703*	-.495	.818**	-.467
ADCT-1100	...	...	...	...	...	...	114	-.445

[a] 12 observations per weight group, d.f. = 9.

[b] Adjusted count per minute (ADCT) for the respective evaluation weights.

[c] Fat-free lean, pounds.

[d] Total body fat, pounds.

* $P < .05$.

** $P < .01$.

TABLE 20. SIMPLE CORRELATIONS BETWEEN COUNT DATA, OBTAINED AT THE FOUR COUNTING WEIGHTS, AND INDICES OF CARCASS COMPOSITION FOR CROSSBRED STEERS[a]

	Slaughter weight group (lbs)							
	500		700		900		1100	
Count[b]	FFL[c]	TBFAT[d]	FFL	TBFAT	FFL	TBFAT	FFL	TBFAT
ADCT-500	.681*	-.369	.111	-.065	.565	-.082	.183	.126
ADCT-700	...	...	.205	-.735**	.480	-.581	-.320	-.416
ADCT-900	...	...	...	...	.567	-.400	-.047	-.370
ADCT-1100	...	...	...	...	...	...	.751**	-.772**

[a] 12 observations per weight group, d.f. = 9.

[b] Adjusted count per minute (ADCT) for the respective evaluation weights.

[c] Fat-free lean, pounds.

[d] Total body fat, pounds.

* $P < .05$.

** $P < .01$.

TABLE 21. STANDARD ERRORS OF ESTIMATE OBTAINED FROM THE REGRESSION OF FAT-FREE LEAN ON ADJUSTED COUNT, EMPTY BODY WEIGHT AND BOTH VARIABLES[a,b,c]

Breed type	Weight group (lbs)	Standard errors of estimate (lbs)		
		X_1	X_2	X_1 and X_2
Herefords				
	500	6.1	6.8	5.9
	700	12.8	14.2	13.5
	900	10.7	12.7	8.9
	1100	18.2	17.3	18.3
Crossbreds				
	500	14.2	10.2	8.5
	700	15.1	15.3	16.0
	900	14.8	17.8	15.8
	1100	13.2	19.9	12.2

[a] 12 observations per weight group.

[b] Single variable regression model, $Y_{FFL} = B_o + B(X)$, where X_1 is adjusted count and X_2 is empty body weight.

[c] Multi-variable regression model, $Y_{FFL} = B_o + B(X_1) + B(X_2)$.

pounds was observed to be associated with this regression when using empty body weight as the independent variable compared to an observed standard error of estimate of 18.1 pounds when adjusted count was used. In those situations in which adjusted count did provide a more precise estimate of fat-free lean on the average than empty body weight, the differences in the standard errors of estimate ranged from 1.3 percent to as much as 34 percent depending on the breed type and slaughter weight group. It was observed that the standard error of estimate developed from the regression of fat-free lean on adjusted count for the 1100 pound Hereford steers was actually larger than the standard deviation (17.6 pounds) in fat-free lean associated with those 12 steers. Therefore, a prediction based simply on the mean value for those steers would miss the true value approximately 17.6 pounds on the average compared to an 18.2 pound miss when using the established regression equation.

The combination of adjusted count and empty body weight generally reduced the standard error of estimate for the respective breed types and slaughter weight groups below that observed when adjusted count alone was used to predict fat-free lean. This reduction in the standard errors of estimate ranged from less than 1 percent to as much as 40.5 percent. Three exceptions to this trend were noted for these data. Increases, in the standard errors of estimate, rather than a reduction, were noted for multi-variable regression for data obtained from the 700 and 1100 pound Hereford steers and likewise for the 700 pound crossbreds. Generally, these increases were not major, and resulted because the reduction in regression sum of squares was not large enough to offset the reduction in residual degrees of freedom.

McLellan (1970) reported data indicating that ^{40}K live count used in a simple linear prediction equation estimated fat-free lean with an average miss of 10.8 pounds. In this sample of cattle the value for the mean and standard deviation for fat-free lean was 228 ± 18 pounds, respectively. The combination of ^{40}K live count and live weight further reduced the standard errors of estimate to as low as 8.79 pounds. His cattle represented 16 Angus heifers and 15 Angus steers of very similar type and a small divergence in weight. In a more extensive study Frahm et al. (1971) reported the association between ^{40}K live count and fat-free lean from data obtained from 40 Angus bulls representing controlled weight groups. These data provided strong evidence that ^{40}K live count alone had a stronger relationship to fat-free lean than live weight (.86 and .20, respectively) and that the addition of live weight to the equation did not significantly reduce the standard error of estimate.

The standard errors of estimate derived from the prediction of total body fat using either adjusted count, empty body weight or both of these variables are presented in table 22. The regression coefficients for these data are presented in table 53 of the Appendix. It appears that some of the same general trends that were observed for the regression of fat-free lean on these variables are evident for these data as well.

The regression of total body fat on adjusted count generally provide more precise estimates than when empty body weight was used as the independent variable. The average difference between the standard errors of estimate when using adjusted count compared to empty body weight was 12.2 percent and ranged from 2.1 percent to 29.0 percent. Larger standard errors of estimate when using adjusted count compared to empty body weight were observed for the 700 pound Hereford group and the 900 pound crossbred group.

When both adjusted count and empty body weight were fitted to the model, the pattern in reduction of the standard errors of estimates were much more erratic than observed for the regression of fat-free lean on the two variables.

Prediction equations, coefficients of determinations (r^2) and standard errors of estimate from the regression of fat-free lean on either adjusted count, empty body weight or both of these variables across weight groups are presented in table 23. Adjusted count accounted for 90.9 and 85.7 percent of the variation associated with fat-free lean for the Hereford and crossbred steers, respectively. The standard errors of estimate associated with these respective equations were 17.1 pounds for the Herefords and 23.2 pounds for the crossbreds. However, Hereford empty body weight accounted for 94.1 percent of the

TABLE 22. STANDARD ERRORS OF ESTIMATE OBTAINED FROM THE REGRESSION OF TOTAL BODY FAT ON ADJUSTED COUNT, EMPTY BODY WEIGHT AND BOTH VARIABLES[a,b,c]

Breed type	Weight group (lbs)	Standard errors of estimate (lbs)		
		X_1	X_2	X_1 and X_2
Herefords				
	500	11.8	12.4	12.6
	700	9.4	9.6	9.8
	900	17.8	15.8	11.4
	1100	25.4	28.4	27.2
Crossbreds				
	500	6.0	6.4	6.2
	700	8.8	12.4	9.2
	900	18.4	15.0	12.2
	1100	18.8	23.8	17.8

[a] 12 observations per weight group.

[b] Single variable regression model, $^{Y}\text{TBFAT} = B_o + B(X)$, where X_1 is adjusted count and X_2 is empty body weight.

[c] Multi-variable regression model $^{Y}\text{TBFAT} = B_o + B(X_1) + B(X_2)$.

TABLE 23. PREDICTION EQUATIONS, r^2 AND STANDARD ERRORS OF ESTIMATE FOR THE ACROSS WEIGHT GROUP REGRESSION OF FAT-FREE LEAN ON ADJUSTED COUNT, EMPTY BODY WEIGHT AND BOTH VARIABLES

Breed type	Dependent[a] variable	B_o	b_1	b_2	r^2	Standard Error of estimate (lbs)
Herefords						
	FFL	-29.849	.2004 (ADCT)[b]		.909	17.12
	FFL	54.483		.2393 (EBWT)[c]	.941	13.82
	FFL	20.070	.0710 (ADCT)	.1604 (EBWT)	.952	12.52
Crossbreds						
	FFL	-42.528	.2047 (ADCT)		.857	23.22
	FFL	65.764		.2626 (EBWT)	.926	16.68
	FFL	13.650	.0765 (ADCT)	.1794 (EBWT)	.952	13.51

[a] Fat-free lean, pounds.

[b] Adjusted count (cpm).

[c] Empty body weight, pounds.

variation in fat-free lean and had a standard error of estimate of only 13.8 pounds and empty body weight for the crossbreds accounted for 92.6 percent of the variation in fat-free lean and had a respective standard error of estimate of 16.7 pounds. These data indicated that empty body weight accounted for from 3 to 7 percent more variation in fat-free lean than did the adjusted count data, as would be expected when weight groups were ignored.

When adjusted count and empty body weight were used in combination to predict fat-free lean, the r^2 values were observed to be larger than when either of these variables were fitted independent of the other (.952 and .952, respectively). More important was the significant reduction in the standard errors of estimate when these two variables were fitted simultaneously to the regression model. This was especially evident for the crossbreds, where a reduction in the standard error of estimate from 16.7 to 13.5 pounds (19.2%) was noted when these two variables were fitted compared to empty body weight alone. A somewhat smaller reduction (9.4%) in the standard error of estimate was observed for the Hereford steers. The across weight means and standard deviation for fat-free lean for the Herefords and crossbreds were 240.2 ± 54.90 and 269.2 ± 59.31, respectively. These data suggest that either adjusted count or empty body weight considerably improved the average miss above that provided by simply using the mean.

Lohman _et_ _al_. (1966) reported R^2 values of .90 and .79, respectively for ^{40}K live count and live weight when predicting carcass lean mass. However, the animals used in his study represented a much more narrow weight range than the across weight group analysis of the present study. The combination of these two variables provided data quite similar to that found in the present study (R^2 = .94). More recently Clark _et_ _al_. (1976) reported data relating ^{40}K live count and live weight to weight of fat-free lean. Fifty-six steers ranging in live weight from 400 to 1260 pounds were used in his study. These workers reported R^2 values of .95 and .94 for the association between live weight and weight of fat-free lean, and ^{40}K live count and weight of fat-free lean, respectively. The standard errors of estimate reported for the regression of fat-free lean on live weight, and on ^{40}K live count were

28.6 and 30.9 pounds. The combination of these two independent variables in the regression equation accounted for 97 percent of the variation in weight of fat-free lean and significantly reduced the standard error of estimate to 24.3 pounds. These data are in agreement with those observed in the present study. However, it should be pointed out that the prediction equations developed from the present data do appear to have somewhat smaller standard errors of estimate.

Regression equations developed for predicting total body fat using adjusted count, empty body weight and a combination of these two variables across weight groups are presented in table 24. For either breed type, empty body weight accounted for a much greater proportion of the variation in total body fat than did adjusted count. The r^2 values for the regression of total body fat on empty body weight for the Herefords and crossbreds were .955 and .945, whereas, the regression on adjusted count derived r^2 values of .794 and .609 for the Herefords and crossbreds, respectively. Likewise, the standard errors of estimate were significantly smaller when empty body weight was used as the independent variable (20.16 and 20.22 pounds for Herefords and crossbreds, respectively) compared to adjusted count (43.46 and 53.74, pounds for Herefords and crossbreds, respectively). The across weight group total body fat means and standard deviations for the Herefords and crossbreds sampled were 173.6 ± 92.38 pounds and 146.3 ± 83.18 pounds, respectively.

When both variables were used in the regression model the resulting r^2 values were .967 and .971 for the Herefords and crossbreds, respectively. For the Hereford steers a reduction in the standard error of estimate of 12.06 percent was noted when both empty body weight and adjusted count were used in combination compared to empty body weight alone. A considerable reduction (26.69%) in the standard error of estimate was observed for the crossbred steers when a combination of empty body weight and adjusted count were used to predict total body fat when weight group was disregarded.

These data suggest that although total body fat can be predicted using empty body weight and adjusted count, the estimate is not as precise as that for fat-free lean. This can be seen by expressing the standard error of estimate as a percent of the mean for the particular

TABLE 24. PREDICTION EQUATIONS, r^2 AND STANDARD ERRORS OF ESTIMATE FOR THE ACROSS WEIGHT GROUP REGRESSION OF TOTAL BODY FAT ON ADJUSTED COUNT, EMPTY BODY WEIGHT AND BOTH VARIABLES

Breed type	Dependent variable[a]	Bo	b_1	b_2	r^2	Standard error of estimate (lbs)
Herefords						
	TBFAT	-126.236	.1579 (ADCT)[b]		.794	43.46
	TBFAT	-71.286		.2034 (EBWT)[c]	.955	20.22
	TBFAT	-42.154	-.0601 (ADCT)	.2702 (EBWT)	.967	17.54
Crossbreds						
	TBFAT	-111.537	.1212 (ADCT)		.609	53.74
	TBFAT	-71.299		.1864 (EBWT)	.945	20.16
	TBFAT	-35.068	-.0532 (ADCT)	.2443 (EBWT)	.971	14.78

[a] Total body fat, pounds.

[b] Adjusted count, cpm.

[c] Empty body weight, pounds.

dependent variable. Standard errors of estimate for the prediction of fat-free lean using both empty body weight and adjusted count estimate the mean with a precision of approximately 5.0 percent on the average regardless of breed type. The precision in which total body fat is estimated using the same variables was 10 percent of the respective means, regardless of breed.

CHAPTER V

CHANGES IN BEEF CARCASS COMPOSITION WITH INCREASING SLAUGHTER WEIGHT AND THE RELATIONSHIPS OF CERTAIN CARCASS MEASUREMENTS TO CARCASS COMPOSITION

Summary

Data from 48 Hereford and 48 crossbred steers were used to evaluate changes in certain carcass measurements and growth curves of fat-free lean, total body fat and bone from 500 to 1100 pounds. Significant ($P<.01$) breed type and weight group effects were noted for all carcass measurements and composition components, with the exception of pounds of kidney, heart and pelvic fat. Crossbred steers deposited greater quantities of fat-free lean and had less total body fat compared to the Herefords at similar slaughter weights. Likewise, the crossbreds were observed to have higher proportions of bone than the Herefords.

The composition components followed rather classical responses to changes in weight, whether expressed on a weight basis or as a percent of carcass weight. Weight of fat-free lean and bone increased rather linearily with increases in slaughter weight. However, there was a tendency for the earlier maturing Hereford steers to deposit fat-free lean at a decreasing rate during the latter growth periods, although the test for non-linearity was non-significant. Weight of total body fat increased, but in a non-linear ($P<.01$) fashion. Both breed types were observed to have a more rapid fat deposition during the latter half of these growth periods. This change was considerably more noticeable for the Hereford steers.

Expressing these data as a percent of carcass weight indicated a decrease in fat-free lean, an increase in total body fat and a decrease in bone relative to increased slaughter weight. Total body fat appeared to show the most rapid rate change, followed by fat-free lean and lastly bone. These data support the classical theories on maturation order of the respective tissues. Significant quadratic effects were observed for the response of percent fat-free lean and bone ($P<.01$), and percent total body fat ($P<.05$). Similar growth patterns were observed for both breed types studied.

Correlations between certain carcass measurements and composition components were observed to vary considerably among breed types and slaughter weight groups. Similar associations were found between these carcass measurements and composition regardless of the method of expressing the data (weight or percent basis). Specific gravity was more strongly related to total body fat for steers slaughtered at 900 and 1100 pounds than at 500 and 700 pounds, however, these associations were only moderate in magnitude. Rib eye area was more closely related to fat-free lean at the first two slaughter weights. A single fat measurement was equal to or better than an average of three measurements of fat thickness for predictive purposes. Associations between fat measurements and total body fat generally increased in magnitude with increased slaughter weight. There was somewhat of a tendency for associations between carcass fat measurements and total body fat to be greater in magnitude for the Herefords compared to the crossbreds.

Introduction

The growth and development of animal tissues and the relationship between these tissues and certain traits has long been of interest to animal scientists. Most of the studies concerned with growth and development have either been related to age or have had nutritional restrictions imposed upon the animals.

Similarly, the majority of the studies dealing with the relationship of carcass traits to indices of carcass composition have involved the slaughter of animals at relatively constant weights. Therefore, little research has been reported concerning the patterns of these relationships with changes in weight. It is important to understand these associations because of the large divergence in slaughter weight among cattle used for beef.

The purpose of this research was to study changes and responses of certain carcass measurements and carcass composition to changes in weight of beef steers representing two beef types and slaughtered at 500, 700, 900 and 1100 pounds. Also, the relationship between certain carcass measurements and carcass composition were investigated to elucidate possible patterns among these cattle.

Materials and Methods

Forty-eight Hereford and 48 crossbred (Charolais x Angus or Charolais x Hereford) steers were randomly allotted to one of four slaughter weight groups (500, 700, 900 or 1100 pounds). These steers were placed on feed in the fall of 1972, 1973, and 1974, in three replications of 16 Herefords and 16 crossbreds with 4 steers of each breed type allotted to one of the pre-designated slaughter weight groups.

The experimental design, description of the animals and handling procedures up to slaughter are presented in the materials and methods section of Chapter IV.

Slaughter Procedures

Upon reaching the respective pre-designated slaughter weight, the steers were transported to the O.S.U. Meat Laboratory for slaughter. The steers were slaughtered and carcasses chilled (4° to 6°C) according to accepted research procedures (A.M.S.A., 1967). After chilling for 48 hours, the right sides were ribbed between the 12th and 13th ribs and acetate overlay tracings were made on the longissimus muscles. Rib eye area (REA, sq in) was determined from the acetate overlays using a compensating polar planimeter. A single fat (SFAT, in) and average fat (AVFAT, in) measures were recorded as previously discussed (Chapter IV, materials and methods).

