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EVALUATION OF TECHNIQUES TO ESTIMATE DEVELOPMENTAL CHANGES IN EMPTY BODY AND CARCASS COMPOSITION IN CONTINENTAL EUROPEAN CROSSBRED STEERS

By

Aubrey Lynn Schroeder

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ABSTRACT

EVALUATION OF TECHNIQUES TO ESTIMATE DEVELOPMENTAL CHANGES IN EMPTY BODY AND CARCASS COMPOSITION IN CONTINENTAL EUROPEAN CROSSBRED STEERS

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Developmental changes in empty body, carcass composition and composition of gain was studied in Simmental X Charolais X Angus crossbred steers representing four slaughter groups. Five steers were slaughtered at each weight group (G1:300; G2:390; G3:480; G4:570 kg live weight). Complete physical dissection and chemical composition of all individual empty body and carcass tissues were conducted on each steer. Percentage empty body fat increased from 15.1 to 27.1% in G1 to G4, respectively. Carcass fat increased from 16.87 in G1 to 32.0% in G4, respectively. Skeletal muscle as a percentage of live weight decreased from 42.3 in G1 to 38.7% in G4, respectively. Carcass skeletal muscle decreased ($P<.01$) from 66.0 to 57.9% from G1 to G4. Empty body and carcass fat gain (g/d) during the 183 d feeding period was 537.0 and 417, respectively. Skeletal muscle accretion g/d was 484.7 during the 183 day feeding period. Skeletal muscle protein as a percentage of empty body protein was constant

at 52% across all groups. Carcass skeletal muscle protein as a percentage of total carcass soft tissue protein was 95% across all groups.

Empty body composition was estimated by one and two pool deuterium oxide dilution techniques. Empty body composition of steers weighing 300 to 390 kg was not accurately predicted by either method.

Urinary creatinine was highly correlated to empty body protein and skeletal muscle protein ($r = .90$ and $.87$, respectively). Prediction equations estimating lean body mass, empty body protein and skeletal muscle protein were developed.

Carcass composition was estimated using the 9-10-11 rib section and specific gravity. Equations developed by Hankins and Howe (1946) using the 9-10-11 rib consistently underestimated ($P<.01$) carcass fat and overestimated ($P<.01$) carcass water and protein in large-frame crossbred steers. Specific gravity underestimated ($P<.05$) carcass fat and overestimated carcass protein in carcasses with greater than 17.0% fat.

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INTRODUCTION

Consumer demand for less fat in meat products and desire to reduce production costs have been driving forces behind attempts to produce leaner, yet palatable, beef products. Emphasis on nutrition, breeding and selection of British breeds of beef cattle to maximize muscle production at young ages have been until recently, the major means by which the beef industry and researchers have reduced production costs and attempted to produce a product that satisfies consumer demands.

During the past 20 years, however, a tremendous influx of various continental European breeds (Dikeman and Crouse, 1975; Koch et al.,1982; Crouse et al., 1985) into beef production systems in the United States has drastically altered the genetic makeup of the beef cattle population. Significant opportunities exist for producers to improve lean meat production and decrease fat in beef animals by utilizing leaner, later maturing, continental European breeds. Today, approximately 15 (out of a potential of 50 or more) predominant continental European breeds are extensively used in either purebred or commercial breeding programs.

With the introduction of continental European breeds, obvious changes in the composition of cattle marketed today

have occurred. Effects of these changes on the ability to measure body composition remains the focus of research for many animal scientists. The search for methods to estimate beef carcass and empty body composition quickly and accurately, with minimal economic loss, has been rather extensive. In order to assess changes in composition of either the live animal or the carcass, over 30 methods to predict composition have been evaluated during the past 60 years (Schaefer, 1982; Hedrick, 1968, 1983).

Most of these prediction methods were developed using the British breeds, i.e., Angus, Hereford, Shorthorn or crosses of them. The majority of animals at that time were small framed and early maturing (by today's standards), reaching market weight between approximately 386 and 454 kg. Additionally, many of the animals included in the development of these prediction equations had considerably more fat, either in the carcass or empty body, than today's larger framed British and continental European breeds. Furthermore, many beef animals used in the early research studies were considerably older (24 to 60 mo) than today's market animal (14 to 18 mo). Work by Charles and Johnson (1976), McAllister et al. (1981) and Schroeder (1987) using breeds other than Angus, Hereford and Shorthorn, has shown considerable differences from earlier published reports (Berg and Butterfield, 1976) in the distribution and partitioning of fat among subcutaneous and intermuscular

depots.