Quality grades (15 = Prime^{+}, 14 = Prime^{0}, and 13 = Prime, etc.) were assigned according to federal standards (U.S.D.A., 1965) to those carcasses representing only the 900 and 1100 pound slaughter weight groups. Percent cutability (% boneless, closely trimmed retail cuts from round, loin, rib and chuck) was predicted using the equation developed by Murphy et al., 1960; Cutability = 52.56 - 4.95 (SFAT, in) - 1.06 (% KHP) + .682 (REA, sq in) - .008 (carcass wt., lbs). Percent kidney, heart and pelvic fat (% KHP) was not an estimate, but the actual percent internal fat as determined from carcass cut-out data.

Specific gravity (SG) of the right side of each carcass was measured by weighing the right fore and hind quarters in air and in water. The temperature of the water was maintained at approximately 4°C. Care was taken to remove all possible air pockets under the fascia or within crevices of the quarters. Under water weights were recorded to the nearest 5 grams. Specific gravity was calculated using the following formula: $SG = \frac{\text{Wt. in air (g)}}{\text{Wt. in air (g) - Wt. in water (g)}}$.

Wholesale cut breakdown procedures, physical separation of the carcass into closely trimmed lean (CTL), separable fat (SF) and bone (B), sampling and the determination of fat-free lean (FFL) and total body fat (TBFAT) has been previously described (Chapter IV , materials and methods).

Statistical Analyses

The data were analyzed using the computer program (SAS) developed by Barr and Goodnight (1972). All data were pooled over replication (year).

One Charolais crossbred steer was lost from the 1100 pound weight group in the first replication. In order for the data to be balanced and complete, all observed values for this missing steer were estimated by using the mean value, for those data considered, of the remaining 3 steers in that particular sub-cell of that replication. The estimated values were treated like normal data. However, the residual degrees of freedom in the analysis of variance were reduced by one.

Results and Discussion

Carcass Measurements

Means and standard errors for carcass measurements obtained on carcasses representing the respective breed types and slaughter weight groups are presented in table 25. The standard errors within weight groups for these carcass measurements were generally small, and reasonably consistent among weight groups. It should be pointed out that some of these steers were subjected to removal of feed and water for as long as 48 hours and up to as many as three times during the duration of this study. This procedure was necessary in order to study the relationship between live ^{40}K whole-body count and composition at the 4 pre-designated live weights before slaughter. Therefore, this should be kept in mind during the discussion of these data, especially with regard to the rate of changes in certain carcass characteristics over the four slaughter weights.

The analysis of variance for these data (table 26) indicated large effects for both breed type and weight group on all carcass measurements ($P<.01$), with the exception of percent kidney, heart and pelvic fat. Interactions were generally non-significant ($P>.10$), and where significance was detected the respective interaction only contributed a small proportion to the total sums of squares. The significant replication x breed type and replication x weight group interactions for certain of these data do suggest somewhat of a reversal with regard to breed type and weight group data patterns during the three replications. However, these were not considered to have a major impact on the interpretation of the data.

The change in these carcass traits generally followed rather consistent patterns as slaughter weight increased from 500 to 1100 pounds, regardless of breed type. Hot carcass weight did not differ significantly ($P>.15$) for the two breed types, but as expected significant differences between weight groups were observed ($P<.01$). Hot carcass weight increased by 124.3, 147.4 and 146.0 pounds and 115.8, 136.0 and 149.9 pounds on the average for the Herefords and crossbreds, respectively. A significant quadratic ($P<.01$) effect was found for hot

TABLE 25. MEANS AND STANDARD ERRORS[a] FOR CERTAIN CARCASS TRAITS AND MEASUREMENTS FOR HEREFORD (H) AND CROSSBRED (X) STEERS BY SLAUGHTER WEIGHT GROUPS

Trait	Breed type	Slaughter weight groups (lbs)							
		500		700		900		1100	
No. of steers		12		12		12		12	
Age in days[b]	H	309	(12)	374	(7)	478	(17)	561	(11)
	X	240	(8)	329	(15)	387	(5)	450	(12)
Hot carcass weight (lbs)	H	291.4	(5.58)	415.7	(3.77)	563.1	(6.70)	709.1	(5.94)
	X	307.1	(6.00)	422.9	(3.34)	558.9	(6.46)	708.8	(7.23)
Specific gravity	H	1.0718	(.0031)	1.0638	(.0035)	1.0505	(.0015)	1.0413	(.0015)
	X	1.0811	(.0019)	1.0678	(.0015)	1.0575	(.0015)	1.0500	(.0020)
Rib eye area (sq in)	H	7.13	(.225)	8.66	(.398)	10.02	(.312)	10.67	(.364)
	X	8.92	(.351)	10.04	(.342)	11.65	(.328)	12.58	(.543)
3/4 fat thickness (in)	H	.23	(.022)	.42	(.024)	.54	(.058)	.81	(.074)
	X	.13	(.034)	.16	(.020)	.33	(.029)	.50	(.050)
Average fat thickness (in)	H	.32	(.057)	.50	(.033)	.63	(.045)	.97	(.080)
	X	.22	(.039)	.30	(.019)	.49	(.036)	.73	(.062)
KHP[c] (lbs)	H	4.4	(.66)	8.6	(.99)	16.8	(1.03)	27.0	(1.58)
	X	5.6	(.38)	11.0	(.84)	21.0	(1.50)	26.4	(1.66)
KHP (%)	H	2.1	(.15)	2.5	(.14)	3.2	(.18)	3.9	(.20)
	X	1.9	(.13)	2.7	(.21)	3.8	(.25)	3.8	(.22)
Ether-extract (%)	H	6.76	(.182)	7.94	(.371)	10.48	(.370)	12.59	(.618)
	X	5.01	(.203)	7.32	(.445)	8.60	(.304)	10.00	(.399)
Cutability[d] (%)	H	51.8	(.32)	50.7	(.37)	49.3	(.57)	47.5	(.58)
	X	53.6	(.20)	52.5	(.30)	51.1	(.32)	49.9	(.60)
Quality[e]	H	...	...	...	...	10.0	(.24)	10.8	(.30)
	X	...	...	...	...	9.3	(.37)	9.9	(.16)

[a] Standard errors of the mean are in parenthesis.

[b] Mean days of age for crossbred only represent 8 animals per weight group obtained in replications I and II.

[c] Kidney, heart and pelvic fat.

[d] Calculated using Murphy's equation, Murphy _et al_. (1960).

[e] Prime^{+} = 15, Choice^{+} = 12, Good^{+} = 9, etc.

TABLE 26. ANALYSIS OF VARIANCE FOR CARCASS MEASUREMENT DATA FROM HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

Source	d.f.	Hot carcass (lbs)	Specific gravity	REA (sq in)	3/4 fat th. (in)	Average fat th. (in)	KHP (lbs)	KHP (%)	Ether extract (%)	Cutability (%)
Total	94									
Replication(R)	2	916.5**	.00011	3.80*	.061	.096	28.9**	2.0**	2.35	4.74
Breed type(BT)	1	570.4	.01291**	76.74**	1.138**	.695**	21.3**	.79	68.88**	92.77**
R x BT	2	1909.6**	.00016**	14.77**	.040	.078	11.6**	.59	.00	3.14
Weight group(WG)	3	755129.4**	.00430**	61.53**	1.010**	1.494**	564.8**	17.16**	133.41**	69.30**
R x WG	6	763.6**	.00013**	1.93	.009	.019	6.4	1.22**	4.52*	5.72
BT x WG	3	390.4	.00004	1.03	.048	.026	5.1	.92*	3.67	1.07
R x BT x WG	6	296.4	.00003	2.50*	.021	.031	5.6	.62	.74	2.02
Residual[a]	71	316.5	.00005	1.12	.021	.027	2.8	.30	1.68	1.86

[a] The residual d.f. were reduced by 1, because of missing data estimation for one sub-cell.

* $P < .05$.

** $P < .01$.

carcass weight; however, the proportion of the sums of squares associated with weight group accounted for by linear effects was in excess of 99 percent (table 27). The quadratic occurance can be attributed to the increased yield of carcass associated with increased fat deposition. The increase in carcass yield associated with the increase in slaughter weight is in agreement with data reported by Moulton et al. (1922); Callow (1944) and Dinkel et al. (1969).

Specific gravity tended to decrease as weight group increased, and the crossbreds consistently had higher specific gravities than the Herefords. This suggests higher lean to fat ratios among the crossbreds compared to their Hereford counterparts at each slaughter weight group. The decrease in specific gravity was essentially linear ($P<.01$) and 99.5 percent of the sum of squares associated with the weight group effects was accounted for by linearity (table 27). At similar slaughter weights the crossbreds had larger rib eye areas (1.67 sq in, on the average) and less external fat thickness, whether recorded as a single 3/4 measurement (.22 in, on the average) or as an average of three measurements (.17 in, on the average) than the Herefords. It was observed that a large proportion of the variation associated with weight group effects for these data were accounted for by linearity; 99.48, 97.60 and 96.69 for rib eye area, 3/4 fat measurement and average fat measurement, respectively. Although, change in external fat thickness was determined to be essentially linear there was a tendency for the rate of external fat deposition to increase during the latter slaughter weights. Similar increases in rib eye area and fat thickness measurement were noted for Hereford steers slaughtered at 800, 900, 1000 and 1100 pounds by Dinkel et al. (1969). However, Guenther et al. (1965) concluded that rib eye area was affected by changes in animal age and carcass weight, but appeared to increase in a curvilinear manner as the animal matured. These data were collected on 36 Hereford steers slaughtered at 520 (weaning), 705, 780, 867, 934 and 969 pounds (dependent on nutritional regime).

Kidney, heart and pelvic fat (pounds) increased as weight group increased. At the three lighter slaughter weights crossbred steers had heavier kidney, heart and pelvic fat than the respective Herefords

TABLE 27. PROPORTION OF WEIGHT GROUP SUM OF SQUARES ASSOCIATED WITH LINEAR, QUADRATIC AND CUBIC EFFECTS FOR HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

	Proportion of weight group SS		
Trait	Linear	Quadratic	Cubic
Hot carcass weight (lbs)	99.99**	.01**	...
Specific gravity	99.49**	.29	.23
Rib eye area (sq in)	99.48**	.28	.24
3/4 fat thickness (in)	97.60**	2.34	.06
Average fat thickness (in)	96.69**	3.00	.31
KHP[a] (lbs)	98.63**	.80**	.57*
KHP (%)	98.11**	.70	1.19
Ether-extract (%)	99.97**	.03	...
Cutability (%)	99.74**	.22	.04

[a] Kidney, heart and pelvic fat.

* $P < .05$.

** $P < .01$.

(5.6, 11.0 and 21.0 compared to 4.4, 8.6 and 16.8 pounds). However, at the 1100 pound slaughter weight Herefords were observed to have slightly heavier kidney, heart and pelvic fat weights. These data may reflect differences in the predisposition of fatty tissue at early weights for these two breed types. When kidney, heart and pelvic fat was expressed as a percent of hot carcass weight, breed type effects were found to be non-significant ($P > .10$). These data were observed to be rather inconsistent across the four weight groups and several significant interactions were noted (table 26).

Percent ether-extract of the closely trimmed lean ranged from 6.76 percent to 12.89 for the 500 and 1100 pound Herefords, and from 5.01 to 10.00 for the respective crossbreds. The change in percent in ether-extract was observed to be linear like ($P < .01$), with linearity accounting for 99.9 percent of the variation associated with weight groups. Waldman et al. (1971) reported a significant increase in total extractable lipids in Holstein steers slaughtered at birth and five other successive weights up to 1300 pounds. A plot of these data suggested a curvilinear response to increased ether-extract over this wide range in live weight.

A 1.95 percent difference in cutability, on the average, was noted across slaughter weight groups with the crossbred having the higher predicted percent boneless closely trimmed retail product ($P < .01$). As expected, with the occurrance of increased carcass weight and fat deposition, percent cutability decreased (Allen et al., 1968). The decrease was reasonably constant for each weight group change, and linear sum of squares accounted for 99.74 percent of the sum of squares associated with slaughter weight groups. Presented in table 54 of the Appendix are the partitioned sum of squares for the above traits.

Carcass Composition

Table 28 presents the mean values and standard errors for carcass composition data, expressed in pounds and as a percent of the hot carcass weight, for the respective breed types and slaughter weight groups. The within weight group standard errors for these data were generally small suggesting that the variation within weight groups was

TABLE 28. MEANS AND STANDARD ERRORS[a] FOR CARCASS COMPOSITION TRAITS FOR HEREFORD (H) AND CROSSBRED (X) STEERS BY SLAUGHTER WEIGHT GROUPS

Trait	Breed type	Slaughter weight groups (lbs)							
		500		700		900		1100	
No. of steers		12		12		12		12	
Age in days[b]	H	309	(12)	374	(7)	478	(17)	561	(11)
	X	240	(8)	329	(15)	387	(5)	450	(12)
Hot carcass weight (lbs)	H	291.4	(5.58)	415.7	(3.77)	563.1	(6.70)	709.1	(5.94)
	X	307.1	(6.00)	422.9	(3.34)	558.9	(6.46)	708.8	(7.23)
Specific gravity	H	1.0718	(.0031)	1.0638	(.0035)	1.0505	(.0015)	1.0413	(.0015)
	X	1.0811	(.0019)	1.0678	(.0015)	1.0575	(.0015)	1.0500	(.0020)
Rib eye area (sq in)	H	7.13	(.225)	8.66	(.398)	10.02	(.312)	10.67	(.364)
	X	8.92	(.351)	10.04	(.342)	11.65	(.328)	12.58	(.543)
3/4 fat thickness (in)	H	.23	(.022)	.42	(.024)	.54	(.058)	.81	(.074)
	X	.13	(.034)	.16	(.020)	.33	(.029)	.50	(.050)
Average fat thickness (in)	H	.32	(.057)	.50	(.033)	.63	(.045)	.97	(.080)
	X	.22	(.039)	.30	(.019)	.49	(.036)	.73	(.062)
KHP[c] (lbs)	H	4.4	(.66)	8.6	(.99)	16.8	(1.03)	27.0	(1.58)
	X	5.6	(.38)	11.0	(.84)	21.0	(1.50)	26.4	(1.66)
KHP (%)	H	2.1	(.15)	2.5	(.14)	3.2	(.18)	3.9	(.20)
	X	1.9	(.13)	2.7	(.21)	3.8	(.25)	3.8	(.22)
Ether-extract (%)	H	6.76	(.182)	7.94	(.371)	10.48	(.370)	12.59	(.618)
	X	5.01	(.203)	7.32	(.445)	8.60	(.304)	10.00	(.399)
Cutability[d] (%)	H	51.8	(.32)	50.7	(.37)	49.3	(.57)	47.5	(.58)
	X	53.6	(.20)	52.5	(.30)	51.1	(.32)	49.9	(.60)
Quality[e]	H	...	...	...	...	10.0	(.24)	10.8	(.30)
	X	...	...	...	...	9.3	(.37)	9.9	(.16)

[a] Standard errors of the mean are in parenthesis.

[b] Mean days of age for crossbred only represent 8 animals per weight group obtained in replications I and II.

[c] Kidney, heart and pelvic fat.

[d] Calculated using Murphy's equation, Murphy *et al*. (1960).

[e] Prime+ = 15, Choice+ = 12, Good+ = 9, etc.

at a minimum. It can be concluded from table 28 that at similar slaughter weights the crossbreds were considerably leaner, possessed less fat and had a higher proportion of bone than the Herefords. It can be seen from the percent carcass composition data that as slaughter weight increased the proportion of the hot carcass associated with estimates of leanness and bone decreased and those associated with fatness increased rather dramatically. These data are in agreement with reports by Tulloh (1964), Guenther et al. (1965), Dinkel et al. (1969), and Waldman et al. (1971) involving the serial slaughter of beef at different weights or ages, similar to those determined for this study.

The analysis of variance for these composition data are presented in table 29. Highly significant breed and weight group effects were observed for all traits considered. It was interesting to note that the change in these traits as slaughter weight increased follow rather consistent patterns. This is evidenced by the few significant two way and three way interactions.

The relationships between pounds of fat-free lean, total body fat and bone on a weight basis are presented graphically in figure 8. The respective changes in these tissues for each successive slaughter weight change are presented in table 30 by breed type. It is evident that the increase in pounds of fat-free lean is reasonably constant across the four slaughter weight groups and follows similar classical trends that have been noted for separable lean (Hedrick, 1967). A change in pounds of fat-free lean of 48.3, 53.4 and 36.7 pounds and 46.5, 50.0 and 53.6 pounds was observed for the Herefords and crossbreds, respectively as slaughter weight increased from 500 to 700, 700 to 900, and 900 to 1100 pounds. Although the change in weights of fat-free lean was determined to be rather linear ($P<.01$), and linearity accounted for greater than 99.9 percent of the sum of squares associated with weight groups (table 31), there was a tendency for the Hereford steers to increase in pounds of fat-free lean at a decreasing rate as slaughter weight increased. This suggested that by 900 pounds the Herefords had deposited a considerable portion of their fat-free lean and rate of deposition had started to diminish. Whereas, for the crossbreds the largest increase in fat-free lean was noted as slaughter weight changed from 900 to 1100 pounds.

TABLE 29. ANALYSIS OF VARIANCE FOR CARCASS COMPOSITION DATA FROM HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700 900 AND 1100 POUNDS

		Mean square									
Source	d.f.	Closely tr. lean(lbs)	Closely tr. lean (%)	Separable fat(lbs)	Separable fat (%)	Bone (lbs)	Bone (%)	Fat-free lean(lbs)	Fat-free lean (%)	Total body fat(lbs)	Total body fat (%)
Total	94	...	...	...	...	...	...	...	...	...	...
Rep. (R)	2	103.2	.0015	20.1	.0004	1.2	.0002	22.67	.0017	144.7	.0022
Breed type(BT)	1	4046.9**	.0497**	4009.3	.0714**	100.4**	.0007**	20208.1**	.0684	4288.0**	.0762**
R x BT	2	200.3**	.0001	85.9	.0005	4.0	.0005*	530.5	.0002	188.6	.0010
Weight group(WG)	3	33824.7**	.0708**	33960.3**	.1280**	1236.8**	.0121**	93918.8**	.0950**	57589.1	.2008**
R x WG	6	108.2	.0025	190.6	.0027	5.0	.0003	617.0	.0034	293.3*	.0038
BT x WG	3	21.5	.0003	134.2	.0002	3.0	.0001	323.1	.0003	224.3*	.0003
R x BT x WG	6	66.3	.0010	34.4	.0008	6.7	.0002	278.3	.0011	77.1	.0012
Residual[a]	71	56.1	.0006	54.3	.0006	5.3	.00010	243.1	.0007	82.8	.0008

[a] The residual d.f. was reduced by 1, because of missing data estimation for one sub-cell.

* P $<$ .05.

** P $<$ .01.

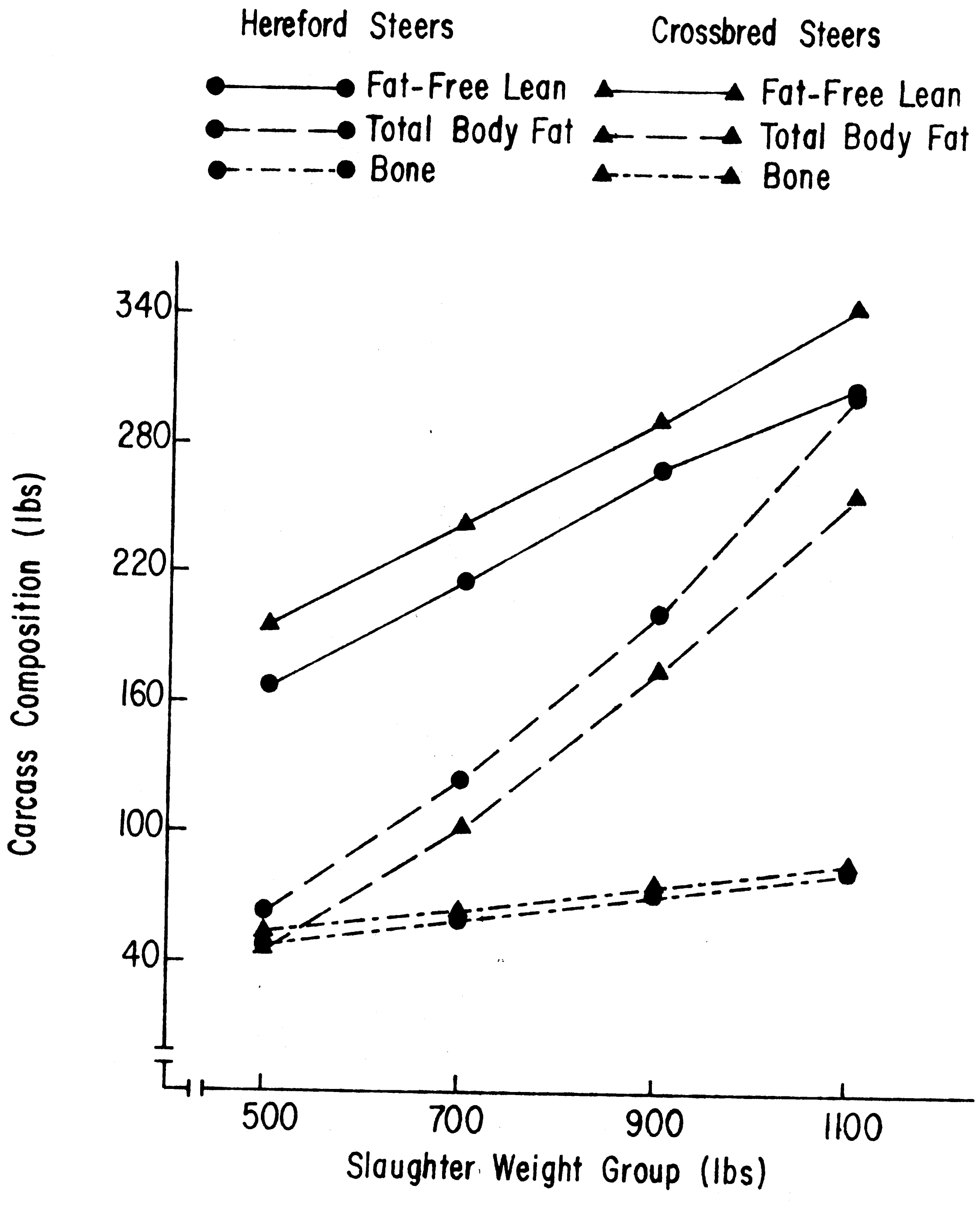

Figure 8. Mean pounds fat-free lean, total body fat and bone for Hereford and Crossbred steers slaughtered at four different weights

TABLE 30. CHANGES IN CARCASS COMPOSITION FOR EACH 200 POUND CHANGE IN SLAUGHTER WEIGHT

Item	Breed[a] type	Slaughter weight group (lbs)		
		500 to 700	700 to 900	900 to 1100
Closely trimmed	H	54.8	66.3	49.3
lean (lbs)	X	55.2	61.0	58.0
Separable	H	51.4	56.4	78.6
fat (lbs)	X	42.2	54.0	65.7
Bone (lbs)	H	9.5	11.8	10.2
	X	8.8	14.1	11.0
Fat-free	H	48.3	53.4	36.7
lean (lbs)	X	46.5	50.0	53.6
Total body	H	61.8	78.0	100.0
fat (lbs)	X	56.4	72.6	83.4

[a] Herefords = H, Crossbreds = X.

TABLE 31. PROPORTION OF WEIGHT GROUP SUM OF SQUARES ASSOCIATED WITH LINEAR, QUADRATIC AND CUBIC EFFECTS FOR HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

	Proportion of weight group SS		
	Linear	Quadratic	Cubic
Closely trimmed lean (lbs)	99.90**	...	.10
Closely trimmed lean (%)	99.24**	.39	.37
Separable fat (lbs)	98.99**	1.00**	.03
Separable fat (%)	98.72**	.99**	.27
Bone (lbs)	99.62**	.08	.30
Bone (%)	95.81**	3.54**	.65
Fat-free lean (lbs)	99.94**	.06	...
Fat-free lean (%)	99.20**	.74**	.06
Total body fat (lbs)	99.05**	.95**	...
Total body fat (%)	99.03**	.92*	.08

* $P < .05$.

** $P < .01$.

Total body fat (pounds) was observed to increase at an increasing rate as slaughter weight changed from 500 to 1100 pounds, irrespective of breed type. However, this increase was markedly greater in the Herefords than in the crossbreds. Although, 99 percent of the sum of squares for weight group effects was attributed to linear effects a significant quadratic ($P<.01$) was observed for these data (table 31). The quadratic effect appears to be more pronounced for the Herefords than the crossbreds. This suggests that not only were the Herefords considerably fatter than the crossbreds at heavier weights, but the rate of fat deposition increased during the latter slaughter weights. These data support the classic conclusions of Palsson (1955) that fat is the latest maturing of the major carcass tissues.

Bone weight increased at a rather constant rate as slaughter weight increased. Increases of 9.5, 11.8 and 10.2 pounds and 8.8, 14.1 and 11.0 pounds for Herefords and crossbreds, respectively were observed as slaughter weight increased. The rate of increase for bone was the lowest of the three tissues studied.

When composition data were expressed as a percent of hot carcass weight, indices of leanness decreased, proportion of fat increased and bone decreased as slaughter weight increased from 500 to 700, 700 to 900 and 900 to 1100 pounds, respectively (figure 9). These data follow the classical growth patterns as described by Berg and Butterfield (1968). That proportion of the slaughter weight effects attributable to linear, quadratic and cubic effects for these traits are presented in table 31. The change in percent composition between the successive weight groups are presented in table 32.

Percent fat-free lean decreased at a reasonably constant rate, however, a significant ($P<.01$) quadratic was detected for change in percent fat-free lean associated with change in weight. Linearity accounted for 99.20 percent of the change, whereas quadratic accounted for less than 1 percent of the sum of squares associated with weight groups. It was observed that the crossbreds decreased in percent fat-free lean at a more marked rate, from 500 to 700 pounds (decrease of 6.5 and 5.6 percent, respectively) and at a slower rate from 900 to 1100 pounds (decrease of 3.5 and 4.7 percent, respectively) than the

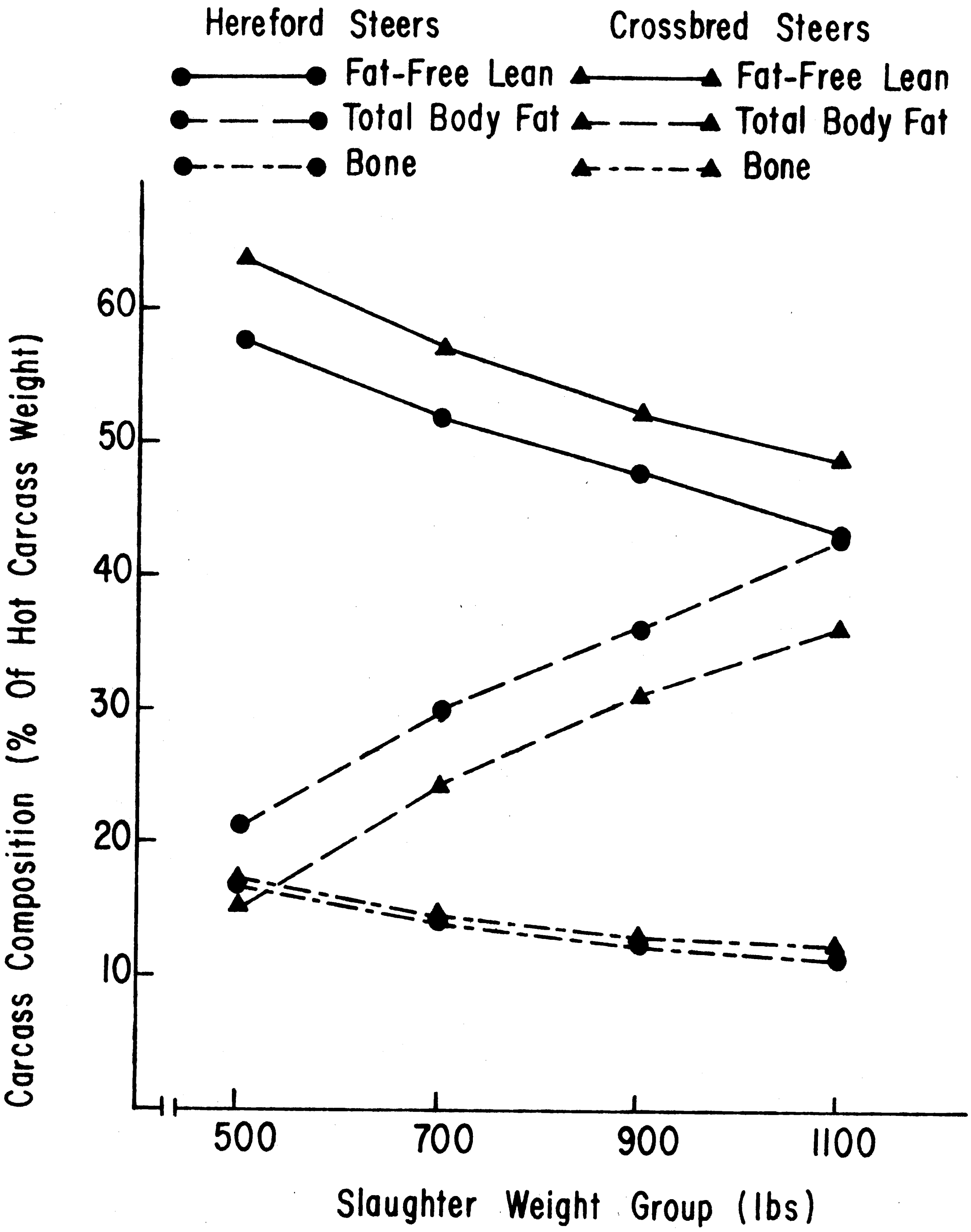

Figure 9.. Mean pounds of fat-free lean, total body fat and bone, expressed as a percent of hot carcass weight, for Hereford and Crossbred steers slaughtered at four different weights

TABLE 32. CHANGES IN PERCENT CARCASS COMPOSITION FOR EACH 200 POUND CHANGE IN SLAUGHTER WEIGHT

Item	Breed[a] type	Slaughter weight group (lbs)		
		500 to 700	700 to 900	900 to 1100
Closely trimmed	H	-5.4	-2.6	-4.4
lean (%)	X	-5.3	-4.2	-3.8
Separable	H	7.7	4.1	5.3
fat (%)	X	7.2	5.2	4.6
Bone (%)	H	-2.9	-1.5	-1.2
	X	-2.6	-1.1	-1.2
Fat-free	H	-5.6	-5.1	-4.7
lean (%)	X	-6.5	-5.0	-3.5
Total body	H	8.7	7.2	6.6
fat (%)	X	9.2	6.9	5.1

[a] Herefords = H, Crossbreds = X.

Herefords. From 700 to 900 pounds the decrease in percent fat-free lean for the two respective breed types was approximately the same.

A significant ($P<.05$) quadratic effect was also observed for the increase in percent total body fat as slaughter weight increased. An inflection in the response curve was apparent as slaughter weight increased from 700 to 900 pounds and this observation was consistent between the two breed types. As the steers increased in weight from 700 to 1100 pounds it appeared that the Herefords were depositing fat at a faster rate than the crossbreds, and therefore a larger change in percent total body fat occurred throughout this range in weight. However, from 500 to 700 pounds an increase of 9.2 percent fat was noted for the crossbreds compared to an 8.7 percent increase for the Herefords. Presented in table 55 of the Appendix are the partitioned sum of squares attributed to linear, quadratic and cubic effects for these composition components.

Percent bone decreased throughout the successive increases in slaughter weight. The decrease from 500 to 700 pounds was essentially the same for the Herefords and crossbreds (decrease of 2.9 and 2.6, respectively). However, from 700 to 900 and 900 to 1100 pounds the percent bone for the Herefords decreased at a faster rate than the percent bone for the crossbreds. This most likely reflects the more rapid increase in fat deposition.

These data suggest that the basic growth patterns for fat-free lean, total body fat and bone follow reasonably similar response curves for these two breed types. Furthermore, it supports the basic growth concepts that bone increases as weight increases but at a lesser rate than either fat or lean, and that fat is the last major tissue to develop and is deposited at an increasing rate with increasing weight. However, these data do not imply the dramatic inflection in fat deposition with increasing weight presented in reports by Berg and Butterfield (1968) and Waldman et al. (1971).

Relationship between Carcass Measurements and Composition on a Weight Basis

The correlation coefficients between certain carcass measurements and carcass composition (fat-free lean, total body fat and bone) are presented by breed type in tables 33, 34, 35 and 36 for the 500, 700, 900 and 1100 pound slaughter weight groups, respectively. It is well established in the literature that there are real associations between these carcass measurements (hot carcass weight, specific gravity, 3/4 fat thickness, average fat thickness and % kidney, heart and pelvic fat) and separable carcass components. However, little data reporting the association of these variables to fat-free lean and total body fat are available.

Because of the small number per breed type and slaughter weight group of major concern in this study was the consistencies or inconsistencies in association patterns between breed types and among the variables considered. It should be emphasized that because of the small number of observations per slaughter weight group, discrepancies in patterns and magnitude of association may be attributable to one "extreme" animal in a particular slaughter weight group.

Because slaughter weight was controlled the associations between hot carcass weight and composition were only moderate in strength but generally had a positive association with carcass composition. The correlations between hot carcass weight and fat-free lean ranged from .212 to .697 for the Herefords and from -.242 to .882 for the crossbreds. The larger correlations were generally associated with groups having the most variation in slaughter weight. For total body fat and bone associations ranging from .178 to .750 and -.556 to .211, respectively with respect to the Hereford steers and from .118 to .862 and -.748 to .421, respectively for the crossbred steers. Stronger associations between hot carcass weight and total body fat were observed for the heavier two slaughter weights than the lighter two.

Several researchers have found carcass weight to be positively correlated with, and even the best predictor of separable muscle, fat and bone of the carcass (Cole _et al._, 1960a; Cole _et al._, 1962; Allen _et al._, 1968; Berg and Bunnage, 1968). However, these data generally

TABLE 33. CORRELATIONS BETWEEN CERTAIN CARCASS MEASUREMENTS AND CARCASS COMPOSITION, 500 POUND SLAUGHTER WEIGHT GROUP[a]

Item	Herefords			Crossbreds		
	Fat-free lean(lbs)	Total body fat(lbs)	Total bone(lbs)	Fat-free lean(lbs)	Total body fat(lbs)	Total bone(lbs)
Hot carcass weight (lbs)	.435	.341	.158	.882[a]	.114	.421
Specific gravity	.419	-.341	.508	.027	-.112	-.006
Rib eye area (sq in)	.701*	-.838*	.512	.743*	-.067	.266
3/4 fat thickness (in)	-.682*	.922**	-.658**	.451	.061	-.267
Average fat thickness (in)	-.376	.468	-.478	.288	-.269	.033
Kidney, heart and pelvic fat (%)	-.276	-.127	-.000	-.552	.109	-.485

[a] 12 observations per weight group, d.f. = 9.

* $P < .05$.

** $P < .01$.

TABLE 34. CORRELATIONS BETWEEN CERTAIN CARCASS MEASUREMENTS AND CARCASS COMPOSITION, 700 POUND SLAUGHTER WEIGHT GROUP[a]

Item	Herefords Fat-free lean (lbs)	Herefords Total body fat (lbs)	Herefords Total bone (lbs)	Crossbreds Fat-free lean (lbs)	Crossbreds Total body fat (lbs)	Crossbreds Total bone (lbs)
Hot carcass weight (lbs)	.697*	.178	-.556	.584	.288	.159
Specific gravity	-.075	-.324	-.216	-.164	-.443	.225
Rib eye area (sq in)	.774**	-.629*	-.590	.827**	-.173	.063
3/4 fat thickness (in)	-.353	.752**	.421	.122	.479	-.247
Average fat thickness (in)	-.381	.774**	.339	-.347	.573	-.079
Kidney, heart and pelvic fat (%)	.424	.206	-.295	-.158	.227	-.538

[a] 12 observations per weight group, d.f. = 9.

* $P < .05$.

** $P < .01$.

TABLE 35. CORRELATIONS BETWEEN CERTAIN CARCASS MEASUREMENTS AND CARCASS COMPOSITION, 900 POUND SLAUGHTER WEIGHT GROUP[a]

	Herefords			Crossbreds		
Item	Fat-free lean(lbs)	Total body fat(lbs)	Total bone(lbs)	Fat-free lean(lbs)	Total body fat(lbs)	Total bone(lbs)
Hot carcass weight (lbs)	.563	.750**	.138	.354	.446	-.047
Specific gravity	.067	-.775**	.594	.590	-.857**	.174
Rib eye area (sq in)	.245	-.243	-.352	.385	-.085	-.155
3/4 fat thickness (in)	-.246	.800**	-.393	-.519	.465	-.854**
Average fat thickness (in)	-.167	.692*	-.183	.112	.214	-.698*
Kidney, heart and pelvic fat (%)	-.192	.703*	-.450	-.395	.403	-.028

[a] 12 observations per group, d.f. = 9.

* P< .05.

** P< .01.

TABLE 36. CORRELATIONS BETWEEN CERTAIN CARCASS MEASUREMENTS AND CARCASS COMPOSITION, 1100 POUND SLAUGHTER WEIGHT GROUP[a]

Item	Herefords			Crossbreds		
	Fat-free lean(lbs)	Total body fat(lbs)	Total bone(lbs)	Fat-free lean(lbs)	Total body fat(lbs)	Total bone(lbs)
Hot carcass weight (lbs)	.212	.469	.211	-.242	.862**	-.748**
Specific gravity	.694*	-.591	.424	-.092	-.432	.651*
Rib eye area (sq in)	.232	-.094	-.260	.281	-.416	-.035
3/4 fat thickness (in)	-.409	.442	-.167	-.183	.686*	-.527
Average fat thickness (in)	-.266	.439	-.123	-.104	.825**	-.689*
Kidney, heart and pelvic fat (%)	-.449	.763**	-.187	-.116	.596	-.542

[a] 12 observations per group, d.f. = 9.

* $P < .05$.

** $P < .01$.

were obtained from studies with a wide divergence in weight. Low correlations between carcass weight and composition were reported by Henderson et al. (1966) when there was little variation in slaughter weights of the cattle studied.

Specific gravity was negatively related to total body fat and it was observed that the associations were considerably lower in magnitude for cattle slaughtered at 500 and 700 pounds than at 900 and 1100 pounds. Associations between specific gravity and total body fat for the Herefords and crossbreds at 500 and 700 pounds, respectively were -.341 and -.112, and -.324 and -.443. Correlations of -.775 ($P<.01$) and -.857 ($P<.01$) were determined for specific gravity and total body fat for the Hereford and crossbred steers slaughtered at 900 pounds. However, associations less in magnitude than obtained at 900 pounds, but generally stronger than observed at 700 and 500 pounds slaughter weights were found for the 1100 pound Herefords and crossbreds (-.591 and -.432, respectively).

The weak association between light weight cattle composition and specific gravity is in agreement with data presented by Cole et al. (1960b); Wedgwood (1960); Kelly et al. (1968) and Waldman et al. (1969). These workers concluded that specific gravity was of little or no use in the estimation of body composition of carcasses from young animals or where the carcass fat content was low. However, numerous literature reporting strong associations between composition and specific gravity of cattle in latter stages of growth and development are available (Guenther et al., 1967; Kelly et al., 1968; Powell and Huffman, 1973; Garrett and Hinman, 1969; Preston et al., 1974; Clark et al., 1976).

The associations between specific gravity and fat-free lean and bone were rather erratic in direction and inconsistent in strength among slaughter weight groups as well as between breed types.

A reasonably strong association was noted between rib eye area and fat-free lean of cattle slaughtered at 500 and 700 pounds. Positive correlations of .701 ($P<.01$) and .743 ($P<.01$) were found for the 500 pound Herefords and crossbred, respectively. Similarly, positive correlations of .774 ($P<.01$) and .827 ($P<.01$) were observed between rib eye area and fat-free lean for Herefords and crossbred steers representing the 700 slaughter weight group. However, at the heavier two slaughter weight groups, a rather dramatic drop in the association of these two variables was noted, although the association remained positive. The strongest correlation at these weights was observed for the 900 pound crossbred steers (.385) and the weakest correlation was observed for the 1100 pound Hereford steers (.232). The relationship between rib eye and measures of total muscle reported in the literature have generally been positive but the magnitude has varied considerably.

The association between rib eye area and total body fat and bone appeared to be somewhat more erratic in magnitude than observed for fat-free lean. Rib eye area had a consistent negative relationship with total body fat, and Hereford steers tended to show a stronger association between these two variables than the crossbred steers. Cole _et al_. (1960a) indicated that there was little relationship between rib eye area and separable fat.

Fat thickness has generally been accepted as a reasonably good indicator of the proportion of fat associated with the carcass. Henderson _et al_. (1966) stated that within narrow weight ranges fat thickness was the best single estimator of muscle or fat. This is in agreement with data reported by Hedrick _et al_. (1965) and Allen _et al_. (1968). For the data obtained in the present study, based on small numbers per weight group, consistent negative associations between 3/4 measurement and fat-free lean were observed for the Herefords but not for the light weight (500 and 700 pound) crossbreds.

Positive and relatively strong associations between 3/4 fat thickness and total body fat were observed for the Herefords. Correlations of .923 ($P<.01$), .752 ($P<.01$), .800 ($P<.01$) and .442 were determined for the 500, 700, 900 and 1100 pound slaughter weight groups, respectively. The low 1100 pound slaughter weight correlation can be attributed to a lack of variation in total body fat (8.2% of the mean) among these steers. The strongest association between 3/4 fat thickness and total body fat with regard to the crossbreds was observed to occur at the 1100 pound slaughter weight (.625, $P<.01$). These cattle were noted to have the greatest variation in total body fat (12.7% of the mean). The associations between 3/4 fat thickness and bone was erratic but tended to be negative.

The association between average fat thickness and carcass composition followed similar trends as observed for 3/4 fat thickness. Average fat thickness tended to be somewhat more strongly related to total body fat of the crossbreds than was 3/4 fat thickness. This could possibly reflect differences in fat deposition and distribution patterns between these two different breed types.

A single fat thickness measurement has been reported to be more highly correlated with composition than an average of three measurements (Cole et al., 1962; Ramsey et al., 1962; Abraham et al., 1968). However, Brackelsberg and Willham (1968) reported no differences in the predictive value of a single measurement than that of an average measurement.

Percent kidney, heart and pelvic fat was in general negatively associated with fat-free lean, with the exception of the 700 pound Herefords (.424). As expected the relationships between percent kidney, heart and pelvic fat and total body fat were for the most part positive, and as slaughter weight progressed the associations between these two variables appeared to increase in magnitude. It was also noted that the Herefords generally had stronger associations between these variables than the crossbreds.

It is apparent from these data that few strong associations among carcass measurements and carcass composition were established. However, these data did provide associations, among slaughter weight groups, consistent in direction as reported in the literature, although a reliable estimate as to the magnitude of these associations were unattainable. It was interesting to note that rib eye area was more strongly related to fat-free lean at the lighter two slaughter weights and measures of fat were more strongly related to total body fat at the heavier two slaughter weights. Also associations between fat measures and total body fat were generally stronger and more consistent for the Herefords than the crossbreds. This could reflect an alteration in the fat deposition pattern or possibly be related to the proportion of fat deposited at a given slaughter weight. However, with these limited numbers no firm conclusion can be drawn.

Relationship between Carcass Measurements and Composition on a Percent Basis

Tables 37, 38, 39 and 40 contain correlation coefficients for the association between carcass measurement and fat-free, total body fat and bone expressed as a percent of hot carcass weight. Again, because of the limited numbers it will be of greater interest to observe patterns of association between these variables as weight groups increased than to be concerned about the level of significance. Correlations between carcass measurements other than weight have generally been more closely related to percent separable muscle and fat than to weights of these components (Cole et al., 1962; Brungradt and Bray, 1963; Henderson et al., 1965; Abraham et al., 1968; Allen et al., 1968).

Expressing composition as a ratio of hot carcass weight is a common method used to reduce the effects of weight and, therefore, low associations were expected. However, the only consistent trend among hot carcass weight and these indices of percent carcass composition were the negative correlations between this variable and percent bone.

The association between specific gravity and percent total body fat followed similar trends to that of the association of this variable on a weight basis; that is, a stronger association was evident at the heavier slaughter weights (-.405 to -.808) when a higher proportion of the carcass was made up of fatty tissue than at the lighter slaughter weights (-.060 to -.361) regardless of breed type. This was especially noticeable at the 900 pound slaughter weight where correlations ($P < .01$) of -.733 and -.808 were observed for the Herefords and crossbreds, respectively. Correlations between specific gravity and fat-free lean were also greater in magnitude for the heavier weight slaughter groups, but generally less than that observed for specific gravity and total body fat. Furthermore, there was a tendency for this association to be stronger for the Herefords compared to the crossbreds.

When specific gravity was related to percent bone, correlations ranged from -.031 to .670 and no pattern in this association was observed. Similar inconsistencies were noted between other carcass measurements and percent bone. These correlations varied considerably in magnitude and were generally smaller than associations between other

TABLE 37. CORRELATIONS BETWEEN CERTAIN CARCASS MEASUREMENTS AND PERCENT CARCASS COMPOSITION, 500 POUND SLAUGHTER WEIGHT GROUP[a]

Item	Herefords			Crossbreds		
	Fat-free lean (%)	Total body fat (%)	Total bone (%)	Fat-free lean (%)	Total body fat (%)	Total bone (%)
Hot carcass weight (lbs)	-.194	.229	-.245	.350	-.337	-.449
Specific gravity	.482	-.361	.540	.045	-.060	.070
Rib eye area (sq in)	.797**	-.839**	.552	.479	-.395	-.381
3/4 fat thickness (in)	-.861**	.924**	-.698*	.248	-.135	-.661*
Average fat thickness (in)	-.455	.491	-.434	.370	-.361	-.188
Kidney, heart and pelvic fat (%)	-.096	-.099	.189	-.245	.335	.037

[a] 12 observations per group, d.f. = 9.

* $P < .05$.

** $P < .01$.

TABLE 38. CORRELATIONS BETWEEN CERTAIN CARCASS MEASUREMENTS AND PERCENT CARCASS COMPOSITION, 700 POUND SLAUGHTER WEIGHT GROUP[a]

	Herefords			Crossbreds		
Item	Fat-free lean (%)	Total body fat (%)	Total bone (%)	Fat-free lean (%)	Total body fat (%)	Total bone (%)
Hot carcass weight	.384	-.148	-.780**	.106	.003	-.325
Specific gravity	.213	-.244	-.076	.093	-.344	.427
Rib eye area (sq in)	.790**	-.764**	-.577	.589	-.387	-.293
3/4 fat thickness (in)	-.554	.693*	.246	-.188	.336	-.492
Average fat thickness (in)	-.512	.742**	.208	-.528	.512	-.187
Kidney, heart and pelvic fat (%)	-.375	.092	-.330	-.066	.281	-.444

[a] 12 observations per group, d.f. = 9.

* $P < .05$.

** $P < .01$.

TABLE 39. CORRELATIONS BETWEEN CERTAIN CARCASS MEASUREMENTS AND PERCENT CARCASS COMPOSITION, 900 POUND SLAUGHTER WEIGHT GROUP[a]

Item	Herefords			Crossbreds		
	Fat-free lean (%)	Total body fat (%)	Total bone (%)	Fat-free lean (%)	Total body fat (%)	Total bone (%)
Hot carcass weight (lbs)	-.339	.418	-.463	-.283	.070	-.525
Specific gravity	.581	-.733*	.834**	.783**	-.808**	.298
Rib eye area (sq in)	.449	-.232	-.221	.322	-.138	-.187
3/4 fat thickness (in)	-.704*	.818**	-.589	-.494	.595	-.697*
Average fat thickness (in)	-.558	.691*	-.368	-.111	.129	-.780**
Kidney, heart and pelvic fat (%)	-.594	.725*	-.621	-.415	.428	-.036

[a] 12 observations per group, d.f. = 9.

* $P < .05$.

** $P < .01$.

TABLE 40. CORRELATIONS BETWEEN CERTAIN CARCASS MEASUREMENTS AND PERCENT CARCASS COMPOSITION, 1100 POUND SLAUGHTER WEIGHT GROUP[a]

	Herefords			Crossbreds		
Item	Fat-free lean (%)	Total body fat (%)	Total bone (%)	Fat-free lean (%)	Total body fat (%)	Total bone (%)
Hot carcass weight (lbs)	-.300	.192	-.092	-.565	.812**	-.875**
Specific gravity	.651*	-.690*	.424	.089	-.405	.655*
Rib eye area (sq in)	.095	-.206	-.344	.255	-.490	.034
3/4 fat thickness (in)	-.594	.335	-.318	-.452	.628	-.664*
Average fat thickness (in)	-.535	.282	-.320	-.400	.788**	-.808**
Kidney, heart and pelvic fat (%)	-.649*	.697*	-.341	-.310	.604	-.594

[a] 12 observations per group, d.f. = 9.

* $P < .05$.

** $P < .01$.

carcass measurements and percent fat-free and total body fat. Because of the lack of pattern developments for either slaughter weight groups or breed types, further association between carcass measurements and percent bone will not be discussed.

As was the case for the relationship between rib eye area and pounds of fat-free lean, the associations between rib eye area and fat-free lean were observed to decrease with increasing slaughter weights. Correlations of .797 ($P<.01$) and .479, and .790 ($P<.01$) and .589, and .449 and .322, and .095 and .225 were found for Hereford and crossbred steers slaughtered at 500, 700, 900 and 1100 pounds, respectively. A consistent negative associations between rib eye area and total body fat was observed, but the magnitude of the associations between the two respective breed types varied considerably (from -.138 to -.839).

With the exception of the 500 pound crossbreds, positive associations between both 3/4 fat thickness and average fat thickness were found. The associations between these two variables for the 500, 700, 900 and 1100 pound Herefords were .924 ($P<.01$), .693 ($P<.01$), .818 ($P<.01$) and .335, respectively. The crossbreds generally had weaker associations at similar weight groups, but the strength of these associations did increase considerably at the two heavier weights (.595 and .628, respectively). These data suggested the possibility that for trim, lean and later maturing cattle (less than 24% fat) a weaker association between linear measures of fatness and percent total body fat. However, for early maturing cattle having greater than 25 percent fat considerably stronger associations were apparent.

When percent kidney, heart and pelvic fat was related to percent composition, negative associations with regard to percent fat-free lean and positive associations with regard to total body fat were generally noted. No consistent breed type pattern was observed, but there was a tendency for the magnitude of these associations to increase with increases in slaughter weight.

These data substantiate the positive association between rib eye area and indicators of muscling (fat-free lean). It was also observed that stronger associations between rib eye and fat-free lean were found when fat-free lean was expressed on a weight basis rather than as a percent of hot carcass weight. Correlations between specific gravity and total body fat were considerably larger for steers slaughtered at 900 and 1100 pounds, but about equally predictive of total body fat whether expressed on a weight basis or as a percent of hot carcass weight. Fat thickness measurements were also somewhat more strongly associated with total body fat than fat-free lean. It was observed that these associations were generally stronger for the Herefords than the crossbreds. However, this association did tend to strengthen as slaughter increased with respect to the crossbreds.

Pooled within slaughter weight group correlations between these carcass measurements and carcass composition expressed on a weight basis and as a percent of hot carcass weight are present in tables 56 and 57, respectively in the Appendix.

CHAPTER VI

GROWTH PATTERNS OF CERTAIN BOVINE MUSCLES AND MUSCLE GROUPS ASSOCIATED WITH INCREASING SLAUGHTER WEIGHT, AND THE RELATIONSHIP OF THESE MUSCLES TO CARCASS CLOSELY TRIMMED LEAN

Summary

Twenty-four Hereford and 24 crossbred steers were used in this study to determine relative growth patterns of nine individual muscles and muscle groups excised from steers slaughtered at 500, 700, 900 and 1100 pounds. Associations between these muscles and carcass closely trimmed lean were also investigated. Individual muscle weights were observed to differ considerably among slaughter weight groups. Analysis of variance revealed significant breed type effects for carcass closely trimmed lean and individual muscles with the exception of the *trapezius* and *rectus abdominus* muscles. As expected, highly significant ($P<.01$) weight group effects were noted, irrespective of breed type. The relative changes in the mean weights of carcass closely trimmed lean and individual muscles as slaughter weight increased were determined to be essentially linear ($P<.01$). However, considerable variation in these changes were apparent. Maximum increases in muscle weights occurred during the 700 to 900 pound growth phase with respect to the crossbreds, whereas the greatest change in muscle weights for Hereford steers were noted during the 500 to 700 pound growth phase. Different growth rates were observed for these muscles with successive changes in slaughter

weights. Generally, those muscles or muscle groups making up a greater proportion of the total muscle were observed to have faster growth rates than the lighter muscles.

Pooled within weight group correlation were for the most part non-significant ($P > .10$). However, highly significant ($P < .01$) association between the longissimus muscle (.681) and the biceps femoris (.698) and carcass closely trimmed lean were observed for the crossbreds and Herefords, respectively. Also, a highly significant ($P < .01$) association (.667) between the semitendinous muscle and carcass closely trimmed lean was noted for the crossbred steers. Highly significant associations ranging in magnitude from .716 to .957 and from .770 to .932 were observed for the Hereford and crossbred steers, respectively when correlated across slaughter weight groups.

Introduction

Considerable research has been reported concerning the relationships of wholesale cuts or joints and closely trimmed cuts to total separable lean and other indicators of carcass leanness. However, with the advances in processing and merchandising of boneless meat as well as the variation of intermuscular fat in wholesale cuts there is a need to study the relationship between individual muscles and total carcass lean.

To date most of the research reported concerning the relationship of various individual muscles (bovine) to total carcass lean has involved sample populations very heterogenious in nature (Butterfield, 1962) or developed from sampled populations of which inferences of practical value were questionable (Orme et al., 1960).

The purpose of this research was to characterize relative growth patterns of certain individual muscles excised from beef steers representing two breed types and four different slaughter weight groups. Furthermore, the relationship between these individual muscles and carcass closely trimmed lean was studied.

Materials and Methods

Twenty-four Herefords and 24 crossbred steers representing slaughter weight groups of 500, 700, 900 and 1100 pounds were used for this study. These steers represented one steer of each breed type and slaughter weight group from replications I and II and all the steers from replication III (Chapter IV, materials and methods).

The experimental design, description of the animals and handling procedures up to slaughter are presented in the materials and methods of Chapter IV. Likewise a detailed description of the carcass handling procedures was presented in Chapter V (materials and methods).

Individual Muscle Excision

Upon whole cut breakdown (Chapter IV, materials and methods) certain individual muscles were excised from the wholesale cuts of the right carcass halves and care was taken to locate the origin and insertion of those muscles where this was feasible. The muscles excised in entirety were the trapezius (chuck and rib portion), supra spinatus (chuck), psoas major (loin), rectus abdominus (thin cuts, flank), biceps femoris (round) and semitendinosus (round). Those muscles excised in part or as muscle groups were the longissimus muscle (rib section, 6th to 12th thoracic vertebrae), semimembranosus and adductor (round) and quadraceps complex (round, and a small cap portion from the sirloin end of the loin). The quadraceps contained the vastus lateralis, vastus intermedius, vastus medialis and rectus femoris muscles. Each muscle was trimmed of excess fat and weighed to the nearest tenth of a pound.

Statistical Analyses

The data were analyzed using the computer program (SAS) developed by Barr and Goodnight (1972). Because there was only one steer per breed type and slaughter weight group from replications I and II, this effect was dropped from the analysis of variance and the correlation data were not pooled within replication as was the case in Chapters IV and V.

Results and Discussion

Relationship between Certain Individual Muscles and Weight

Before determining the association between certain individual muscles and carcass closely trimmed lean it was of interest to study the relative growth patterns of these muscles associated with successive changes in slaughter weight. The means and standard errors for the hot carcass weight, carcass closely trimmed lean and the nine individual muscles or muscle groups expressed on a weight basis are presented in table 41. It was evident from the magnitude of the standard errors associated with the muscles that considerable animal to animal variation within breed type and slaughter weight group occurred.

Mean squares from the analysis of variance of these data are presented in table 42. Significant ($P < .01$) breed type differences were observed for carcass closely trimmed lean and individual muscles with the exception of the *trapezius* and *rectus abdominus* muscles. These muscles were rather difficult to dissect in a consistent manner and varied considerably in weight within the respective breed types and slaughter weight groups. For those muscles in which significant differences were detected the crossbreds consistently had amassed heavier muscles than the Herefords at similar slaughter weights. As expected hot carcass weight differences were non-significant ($P > .50$) with respect to breed types.

Significant ($P < .01$) weight group effects were observed for all of these data suggesting that even in the later stages of development, total lean and these various muscles were increasing in weight at a significant rate. The only significant breed type x weight group interaction was found for the *rectus abdominus* muscle, suggesting somewhat of a reversal in the development pattern of this muscle as weight group increased from 500 to 1100 pounds. However, this most likely reflects the variation in the sampled population and not the true growth pattern for this muscle.

The relationship of carcass closely trimmed lean and these nine individual muscles to increases in slaughter weight can be more clearly

TABLE 41. MEANS AND STANDARD ERRORS[a] FOR CARCASS WEIGHT, CLOSELY TRIMMED LEAN AND CERTAIN INDIVIDUAL MUSCLE WEIGHTS FOR HEREFORD (H) AND CROSSBRED (X) STEERS BY SLAUGHTER WEIGHT GROUPS

		Slaughter weight group (lbs)							
Item	Breed type	500		700		900		1100	
No. of steers		6		6		6		6	
Hot carcass weight(lbs)	H	303	(5.7)	421	(3.5)	560	(8.1)	708	(6.8)
	X	308	(7.0)	420	(3.1)	554	(7.0)	694	(6.6)
Closely tr. lean(lbs)	H	179.4	(3.1)	241.0	(1.9)	295.2	(2.5)	351.6	(4.9)
	X	203.5	(4.5)	247.2	(2.9)	324.8	(7.1)	380.2	(3.9)
<u>Trapezius</u>[b](lbs)	H	1.2	(.10)	1.6	(.10)	1.9	(.13)	2.4	(.13)
	X	1.0	(.05)	1.4	(.13)	2.1	(.12)	2.2	(.05)
<u>Supra spiratus</u>(lbs)	H	1.4	(.12)	1.4	(.02)	1.7	(.07)	2.2	(.04)
	X	1.4	(.07)	1.8	(.09)	2.1	(.05)	2.2	(.04)
<u>Longissimus</u> (rib section, lbs)	H	2.2	(.08)	3.2	(.11)	4.0	(.05)	4.5	(.13)
	X	3.2	(.19)	3.4	(.04)	4.6	(.11)	5.1	(.13)
<u>Psoas major</u>(lbs)	H	1.8	(.08)	2.3	(.05)	2.9	(.09)	3.2	(.07)
	X	2.1	(.08)	2.7	(.11)	3.3	(.10)	3.8	(.17)
<u>Rectus abdominus</u>(lbs)	H	.8	(.03)	1.2	(.14)	1.2	(.02)	1.6	(.03)
	X	1.0	(.04)	1.0	(.02)	1.6	(.05)	1.7	(.03)
<u>Biceps femoris</u>(lbs)	H	5.0	(.18)	6.5	(.19)	7.8	(.29)	8.4	(.33)
	X	6.0	(.11)	7.1	(.23)	8.6	(.31)	9.8	(.26)
<u>Semimembranosus</u>(lbs)	H	7.2	(.43)	9.4	(.29)	10.8	(.44)	12.6	(.60)
	X	9.0	(.33)	10.7	(.39)	13.3	(.30)	14.0	(.55)
<u>Semitendinosus</u> (lbs)	H	2.0	(.05)	2.5	(.09)	3.0	(.07)	3.4	(.05)
	X	2.5	(.07)	2.8	(.10)	3.6	(.13)	4.0	(.10)
<u>Quadraceps complex</u>(lbs)	H	4.6	(.25)	5.2	(.11)	6.6	(.24)	7.9	(.26)
	X	5.0	(.14)	6.0	(.22)	7.5	(.24)	8.4	(.41)

[a] Standard errors of the mean are in parenthesis.

[b] Individual weights obtained from the right carcass half.

TABLE 42. ANALYSIS OF VARIANCE FOR INDIVIDUAL MUSCLE DATA FOR HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

		Mean square										
Source	d.f.	Hot carc. wt.(lbs)	closely tr. lean(lbs)	TRAP^{a} (lbs)	SS (lbs)	LD (lbs)	PM (lbs)	RA (lbs)	BF (lbs)	SM (lbs)	ST (lbs)	QUAD (lbs)
Total	47	...	...	...	...	...	...	...	...	...	...	...
Breed type(BT)	1	188.02	1463.02**	.1302	.3502**	4.2008**	2.6133**	.1008	10.9252**	36.4008**	2.6133**	4.4408**
Weight group(WG)	3	351078.19**	17375.22**	3.4408**	1.3146**	11.4025**	5.8689**	1.3889**	30.4235**	63.1861**	5.0794**	27.1058**
BTxWG	3	221.46	88.87	.1452	.1441	.2603	.0400	.1430*	.3130	0.7847	.0638	.1592
Residual	40	465.04	51.86	.1384	.0588	.1552	.1212	.0422	.7384	2.7321	.0880	.7326

[a] Abbreviations refer to _trapezius_, _supra spinatus_, _Longissimus_ (rib section), _psoas major_, _rectus femoris_, _biceps femoris_, _semimembranosus_ and _adductor_, _semitendinosus_ and _quadraceps_ complex, respectively.

* $P < .05$.

** $P < .01$.

seen in figures 10 and 11 for the Hereford and crossbred steers, respectively. The relative changes in the mean weights of carcass closely trimmed lean and these muscles as slaughter weight increased successively from 500 to 700, 700 to 900 and 900 to 1100 pounds are presented in table 43. Orthogonal contrasts were conducted on these data to determine whether or not the respective weight changes in these muscles were constant within the realm of chance deviations. The proportion of weight group sum of squares associated with linear, quadratic and cubic sum of squares are presented in table 44. Actual weight group, linear, quadratic and cubic sum of squares is presented in table 58 of the Appendix.

Although these changes were found to be essentially linear ($P<.01$) and the sum of squares associated with the linear effects accounted for in excess of 98 percent of the weight group sum of squares, considerable variation in the change from one growth phase to the next was observed for weights in these individual muscles. This is in agreement with individual muscle data reported by Hiner et al. (1971) in which fifty-one Angus steer calves were slaughtered over a range in age from 6 to 36 months. However, it is apparent from table 43 and figures 10 and 11 that the general growth patterns of these muscles were reasonably consistent between the two breed types. There was a tendency for maximum muscle weight increases to occur as slaughter weight increased from 700 to 900 pounds with respect to the crossbred steers. The changes in these individual muscle weights paralleled the dramatic increase in carcass closely trimmed lean (77.6 pounds) associated with the same respective slaughter weight change (700 to 900 pounds). When all crossbred steers (48) slaughtered at the four slaughter weight groups (Chapter V) were considered, similar changes in carcass closely trimmed lean weights were observed for each of the three successive changes in slaughter weight (55.2, 61.0 and 58.0 pounds, respectively), although the largest change did occur during the 700 to 900 growth phase. Based on the data from Chapter V, it seems somewhat presumptuous to suggest a diphasic growth pattern for total lean deposition or certain individual muscle with respect to these crossbred steers. More consistent changes in carcass closely trimmed lean (61.6, 54.2 and 56.4

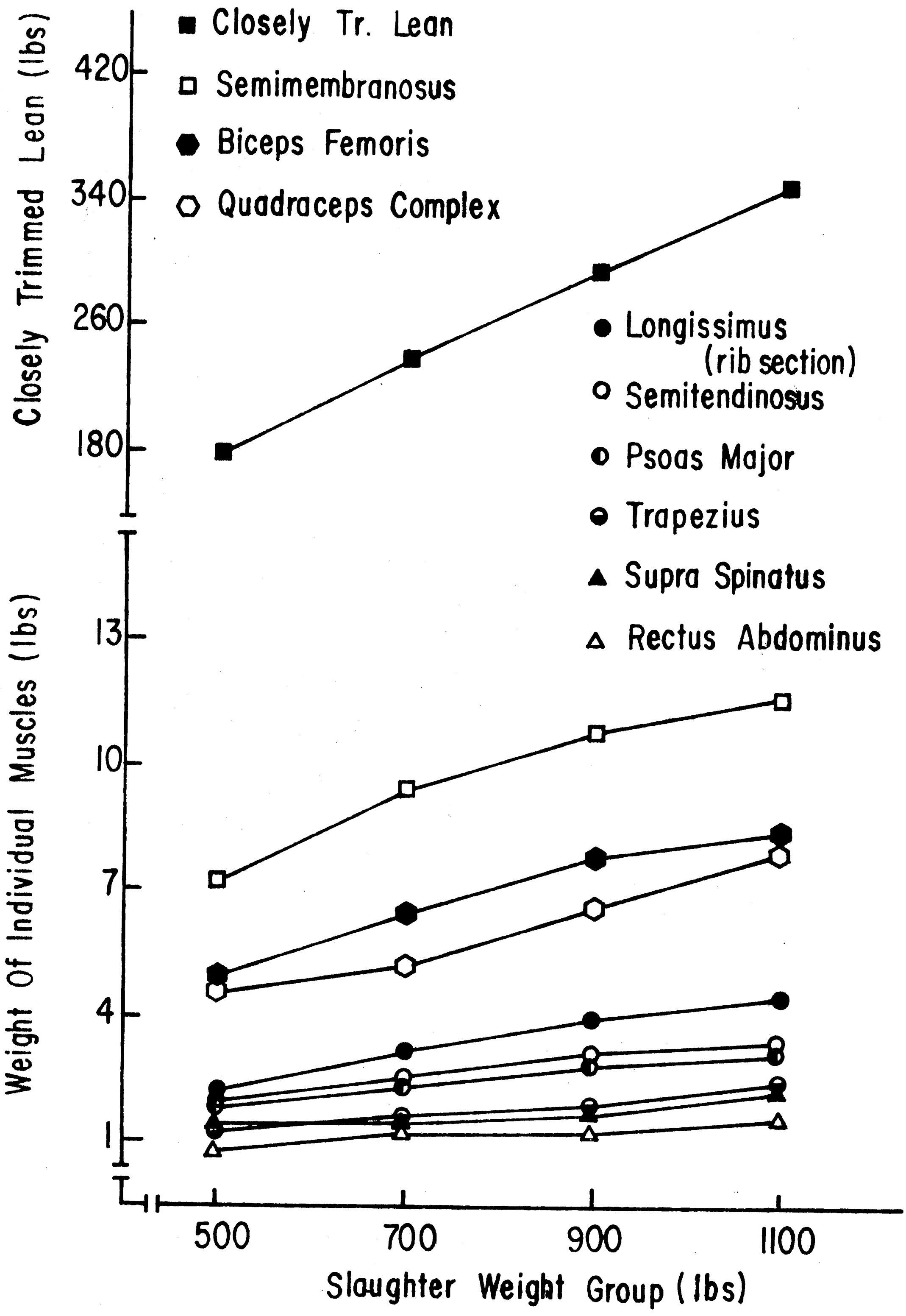

Figure 10. Mean plot of carcass closely trimmed lean and individual muscles for Hereford steers

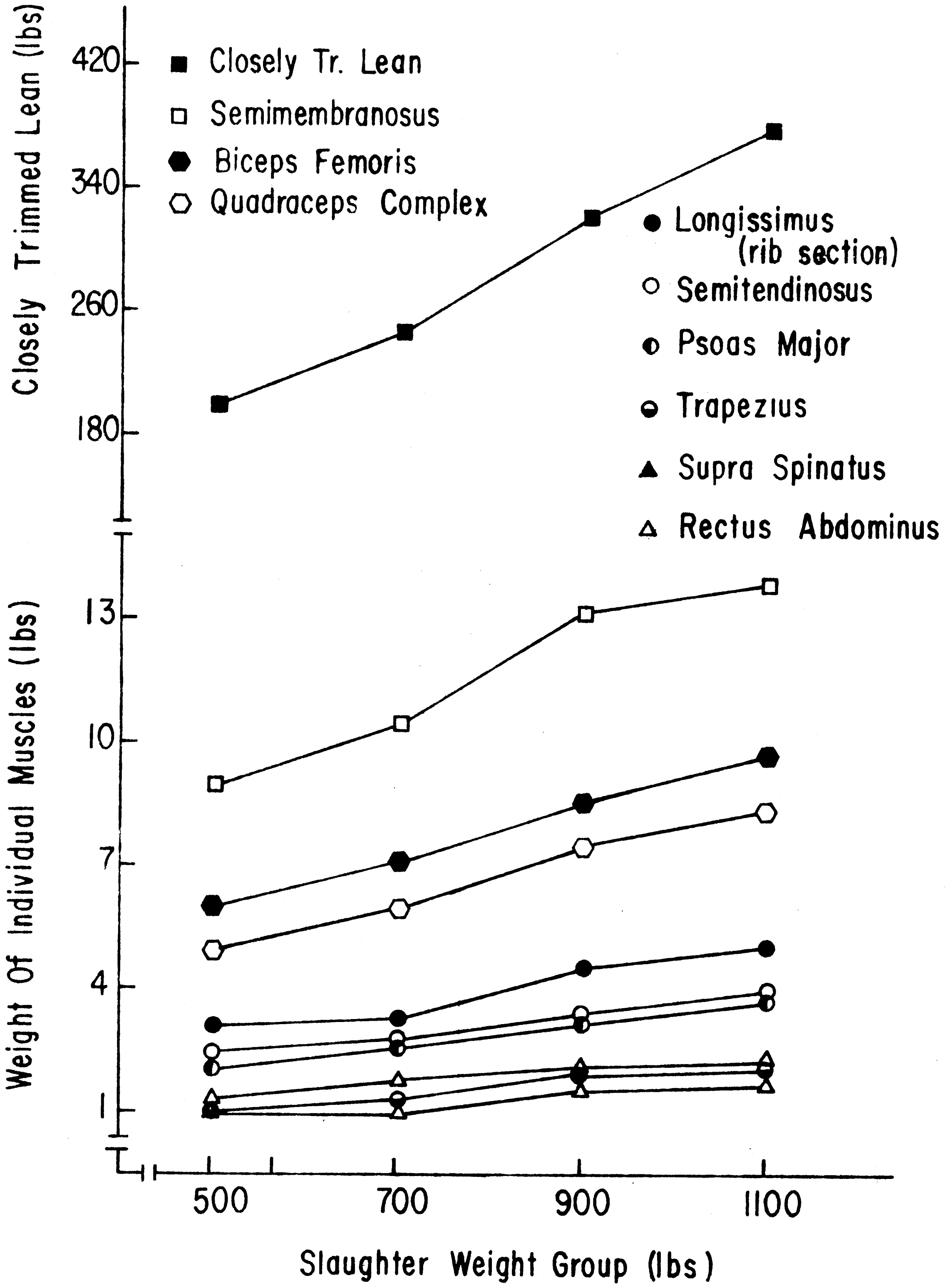

Figure 11. Mean plot of carcass closely trimmed lean and individual muscles for crossbred steers

TABLE 43. CHANGES IN CLOSELY TRIMMED LEAN AND INDIVIDUAL MUSCLE WEIGHTS FOR EACH 200 POUND CHANGE IN SLAUGHTER WEIGHT

	Breed type[a]	Change in slaughter weight (lbs)		
		500 to 700	700 to 900	900 to 1100
Closely tr. lean (lbs)	H	61.6	54.2	56.4
	X	43.7	77.6	55.4
Trapezius[b] (lbs)	H	.4	.3	.5
	X	.4	.7	.1
Supra spinatus (lbs)	H	.0	.3	.5
	X	.4	.3	.1
Longissimus (rib section, lbs)	H	1.0	.8	.5
	X	.2	1.2	.5
Psoas major (lbs)	H	.5	.6	.3
	X	.6	.6	.5
Rectus abdominus (lbs)	H	.4	.0	.4
	X	.0	.5	.1
Biceps femoris (lbs)	H	1.5	1.3	.6
	X	1.1	1.5	1.2
Semimembranosus (lbs)	H	2.2	1.4	1.8
	X	1.7	2.6	.7
Semitendinosus (lbs)	H	.5	.5	.4
	X	.3	.8	.4
Quadraceps complex (lbs)	H	.6	1.4	1.3
	X	1.0	1.5	.9

[a] Herefords = H, Crossbreds = X.

[b] Individual muscles from the right sides only.

TABLE 44. PROPORTION OF WEIGHT GROUP SUM OF SQUARES ASSOCIATED WITH LINEAR, QUADRATIC AND CUBIC EFFECTS FOR HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

	Proportion weight group SS		
	Linear	Quadratic	Cubic
Closely trimmed lean (lbs)	99.83**	...	.17
Trapezius (lbs)	99.71**	.29	...
Supra spinatus (lbs)	95.57**	.42	...
Longissimus (lbs)	98.66**	.12	1.22
Psoas major (lbs)	99.37**	.18	.45
Rectus abdominus (lbs)	98.86**	.08	.06
Biceps femoris (lbs)	99.32**	.42	.26
Semimembranosus (lbs)	99.10**	...	.90
Semitendinosus (lbs)	98.98**	.76	.26
Quadraceps complex (lbs)	99.00**	.26	.74

* $P < .05$.

** $P < .01$.

pounds, respectively) were observed for the Hereford steers as slaughter weight increased from 500 to 700, 700 to 900 and 900 to 1100 pounds. However, there was a tendency for the largest increase in individual muscle weights for the Herefords to occur during the 500 to 700 pound growth phase.

Berg and Butterfield (1966) reported that the major differential growth within the musculature takes place soon after birth and thus would play a minor role in affecting the composition of animals of normal slaughter weight and that changes in individual musculature were reasonably constant with respect to total lean. Hiner *et al*. (1971) indicated that the growth period from 6 to 12 months was associated with the greatest increase in separable lean when steers were full-fed. However, this period also represented whole-body weight changes (375 to 800 pounds) considerably greater than observed at the subsequent four 6 month growth periods.

The individual muscle weight changes shown in figures 10 and 11 indicate that certain muscles have different growth rates, regardless of breed. The *semimembranosus* muscle appears to have increased at the fastest rate and the *rectus abdominus* muscle was observed to show one of the slowest rates of increase. It was also apparent that those individual muscles making up the largest portion of carcass closely trimmed lean (*semimembranosus*, *biceps femoris*, *quadraceps* complex and *longissimus* muscle) generally showed more rapid growth rates than those muscles which contribute considerably less to the total (*semitendinosus*, *psoas major*, *trapezius*, *supra spinatus* and *rectus abdominus*), regardless of breed type. Hiner *et al*. (1971) also found weight changes for certain individual muscles to have different rates of growth.

Correlations

Pooled within slaughter weight group correlations between certain individual muscles and carcass closely trimmed lean are presented in table 45. The validity of pooling within slaughter weight groups is dependent on the assumption that the within weight group correlations are estimating the same rho value. The test for homogeneity of correlation coefficients indicated that within weight group correlations

TABLE 45. POOLED WITHIN SLAUGHTER WEIGHT GROUP CORRELATIONS BETWEEN CERTAIN INDIVIDUAL MUSCLES AND CLOSELY TRIMMED LEAN BY BREED TYPES[a]

	Individual muscles[b] (lbs)								
Item	TRAP	SS	LD	PM	RA	BF	ST	SM	QUAD
Closely trimmed lean (lbs) - Herefords	.525	-.109	.563*	-.125	-.040	.698**	.377	.495	.326
Closely trimmed lean (lbs) - Crossbreds	.258	.086	.681**	.145	.415	.618*	.667**	.254	.160

[a] 6 observations per weight group, d.f. = 12.

[b] Abbreviations refer to <u>trapezius</u>, <u>supra spinatus</u>, rib section of the <u>longissimus</u> muscle, <u>psoas major</u>, <u>rectus abdominus</u>, <u>biceps femoris</u>, <u>semitendinosus</u>, <u>semimembranosus</u> and <u>adductor</u>, and <u>quadraceps</u> complex, respectively.

* $P < .05$.

** $P < .01$.

were from estimating the same rho value. It should be pointed out that this test is rather crude and that a correlation coefficients which differed as much as .9 were determined to be estimating the same rho value. The weight of the biceps femoris muscle was more highly associated with carcass closely trimmed lean (.698) than any other muscle with respect to the Herefords. For the crossbred steers, weights of the longissimus muscle (rib section), biceps femoris and semitendinosus muscles showed the highest associations with carcass closely trimmed lean (.681 and .667, respectively). However, several nonsignificant correlations were observed for certain of these individual muscles and carcass closely trimmed lean. These results suggested that there tends to be a positive association between these muscles and carcass closely trimmed lean; however, within these narrow weight ranges even the strongest correlations are not of the magnitude to suggest much, if any, predictive value. Also, even though pooled within slaughter weight, the small numbers on which these estimates are based may not provide good estimates of the real association between these variables.

Simple correlations between these individual muscles and carcass closely trimmed lean are presented in table 46 ignoring slaughter weight groups. It is apparent that when the large divergence in slaughter weight was allowed to enter into the association between these muscle weights and carcass closely trimmed lean, correlations considerably stronger in magnitude were observed than when slaughter weight group effects were minimized by pooling within weight groups. All associations were highly significant ($P<.01$). The weights of individual muscles studied accounted for from 51.3 to 91.6 percent and 59.3 to 86.7 percent of the variation in the weight of the carcass closely trimmed lean for the Herefords and crossbreds, respectively. The weights of the longissimus muscle (rib section) and the semitendinosus showed the highest association with carcass closely trimmed lean (.957 and .941, respectively) with respect to the Herefords. These two individual muscles as well as the rectus abdominus and biceps femoris were most highly associated with carcass closely trimmed lean with regards to the crossbreds. It did appear that the associations between these individual muscle weights and carcass closely trimmed lean

TABLE 46. ACROSS SLAUGHTER WEIGHT GROUP CORRELATIONS BETWEEN CERTAIN INDIVIDUAL MUSCLES AND CLOSELY TRIMMED LEAN BY BREED TYPES[a]

	Individual muscles[b] (lbs)								
Item	TRAP	SS	LD	PM	RA	BF	ST	SM	QUAD
Closely trimmed lean (lbs) - Herefords	.794**	.716**	.957**	.894**	.722**	.890**	.941**	.845**	.878**
Closely trimmed lean (lbs) - Crossbreds	.848**	.770**	.932**	.855**	.927**	.927**	.923**	.840**	.839**

[a] 24 observations, d.f. = 21.

[b] Abbreviations refer to trapezius, supra spinatus, rib section of longissimus muscle, psoas major, rectus abdominus, biceps femoris, semitendinosus, semimembranosus and adductor and quadraceps complex, respectively.

** $P < .01$.

were somewhat more consistent with respect to the crossbreds.

It should be pointed out that the strong relationships found when slaughter weight groups were ignored could possibly reflect an association of these individual muscles and weight; hence, in actuality all these correlations are measuring, is the tendency for larger animals to have heavier muscles with little true relationship to the proportion of closely trimmed lean. The amount of bias resulting from weight effects was not determined. Furthermore, hot carcass weight was found to have the strongest relationship to carcass closely trimmed lean. Correlations of .978 and .984 for the Hereford and crossbred steers, respectively, were found for these two variables when slaughter weight groups were not considered.

Orme *et al*. (1960) reported very strong associations between certain individual muscles and total carcass lean (accounting for from 64 to 92% of the variation). These data were obtained from mature (8½ to 11 year old) cattle that were quite variable in weight as well as composition. When this worker removed the effects of weight by regression techniques, significant, but without exception, smaller correlations were reported. The *longissimus* muscle and *biceps femoris* muscles proved to have the most predictive value. Butterfield (1962) reported similar findings with respect to predicting separable lean from knowledge of the weight of the *biceps femoris*. Likewise Butterfield (1965b) reported certain individual muscles accounted for from 76 to 98 percent of the variation in total carcass muscle.

The results of the present study and those reported in the literature suggests that relative strong associations do exist between certain individual muscles and indicators of total leanness. Because certain individual muscles lend themselves well to controlled excision and the fact that adjustment for weight effects are reasonably easy, more work with larger sample numbers and controlled dissection is needed to obtain a reliable estimate of the true relationship between certain muscles and total carcass lean.

LITERATURE CITED

Abraham, H.C., Z.L. Carpenter, G.T. King and O.D. Butler. 1968. Relationships of carcass weight, conformation and carcass measurements and their use in predicting beef carcass cutability. J. An. Sci. 27:604.

Addison, C.E. 1973. The use of 40-K counter as an estimator of lean yield in swine. Master's Thesis. Oklahoma State University, Stillwater.

Allen, T.H., E.C. Anderson and W.H. Langham. 1960. Total body potassium and gross body composition in relation to age. J. Gerontol. 15:348.

Allen, D.M., R.A. Merkel, W.T. Magee and R.H. Nelson. 1968. Variation in some beef carcass compositional characteristics within and between selected weight and fat thickness ranges. J. An. Sci. 27:1239.

A.M.S.A. 1967. Recommended guides for carcass evaluation and contest. Am. Meat Sci. Assn., Chicago, Ill.

Anderson, E.C., R.L. Schuck, W.R. Fisher, and W. Langham. 1957. Radioactivity of people and foods. Sci. 125:1273.

Anderson, E.C. 1959. Data reduction for the Las Alamos' Human Counter. Las Alamos Scientific Laboratory, Las Alamos, New Mexico. p. 23.

Anderson, E.C. and W.H. Langham. 1959. Average potassium concentration of the human body as a function of age. Science 130:713.

Anderson, C.E. 1968. Organic scintillation detectors and their use in the study of body composition. Proceedings of Symposium on Body Composition of Animals and Man. Nat'l. Acad. of Sci., p. 266.

Andrews, F.N. 1958. Fifty years of progress in animal physiology. J. An. Sci. 17:1064.

A.O.A.C. 1965. Official Methods of Analysis (10th Ed.). Association of Official Agriculture Chemist. Washington, D.C.

Barlow, J.S. and J.F. Manery. 1954. The changes in electrolytes, particularly chloride, which accompany growth in chick muscle. J. Cellular and Comparative Physiol. 43:165.

Barr, A.J. and J.H. Goodnight. 1972. A Users Guide to the Statistical Analysis System. Student Supply Stores, North Carolina State Univ., Raleigh.

Behnke, A.R., B.G. Feen and W.C. Wilham. 1942. Specific gravity of healthy men. J. Amer. Med. Assn. 118:495.

Bennink, M.R., G.M. Ward, J.E. Johnson and D.A. Cramer. 1968. Potassium content of carcass components and internal organs of cattle as determined by K-40 and atomic absorption spectrometry. J. An. Sci. 27:600.

Berg, R.T. 1968. Relative growth within the bovine musculature. 21st Reciprocal Meat Conference Proceedings.

Berg, R.T. and R.M. Butterfield. 1966. Muscle: bone ratio and fat percentage as measures of beef carcass composition. An. Prod. 8:1.

Berg, R.T. and R.J. Bunnage. 1968. Predicting cutability in beef carcasses. 47 Annual Feeders' Day Rpt. Dept. of An. Sci., Univ. of Alberta; Edmonton, Alta., Canada. pp. 19-23.

Berg, R.T. and R.M. Butterfield. 1968. Growth patterns of bovine muscle, fat and bone. J. An. Sci. 27:611.

Bieber, D.D., R.L. Saffle, and L.D. Kamstra. 1961. Calculation of fat and protein content of beef from specific gravity and moisture. J. An. Sci. 20:239.

Blaxter, K.L. and J.A.F. Rook. 1956. The indirect determination of energy retention in farm animals. I. The development of method. J. Agr. Sci. 48:194.

Brackelsberg, P.O. and R.L. Willham. 1968. Relationships among some common live and carcass measurements and beef carcass composition. J. An. Sci. 27:53.

Bray, R.W., E.H. Rupnow, F.M. Hanning, N.N. Allen and R.R. Niedermeier. 1959. Effect of feeding method on veal production and carcass quality. II carcass grades, liver, hide, specific gravity, yield and chemical analyses of the muscle. J. An. Sci. 18:732.

Breidenstein, B.C. 1964. Cited from Hillier, J.C., R.L. Noble, I.T. Omtvedt, L.E. Walters, J.V. Whiteman, and R.R. Frahm. 1966. The development and testing of improved methods for live evaluation of meat animals. Project Outline, Oklahoma State University, Stillwater.

Breidenstein, B.C., T.G. Lohman, G.S. Smith, and H.W. Norton. 1965a. Comparison of 40-K measurement with other methods for determining lean muscle mass in sheep. J. An. Sci. 24:860. (Abstr.)

Breidenstein, B.C., T.G. Lohman, G.S. Smith, and H.W. Norton. 1965b. 40-K and other indices of carcass lean muscle mass in pigs. J. An. Sci. 24:860. (Abstr.)

Brozek, Josef. 1965. Nutrition and body composition, Bordeus Review of Nutritional Research, 26:31.

Brungardt, V.H. and R.W. Bray. 1963. Estimate of retail yield of the four major cuts in the beef carcass. J. An. Sci. 22:177.

Butterfield, R.M. 1962. Prediction of muscle content of steer carcasses. Nature, 195:194.

Butterfield, R.M. 1965a. Practical implication of anatomical research in beef cattle. Proc. N.Z. Soc. An. Prod. 25:152.

Butterfield, R.M. 1965b. The relationships of carcass measurements and dissection data to beef carcass composition. Res. Vet. Sci. 6:24.

Butterfield, R.M. and R.T. Berg. 1966a. A classification of bovine muscles based on their relative growth patterns. Res. Vet. Sci. 7:326.

Butterfield, R.M. and R.T. Berg. 1966b. Relative growth patterns of commercially important muscle groups of cattle. Res. Vet. Sci. 7:389.

Butterfield, R.M. and E.R. Johnson. 1971. A study of growth in calves. II. Relative growth in muscles. J. Agr. Sci., Camb. 76:457.

Butterfield, R.M. and N.D.S. May. 1966. Muscles of the Ox. University of Queensland Press. Brisbane, Australia.

Callow, E.H. 1944. The food value of beef from steers and heifers, and its relation to dressing-out percentage. J. Agr. Sci. 34:177.

Callow, E.H. 1948. Comparative studies of meat. II. The changes in the carcass during growth and fattening, and their relation to the chemical composition of the fatty and muscular tissues. J. Agr. Sci. 38:174.

Callow, E.H. 1949. Comparative studies of meat. III. Rates of fattening in relation to the percentage of muscular and fatty tissue in a carcass. J. Agr. Sci. 39:347.

Callow, E.H. 1962. The relationship between the weight of a tissue in a single joint and the total weight of the tissue in a side of beef. An. Prod. 4:37.

Carr, T.R. 1975. The relation of K^{40} net count and probe to body composition changes in growing and finishing swine. Ph.D. Thesis, Oklahoma State University, Stillwater.

Cheek, D.B. and C.D. West. 1955. An appraisal of methods of tissue chloride analysis: the total carcass chloride, exchangeable chloride, potassium and water of the rat. J. Clin. Invest. 34:1744.

Clark, J.L., H.B. Hedrick, G.B. Thompson, J.G. Riley, W.L. Mies, R.J. Epley and R.L. Preston. 1972. Level and distribution of potassium in beef carcasses. J. An. Sci. 35:542.

Clark, J.L., H.B. Hedrick and G.B. Thompson. 1976. Determination of body composition of steers by 40-K. J. An. Sci. 42:352.

Cobb, E.H. and Overjera. 1965. Predicting yield of trimmed retail cuts in beef carcass. J. An. Sci. 24:529. (Abstr.)

Cole, J.W., L.E. Orme and C.M. Kincaid. 1960a. Relationship of loin eye area, separable lean of various beef cuts and carcass measurements to total lean in beef. J.An. Sci. 19:89.

Cole, J.W., W.R. Backus and L.E. Orme. 1960b. Specific gravity as an objective measure of beef eating quality. J. An. Sci. 19:167.

Cole, J.W., C.B. Ramsey and R.H. Epley. 1962. Simplified method for predicting pounds of lean in beef carcasses. J. An. Sci. 21:355.

Dinkel, C.A., D.A. Busch, D.E. Schafer, H.J. Tuma, J.A. Minyard and W.A. Costello. 1969. Changes in composition of beef carcasses with increasing weight. J. An. Sci. 28:1969.

Duggleby, J.C. and R.M. Seebeck. 1967. Potassium and Cesium-137 distributions in Angus steer carcasses. J. Agr. Sci. 69:149.

Elsley, F.W.H., I. McDonald and V.R. Fowler. 1964. The effects of plane of nutrition on the carcasses of pigs and lambs when variations in fat content are excluded. An. Prod. 6:141.

Epley, R.J., H.B. Hedrick, W.C. Stringer and D.P. Hutcheson. 1970. Prediction of weight and percent retail cuts of beef using five carcass measurements. J. An. Sci.

Forbes, G.B. 1963. Nutritional implications of the whole-body counter. Nutr. Rev. 21:321.

Forbes, G.B. 1968. A 4-pi plastic scintillation detector. Internat. J. Appl. Radiation and Isotopes. 19:535.

Frahm, R.R., L.E. Walters and C.R. McLellan, Jr. 1971. Evaluation of K-40 count as a predictor of muscle in yearling beef bulls. J. An. Sci. 32:463.

Garrett, W.N. and N. Hinman. 1969. Re-evaluation between carcass density and body composition of beef steers. J. An. Sci. 28:1.

Garrett, W.N. 1968. Experiences in the use of body density as a predictor of body composition. Proceeding of Symposium on Body Composition in Animals and Man. Nat'l. Acad. of Sci. p. 170.

Garrett, W.N., W.C. Rollins, Maria Tanaka and N. Hinman. 1971. Empty body and carcass composition of cattle. J. An. Sci. 33:194. (Abstr.)

Gil, E.A., R.R. Johnson, V.R. Cahill, K.E. McClure and E.W. Klosterman. 1970. An evaluation of carcass specific dye dilution and empty body parameters as predictors of beef carcass composition over a wide range of fatness. J. An. Sci. 31:459.

Gillett, T.A., A.M. Pearson and A.H. Kirton. 1965. Variation in potassium and sodium in muscles of the pig. J. An. Sci. 24:177.

Gillett, T.A., A.M. Pearson, D.M. Allen and R.A. Merkel. 1967. Variation in potassium and sodium content of bovine muscles. J. An. Sci. 26:46.

Gillett, T.A., A.M. Pearson, R.A. Merkel and W.T. Magee. 1968. Potassium and sodium content of muscle from sheep with high and low blood potassium. J. An. Sci. 27:645.

Green, R.M., K.G. McNeill and G.A. Robinson. 1961. The distribution of potassium and Cesium-137 in the calf and the pig. Can. J. Biochem. Physiol. 39:1021.

Guenther, J.J., D.H. Bushman, L.S. Pope and R.D. Morrison. 1965. Growth and development of the major carcass tissues in beef calves from weaning to slaughter with reference to the effects of plane of nutrition. J. An. Sci. 24:1184.

Guenther, J.J., J.A. Stuedemann, S.A. Ewing and R.D. Morrison. 1967. Determination of beef carcass fat content from carcass specific gravity measurements. J. An. Sci. 26:210. (Abstr.)

Haecker, T.L. 1920. Investigations in beef productions. Minn. Agr. Exp. Sta. Bell. 193.

Hammond, J. 1932. Growth and Development of Mutton Qualities in the Sheep. Oliver and Boyd, Edinburgh.

Hammond, J. 1933. How science can help improve the nation's food supply. Soc. Chem. Industries. J. 52:637.

Hankins, O.G. and H.W. Titus. 1939. Growth, fattening, and meat production. U.S.D.A. Yearbook. 450.

Hedrick, H.B., J.C. Miller, G.B. Thompson and R.R. Freitag. 1965. Factors effecting longissimus dorsi area and fat thickness of beef and relationship between these measurements and retail yield. J. An. Sci. 24:333.

Hedrick, H.B. 1967. Bovine growth and composition. Mo. Agr. Exp. Sta. Res. Bul. 928, N.C. Regional Publ. No. 181.

Hedrick, H.B. 1975. Perspective on growth and development. 28th Reciprocal Meat Conference Proceedings.

Henderson, D.W., D.E. Goll, and E.A. Kline. 1966. Relationships of muscling and finish measurements from three different groups of beef carcasses with carcass yield. J. An. Sci. 25:323.

Hiner, R.L. and J. Bond. 1971. Growth of muscle and fat in beef steers from 6 to 36 months of age. J. An. Sci. 32:225.

Huxley, J. 1932. Problems of relative growth. 1st ed. Methuen, London.

Johnson, R.K., L.E. Walters and J.V. Whiteman. 1972. Importance of the different levels of potassium in the diet on whole-body 40-K count and muscle and blood potassium. J. An. Sci. 35:931.

Judge, M.C., M. Strob, W.V. Kessler and J.E. Christianson. 1963. Lamb carcass and live lamb evaluation by potassium-40 and carcass measurement. J. An. Sci. 22:418.

Kelly, R.F., J.P. Fonenot, P.P. Graham, W.S. Wilkinson and C.M. Kincaid. 1968. Estimates of carcass composition of beef cattle fed at different planes of nutrition. J. An. Sci. 27:621.

Kirton, A.H. and A.M. Pearson. 1961. The use of naturally occurring K-40 to predict the composition of live animals, their carcass and meat samples. 14th Reciprocal Meat Conference Proceedings.

Kirton, A.H., A.M. Pearson, R.H. Nelson, E.C. Anderson and R.L. Schuch. 1961. The use of naturally occurring ^{40}K to determine the carcass composition of live sheep. J. An. Sci. 20:635.

Kirton, A.H. and A.M. Pearson. 1963. Comparison of methods of measuring potassium in pork and lamb and prediction of their composition from sodium and potassium. J. An. Sci. 22:125.

Kirton, A.H., R.H. Gnaedinger and A.M. Pearson. 1963. Relation of potassium and sodium content to the composition of pigs. J. An. Sci. 22:904.

Kraybill, H.F., O.G. Hankins and H.L. Bitter. 1952. Body composition of cattle. II. Determination of fat and water content from measurement of specific gravity. J. Appl. Physiol. 4:575.

Kulwich, R.L., L. Feinstein and E.C. Anderson. 1958. Correlation of potassium-40 concentration of fat-free lean content of hams. Science 127:338.

Kulwich, R., L. Feinstein, C. Golumbic, W.R. Seymour, W.R. Kauffman and R.L. Hiner. 1961. Relation of gamma-ray emission to the lean content of beef rounds. Food Tech. 15:411.

Kulwich, Roman. 1961. Relationship of radioisotope content to the composition of meat. 14th Reciprocal Meat Conference Proceedings.

Lawrie, R.A. and R.W. Pomeroy. 1963. Sodium and potassium in the pig muscle. J. Agr. Sci. 61:409.

Lohman, T.G., O.B. Ross, B.C. Breidenstein, A.R. Twardock, A.L. Newmann and G.S. Smith. 1964. Estimation of fat-free lean tissue in live cattle and carcasses by measurement of K-40. J. An. Sci. 23:862.

Lohman, T.G., E.E. Hatfield, V.S. Garrigus, B.C. Breidenstein and B.B. Doane. 1965. Use of ^{40}K in sheep research. Ill. Agr. Exp. Sta. Sheep Day.

Lohman, T.G., B.C. Breidenstein, A.R. Twardock, G.S. Smith and H.W. Norton. 1966. Symposium on atomic energy in animal science. Estimation of carcass lean muscle mass in steers by K-40 measurement. J. An. Sci. 25:1218.

Lohman, T.G. 1968. Distribution of Potassium in steers by K^{40} measurement. Ph.D. Thesis, Univ. Ill., Urbana.

Lohman, T.G. and H.W. Norton. 1968. Distribution of potassium in steers by 40-K measurement. J. An. Sci. 27:1266.

Lohman, T.G., W.J. Coffman, A.R. Twardock, B.C. Breidenstein and H.W. Norton. 1968. Factors affecting potassium-40 measurement in the whole-body and body components. Proceeding of Symposium on <u>Body Composition of Animals and Man</u>. Nat'l. Acad. of Sci. p. 291.

Lohman, T.G., R.C. Dieter and H.W. Norton. 1970a. Biological and technical sources of variation in bovine carcass lean tissue composition. I. Technical variation in measurements of potassium, nitrogen and water. J. An. Sci. 30:15.

Lohman, T.G., R.H. Ball and H.W. Norton. 1970b. Biological and technical sources of variability in bovine carcass lean tissue composition. II. Biological variation in potassium, nitrogen and water. J. An. Sci. 30:21.

Lowry, O.H., A.B. Hastings, T.Z. Hull, and A.N. Brown. 1942. Histochemical changes associated with aging II. Skeletal and cardiac muscle in the rat. J. Biol. Chem. 143:271.

Martin, T.G., R.B. Harrington and W.V. Kessler. 1968. Factors affecting estimates of potassium content by whole-body liquid scintillation counting. Proceeding of Symposium on Body Composition of Animals and Man. Nat'l. Acad. of Sci., p. 350.

McLellan, C.R., Jr. 1970. Analysis of a permian potassium-40 counter as a predictor of lean in beef cattle. Master's Thesis, Oklahoma State University, Stillwater.

McMeekan, C.P. 1959. Principles of Animal Production. Whitcombe and Tombe, Ltd.

Miller, C.E. and A.P. Remenchik. 1963. Problems involved in accurately measuring the K content of the human body. Ann. N.Y. Acad. Sci. 110:175.

Miller, D.G. 1972. Radioactivity and Radiation Detection. Gordon and Breach, Sci. Publ., New York.

Mitteldorf, A.J. and D.O. Landon. 1952. Spectrochemical determination of the mineral-element content of beef. Anal. Chem. 24:469.

Moser, B.D. 1970. The association between certain live and carcass measurements in growing and finishing swine. Master's Thesis. Oklahoma State University, Stillwater.

Moulton, C.R., P.F. Trowbridge and L.D. Haigh. 1922. Studies in animal nutrition. II. Changes in proportion of carcass and of fat on different planes of nutrition. Mo. Agr. Exp. Sta. Res. Bul. 54.

Mukhotz, H. and B.T. Berg. 1971. Influence of breed and sex on the allometric growth patterns of major bovine tissues. An. Prod. 13:219.

Mukhotz, H. and R.T. Berg. 1973. Influence of breed and sex on muscle weight distribution of cattle. J. Agr. Sci., Camb. 81:317.

Mullins, M.F., S.E. Zobrisky, H.B. Hedrick and M.A. Alexander. 1968. Indices of pork carcass composition. J. An. Sci. 27:1122.

Mullins, M.F., H.B. Hedrick, S.E. Zobrisky, W.J. Coffman and C.V. Gehrke. 1969. Comparison of potassium and other chemical constituents as indices of pork carcass composition. J. An. Sci. 28:992.

Munson, A.W., J.V. Whiteman and L.E. Walters. 1966. A method for estimating ether extract in the boneless portion of lamb carcasses. J. An. Sci. 25:967.

Murphy, C.E., D.K. Hallett, W.E. Tyler and J.C. Pierce, Jr. 1960. Estimating yields of retail cuts from beef carcasses. J. An. Sci. 19:1240. (Abstr.)

Orme, L.E. 1958. Specific gravity as an objective measure of marbling. J. An. Sci. 17:693.

Orme, L.E., J.W. Cole, C.M. Kincaid and R.J. Cooper. 1960. Predicting total carcass lean in mature beef from weights of certain entire muscles. J. An. Sci. 19:726.

Overman, R.T. 1967. Basic concepts of nuclear chemistry. Reinhold Publ. Corp.

Palsson, H. and J.B. Verges. 1952. Effects of the plane of nutrition on growth and development of carcass quality in lambs. Part II. Effects on lambs of 30 lb. carcass weight. J. Agr. Sci. 42:93.

Palsson, H. 1955. Conformation and body composition. In Progress in Physiology of Farm Animals. J. Hammond (ed.). Butterworths Scientific Publ. London, Eng. 2:430.

Pearson, A.M., P.W. Purchas and E.P. Reincke. 1968. Theory and potential usefulness of body density as a predictor of body composition. Proceeding of Symposium on Body Composition in Animals and Man. Nat'l. Acad. of Sci. p. 153.

Pfau, Von A., G. Kallistratos, B. Ossowski, H. Hoeck and Z. Zivkovic. 1963. Untersuchungen zur Bestimmung Von Korperbestandteilon lebender Schweine uber ^{40}K-gamma-radio-aktivitatsmessungen. I. Der Kaliungehalt des M. longissimus dorsi unddes M. semimembranosus bei eloky Schweren Schweinen untershiredlichen Geschlechts and Rasse. Z. Tierz. Zuchtungsbiol. 78:170. Cited from Kirton, Gnaedenger, and Pearson (1963).

Pfau, Von A. and G. Kallistratos. 1963. Untersuchungen zur Bestimmung von Korperbestandteilen lebender Schweine uber ^{40}K-gamma-radio-aktivitatsmessungen. II. Der Kaliumgehalt der Muskolatur eines 110 kg. schweren Schweines. Z. Tierz. Zuchtungsbiol. 79:249.

Pfau, A. 1965. Interpretation problems of whole-body potassium measurements studied on various components of dissected pigs. Radioactivity in Man. G.R. Meneely, Ed. Cited from Lohman and Norton. 1968.

Powell, W.E. and D.L. Huffman. 1968. An evaluation of quantitative estimates of beef carcass composition. J. An. Sci. 27:1554.

Powell, W.E. and D.L. Huffman. 1973. Predicting chemical composition of beef steers from easily obtainable carcass variables. J. An. Sci. 36:1069.

Preston, R.L., R.D. Vance, V.R. Cahill and S.W. Kock. 1974. Carcass specific gravity and carcass composition in cattle and the effect of bone proportionality on this relationship. J. An. Sci. 38:47.

Ramsey, C.B., J.W. Cole and C.S. Hibbs. 1962. Relationship of beef carcass grades, proposed yield grades and fat thickness to separable lean, fat and bone. J. An. Sci. 21:193.

Rathbun, E.N. and N. Pace. 1945. Studies on body composition. I. Determination of body fat by means of the body specific gravity. J. Biol. Chem. 158:667.

Schmidt, M.K., J.L. Clark, T.L. Veum and G.F. Krause. 1974. Prediction of composition of crossbred swine from birth to 136 kg. live weight via the liquid scintillation whole body counter. J. An. Sci. 39:855.

Sim, D.W. and G.H. Wellington. 1976. Potassium concentration in bovine muscle as influenced by carcass location, breed, sex, energy intake and shrunk body weight. J. An. Sci. 42:84.

Smith, G.S., T.G. Lohman, B.C. Breidenstein and A.R. Twardock. 1964. Illasco .... can it predict lean meat from radioactivity of the animal. Ill. Exp. Sta. AS-608.

Smith, G.S., T.G. Lohman, A.R. Twardock and B.C. Breidenstein. 1965. An animal's natural radioactivity is a measure of meatiness. Ag. Exp. Sta. Cattle Feeders Rpt.

Spray, C.M. and E.M. Widdowson. 1950. The effect of growth and development on the composition of mammals. British J. Nutr. 4:332.

Swift, C.E. and M.D. Berman. 1959. Factors affecting the water retention of beef. I. Variations in composition and properties among eight muscles. Food Tech. 13:365.

Stant, E.G., Jr., T.G. Martin and W.V. Kessler. 1969. Potassium content of the porcine body and carcass at 23, 46, 68, and 91 kilograms live body weight. J. An. Sci. 29:547.

Steel, G.D. and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York.

Talso, P.J., C.E. Miller, A.J. Carballo and I. Vasquez. 1960. Exchangeable potassium as a parameter of body composition. Metabolism. 9:446.

Thomas, David L. 1975. Carcass traits of wether lambs produced by crossbred dams of Finnsheep, Dorset and Rambouillet breeding and slaughtered at two live weights. Master's Thesis, Oklahoma State University, Stillwater.

Topel, D.G., R.A. Merkel and D.C. Mackintosh. 1965. Relationships between certain whole muscles and measures of pork carcass muscling. J. An. Sci. 24:514.

Tulloh, N.M. 1963. The carcass composition of sheep, cattle and pigs as a function of body weight. Carcass Composition and Appraisal of Meat Animals. The Commonwealth Sci. and Ind. Res. Org. Melbourne, Australia. pp. 5.1-5.32.

Tulloh, N.M. 1964. Comparative breed studies of beef cattle. III. Carcass composition. Austr. J. Agr. Res. 15:333.

Twardock, A.R., T.G. Lohman, G.S. Smith and B.C. Breidenstein. 1966. Part I: The Illinois Animal Science Counter; Performance characteristics and animal radioactivity measurement procedures. J. An. Sci. 25:1209.

U.S.D.A. 1965. Official United States Standards for Grades of Carcass Beef. SRA-C & MS, 99.

Van Dilla, M.A., G.R. Farmer and V.R. Bohman. 1961. Fallout radioactivity in cattle and its effects. Science 133:1075.

Van Dilla, M.A. and E.C. Anderson. 1962. Human counters using liquid scintillators, p. 41. In Whole-body counting. International Atomic Energy Agency, Vienna.

Vinogrador, A.P. 1957. The isotope K^{40} and its role in biology. Biokhimiya 22:14. Cited from Kulwich 1961, 14th RMC.

Waldman, R.C., W.J. Tyler and V.H. Brungardt. 1969. Estimation of body composition in young calves. J. An. Sci. 29:426.

Waldman, R.C., W.J. Tyler and V.H. Brungardt. 1971. Changes in the carcass composition of Holstein steers associated with ration energy levels and growth. J. An. Sci. 32:611.

Ward, G.M., J.E. Johnson and T.R. Tyler. 1967. Relationship of potassium measured as K^{40} to the moisture and fat of ground beef. J. An. Sci. 26:298.

Ward, G.M. 1968. Introduction to whole-body counting. Proceedings of Symposium on Body Composition of Animals and Man. Nat'l. Acad. of Sci., p. 263.

Wedgwood, R.J. 1963. Inconsistency of the lean body mass. An. N.Y. Acad. Sci. 110:141.

Winchester, C.F. and P.E. Howe. 1955. Relative effects of continuous and interupted growth on beef steers. Tech. Bul. U.S. Dept. Agric. No. 1108, 34 pp.

Winchester, C.F. and N.R. Ellis. 1957. Delayed growth of beef cattle. U.S.D.A. Tech. Bul. 1159.

Woodward, K.T., T.T. Trujillo, R.L. Schuch and E.C. Anderson. 1956. Correlation of total body potassium with body water. Nature 178:97.

Zinn, D.W. 1967. Quantitative and qualitative beef carcass characteristic as influenced by time on feed. Ph.D. Thesis. University of Missouri, Columbia.

Zobrisky, S.E., H.D. Naumann, J.F. Lasley, D.E. Brady and A.M. Mullins. 1958. Physical composition of swine during growth and fattening. Mo. Agr. Exp. Sta. Res. Bul. 672.

APPENDIXES

TABLE 47. ANALYSIS OF VARIANCE FOR PERCENT ETHER-EXTRACT AND PERCENT MOISTURE, IN A NESTED CLASSIFICATION, FOR HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

		Mean square	
Source	d.f.	Ether-extract(%)	Moisture (%)
Replication(R)	2	6.8782	12.6102
Breed type (BT)	1	179.1080**	56.7197**
R*BT	2	.0838	.73460
Weight Group(WG)	3	329.6031**	256.4064**
R*WG	6	10.6165	5.4206
BT*WG	3	10.0517	11.5663
R*BT*WG	6	2.2910	2.9935
Animal(R*BT*WG)[a]	71	4.1966	4.1602
Determination	160	.0780	.0844

[a] Animal nested in R*BT*WG was used as the error term, and the d.f. was reduced by 1, because of missing data estimation for one sub-cell.

** $P < .01$.

TABLE 48. PROPORTION OF VARIATION IN CHEMICAL ANALYSIS ACCOUNTED FOR BY ANIMAL AND DETERMINATION VARIATION FOR HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

	Proportion of variation	
Classification[a]	Ether-extract (%)	Moisture (%)
Animal	96.04	95.62
Determination (Grab)	3.96	4.38

[a] Animal d.f. = 71, Determination d.f. = 160.

TABLE 49. MEAN SQUARES FOR SLAUGHTER WEIGHT GROUP EFFECTS AND PARTITIONED SUM OF SQUARES ASSOCIATED WITH LINEAR, QUADRATIC AND CUBIC EFFECTS FOR HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

Trait	Slaughter weight S.S.	Slaughter weight M.S.	Linear S.S.	Quadratic S.S.	Cubic S.S.	E.M.S.[a]
Adjusted count	5526003.61	1842001.20**	549306.00**	25839.84	4857.77	9941.16
Ratio ADCT/EBWT	5.173	1.724**	5.114**	.056	.004	.0168
Ratio ADCT/FFL	7.302	2.343**	7.300**	.001	.000	.1277

[a] Error mean squares (EMS) are based on 71 d.f.

** $P < .01$.

TABLE 50. MEANS AND STANDARD DEVIATIONS[a] FOR FAT-FREE LEAN AND TOTAL BODY FAT EXPRESSED AS A PERCENT OF EMPTY BODY WEIGHT

		Slaughter weight group (lbs)							
Item	Breed[b] type	500		700		900		1100	
No. of steers		12		12		12		12	
Fat-free lean (%)[c]	H	34.8	(1.99)	32.2	(2.10)	30.7	(1.36)	28.7	(1.55)
	X	39.6	(2.49)	36.1	(3.04)	33.7	(1.92)	32.5	(1.72)
Total body fat (%)[c]	H	12.9	(3.36)	18.5	(1.78)	23.0	(1.79)	28.4	(2.34)
	X	9.5	(1.49)	15.4	(2.35)	20.3	(2.15)	24.3	(2.92)

[a] Standard deviations are in parenthesis.

[b] Herefords = H, Crossbred = X.

[c] Data expressed as a percent of empty body weight.

TABLE 51. POOLED WITHIN SLAUGHTER WEIGHT GROUP CORRELATIONS BETWEEN CERTAIN LIVE ESTIMATES AND BODY COMPOSITION EXPRESSED AS A PERCENT OF EMPTY BODY WEIGHT AND HOT CARCASS WEIGHT

	Herefords		Crossbreds	
Trait	Adjusted count (cpm)	Empty body weight (lbs)	Adjusted count (cpm)	Empty body weight (lbs)
Fat-free lean (%)[a]	.433**	.348*	.555**	.101
Total body fat (%)[a]	-.431**	-.005	-.658**	.156
Fat-free lean (%)[b]	.498**	.040	.644**	.022
Total body fat (%)[b]	-.477**	-.030	-.654**	.126

[a] Fat-free lean and total body fat expressed as a percent of empty body weight.

[b] Fat-free lean and total body fat expressed as a percent of hot carcass weight.

* $P < .05$.

** $P < .01$.

TABLE 52. INTERCEPTS AND REGRESSION COEFFICIENTS FOR THE REGRESSION OF FAT-FREE LEAN (POUNDS) ON ADJUSTED COUNT, EMPTY BODY WEIGHT AND BOTH VARIABLES[a,b,c]

Breed type	Weight group (lbs)	Intercepts and regression coefficients						
		B_o	B_1	B_o	B_2	B_o	B_1	B_2
Herefords								
	500	82.56	.0846	3.79	.3403	21.65	.0619	.1738
	700	103.96	.0911	52.50	.2435	14.40	.0845	.1451
	900	-118.89	.1010	-182.32	.5142	-250.58	.0928	.4344
	1100	261.77	.0271	-299.90	.5672	-364.04	.0311	.5792
Crossbred								
	500	-26.18	.1425	-105.80	.6102	-139.04	.0781	.4891
	700	198.72	.0304	52.46	.2829	63.18	.0280	.2070
	900	139.06	.0934	172.52	.1382	84.60	.0922	.0649
	1100	181.34	.0904	371.90	-.0243	-364.92	.1094	.4802

[a] 12 observations per weight group.

[b] Single variable regression model, $Y_{FFL} = B_o + B(X)$, where B_o is the intercept, B_1 is the regression coefficient for adjusted count and B_2 is the regression coefficient for empty body weight.

[c] Multi-variable regression model, $Y_{FFL} = B_o + B_1(X) + B_2(X)$.

TABLE 53. INTERCEPTS AND REGRESSION COEFFICIENTS FOR THE REGRESSION OF TOTAL BODY FAT ON ADJUSTED COUNT, EMPTY BODY WEIGHT AND BOTH VARIABLES[a,b,c]

Breed type	Weight group (lbs)	Intercepts and regression coefficients						
		B_o	B_1	B_o	B_2	B_o	B1	B_2
Herefords								
	500	57.03	-.0255	52.09	.0432	43.22	-.0307	.0394
	700	82.84	-.0168	37.23	.0370	46.10	-.0195	.0597
	900	173.64	-.0486	-263.42	.4148	-221.27	-.0573	.4643
	1100	288.16	-.0827	22.56	.1207	191.95	-.082	.0890
Crossbreds								
	500	38.74	-.0129	18.37	.0101	25.97	-.0179	.0378
	700	118.48	-.0466	251.36	-.2976	234.32	-.0445	-.1770
	900	148.15	-.0366	-267.96	.4103	-225.53	-.0445	.445
	1100	255.81	-.0692	-485.12	.5770	-102.80	-.0567	.3152

[a] 12 observations per weight group.

[b] Single variable regression model, $Y_{TBFAT} = B_o + B(X)$, where B_o is the intercept, B_1 is the regression coefficient for adjusted count and B_2 is the regression coefficient for empty body weight.

[c] Multi-variable regression model, $Y_{TBFAT} = B_o + B_1(X) + B_2(X)$.

TABLE 54. MEAN SQUARES FOR SLAUGHTER WEIGHT GROUP EFFECT AND PARTITIONED SUM OF SQUARES ASSOCIATED WITH LINEAR, QUADRATIC AND CUBIC EFFECTS FOR HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

Trait	Slaughter weight S.S.	Slaughter weight M.S.	Linear S.S.	Quadratic S.S.	Cubic S.S.	E.M.S.[a]
Hot carcass weight (lbs)	2265388.21	755129.40**	225958.5333**	5162.6667**	267.0083	316.5070
Specific gravity	.01290	.00430**	.01283**	.00004	.00003	.00005
Rib eye area (sq In)	202.5904	67.5301**	201.5410**	.5750	.4744	1.1238
3/4 fat thickness (in)	3.0289	1.0096**	2.9563**	.0710	.0016	.0218
Average fat thickness (in)	4.4821	1.4940**	4.3377**	.1342*	.0102	.0276
Kidney, heart and pelvic fat (lbs)	1694.2675	564.7558**	1671.0403**	13.6504**	9.5768*	2.8104
Kidney, heart and pelvic fat (%)	51.4770	17.1590**	50.5052**	.3626	.6092	.2988
Ether-extract (%)	402.2184	133.4062**	400.1131**	.0113	.0941	1.6846
Cutability	207.8996	69.2998**	207.3624**	.4579	.0793	1.8903

[a] Error Mean Squares (EMS) are based on 71 d.f.

* $P < .05$. ** $P < .01$.

TABLE 55. MEAN SQUARES FOR SLAUGHTER WEIGHT GROUP EFFECTS AND PARTITIONED SUM OF SQUARES ASSOCIATED WITH LINEAR, QUADRATIC AND CUBIC EFFECTS FOR HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

Trait	Slaughter weight S.S.	Slaughter weight M.S.	Linear S.S.	Quadratic S.S.	Cubic S.S.	E.M.S.[a]
Closely tr. lean (lbs)	101474.112	33824.7040**	101370.005**	1.8984	102.2130	56.1146
Closely tr. lean (%)	.2125	.0785**	.2109**	.0008	.0008	.00058
Separable fat (lbs)	101880.891	33960.2971**	100833.0188**	1023.1204**	24.7521	54.3022
Separable fat (%)	.3840	.1280**	.3791**	.0038	.0011	.00066
Bone (lbs)	3710.4750	1236.3000**	3696.3000**	3.3750	10.8000	5.3850
Bone (%)	.0362	.0121**	.0347**	.0013**	.0002	.00011
Fat-free lean (lbs)	281756.321	93918.7737**	281586.0798**	29.0070**	141.2445	246.5380
Fat-free lean (%)	.2850	.0950**	.2827	.0021	.0001	.00076
Total body fat (lbs)	172767.320	57589.1067**	171125.5325**	1643.5817**	.2058	83.9597
Total body fat (%)	.6023	.2008**	.5965**	.0055*	.0003	.00086

[a] Error Mean Squares (EMS) are based on 71 d.f.

* P <.05. ** P <.01.

TABLE 56. POOLED WITHIN SLAUGHTER WEIGHT GROUP CORRELATIONS BETWEEN CERTAIN CARCASS MEASUREMENTS AND CARCASS COMPOSITION FOR STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS[a]

	Herefords			Crossbreds		
	Fat-free lean (lbs)	Total body fat (lbs)	Bone (lbs)	Fat-free lean (lbs)	Total body fat (lbs)	Bone (lbs)
Hot carcass weight (lbs)	.421**	.528**	.090	.398*	.476**	-.105
Specific gravity	.277	-.428**	.298	.066	-.447**	.241
Rib eye area (sq in)	.424**	-.273	-.256	.521**	-.244	.030
3/4 fat thickness (in)	-.355*	.584**	-.214	-.044	.530**	-.457**
Average fat thickness (in)	-.257	.518**	-.135	.015	.536**	-.402*
Kidney, heart and pelvic fat (%)	-.162	.558**	-.250	-.023	.461**	-.288

[a] 12 observations per group, d.f. = 36.

* $P < .05$.

** $P < .01$.

TABLE 57. POOLED WITHIN SLAUGHTER WEIGHT GROUP CORRELATIONS BETWEEN CERTAIN CARCASS MEASUREMENTS AND CARCASS COMPOSITION EXPRESSED AS A PERCENT OF HOT CARCASS WEIGHT FOR STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS[a]

	Herefords			Crossbreds		
	Fat-free lean (%)	Total body fat (%)	Bone (%)	Fat-free lean (%)	Total body fat (%)	Bone (%)
Hot carcass weight (lbs)	-.160	.208	-.320	-.099	.166	-.511**
Specific gravity	.444**	-.450**	.398*	.216	-.396*	.321*
Rib eye area (in)	.476**	-.418*	-.208	.386*	-.361*	-.209
3/4 fat thickness (in)	-.559**	.505**	-.315	-.236	.417*	-.574**
Average fat thickness (in)	-.469**	.420**	-.245	-.157	.373*	-.473**
Kidney, heart and pelvic fat (%)	-.282	.400*	-.284	-.284	.450**	-.206

[a] 12 observations per group, d.f. = 36.

[*] P< .05.

[**] P< .01.

TABLE 58. MEAN SQUARES FOR SLAUGHTER WEIGHT GROUP EFFECTS AND PARTITIONED SUM OF SQUARES ASSOCIATED WITH LINEAR, QUADRATIC AND CUBIC EFFECTS FOR HEREFORD AND CROSSBRED STEERS SLAUGHTERED AT 500, 700, 900 AND 1100 POUNDS

Trait	Slaughter weight S.S.	Slaughter weight M.S.	Linear S.S.	Quadratic S.S.	Cubic S.S.	E.M.S.[a]
Closely tr. lean (lbs)	52125.668	17375.222**	52038.000**	8.168	79.350	51.859
Trapezius (lbs)	10.322	3.441**	10.292**	.0252	.0050	.1384
Supra Spinatus (lbs)	3.944	1.315**	3.927**	.0167	.0000	.0588
Longissimus (lbs)	34.208	11.402**	33.750**	.0408	.4167	.1552
Psoas major (lbs)	17.607	5.869**	17.496**	.0300	.0807	.1212
Rectus abdominus (lbs)	4.167	1.389**	4.161**	.0333	.0027	.0422
Biceps femoris (lbs)	91.271	30.424**	90.651**	.3852	.2344	.7384
Semimembranosus (lbs)	189.558	63.186**	187.620**	1.4700	.4682	2.2320
Semitendinosus (lbs)	15.238	5.079**	15.1001**	.0075	.1307	.0880
Quadraceps complex (lbs)	81.318	27.106	80.5042	.2133	.6000	.7326

[a] Error mean squares (EMS) are based on 40 d.f.

* $P < .05$.

** $P < .01$.

VITA 2

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Candidate for the Degree of

Doctor of Philosophy

Thesis: THE ASSOCIATION OF WEIGHT AND BREED TYPE WITH ADJUSTED ^{40}K COUNT AND CERTAIN INDICES OF CARCASS COMPOSITION IN BEEF STEERS

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