The increased use of continental European breeds and apparent differences in composition have resulted in numerous research studies to evaluate differences in composition between British breeds and continental European cattle. Furthermore, the reliability and accuracy of present predictive methods developed during the 1940's and 50's, to estimate empty body and carcass composition, need to be reevaluated for use with continental European cattle.

The primary objective of this study was to investigate developmental changes in the partitioning of protein among major empty body tissues, especially skeletal muscle, bone and viscera, in continental European crossbred steers. Additional objectives were : 1) to evaluate the accuracy and reliabilty of present predictive equations which utilize deuterium oxide dilution techniques to estimate empty body water, protein and fat in continental European crossbred steers; 2) to develop regression equations using deuterium oxide dilution to predict skeletal muscle and 3) to examine the usefulness, accuracy and reliability of the 9-10-11 rib section (RIB), specific gravity (SG) of both the carcass and RIB in estimating carcass composition and develop new prediction equations if necessary, for continental European crossbred steers.

REVIEW OF LITERATURE

Early Studies Evaluating Animal Composition. The literature is replete with studies which reveal the vast changes that have occurred in the production and composition of the beef population over the past 150 years. Lawes and Gilbert (1859) and Henry and Sanborn (1883-1890) are credited with being among the first to report studies examining changes in the growth and fattening of sheep, oxen and pigs.

Wilson and Curtis (1893) reported data in the Iowa Agriculture Experiment Station Bulletin, comparing performance and carcass traits of dairy and beef type steers. These researchers reported dairy type animals were deficient in carcass conformation and shape of the high priced cuts and contained excessive internal fat in some carcasses. This observation still holds today. A second observation was that 18 to 24 mo old dairy steers had less marbling, which is generally recognized as invalid in today's dairy beef population.

Meek (1901), Brody and Ragsdale (1924) and Lush (1926) concluded live weight was the variable that increased most rapidly of all variables studied and that with increasing age, fat and muscling increased more rapidly than linear measurements at the shoulder and rump.

Trowbridge et al. (1918; 1919) reported several in depth studies examining the changes in and effects on composition related to: a) limited feeding, b) energy costs of fattening and c) heifer versus steer production. Others have reported either developmental changes (Haecker, 1920), differential growth patterns (Hammond, 1932), calculations of growth by allometric equations (Huxley, 1932), sample joints (primal cuts) as indices for composition (McMeekan, 1941), order of tissue growth (Brody, 1945), changes in chemical composition of fatty tissues and muscles (Callow, 1947;1948) or carcass quality (Palsson and Verges, 1952a,b) in cattle, pigs and lambs during the early years of the animal husbandry research programs.

Differences Among Biological Types and Breeds. The majority of information describing compositional changes in beef has been published since the 1950's. It is beyond the scope of this dissertation to provide a complete review of all studies examining changes in composition. However, it is important to realize few events will ever equal the impact of the introduction of the continental European beef breeds on beef production in North America. Since importation began in the late 1960's and early 1970's, producers have quickly recognized the outstanding potential for increasing growth rates and improving the muscle to fat ratio when compared to British breeds. Mason (1971) summarized available performance and carcass data on the

large cattle breeds of Western Europe. Prior to that time, most studies examining changes in composition involved British breeds (Callow, 1962; Luitingh, 1962; Butterfield, 1963; Allen et al., 1966,1969; Busch et al., 1968; Lohman et al., 1968; Garrett and Hinman, 1969; Johnson et al., 1972).

Dikeman and Crouse (1975) were among the first to report differences in chemical composition, growth rates and palatability between Hereford x Angus (H x A), Simmental x Angus (S x A) and Limousin x Angus (L x A) steers. Koch et al. (1976) studied carcass traits of S x A and A steers and among other findings, they reported A steers had lighter carcass weights at 5% adjusted fat content in the longissimus muscle. Kauffman et al. (1976), deviating from the historical premise that increased dressing percentage was solely related to fatness, suggested that heavier muscled (continental) cattle had higher dressing percentages. Martin et al. (1980) examined carcass traits among creep fed steers sired by Angus (A), Holstein (H), Simmental (S) and Chianina (C) bulls. They found dramatic differences between 9-10-11 rib fat percentages of these cattle ranging from 45.2 for H, 40.3 for A, 35.4 for S and 29.6 for C, respectively. Since these reports other studies have been conducted comparing carcass characteristics and retail yields of British and continental European cattle (Charles and Johnson, 1976b;

Kempster et al., 1976b,c, 1977, 1986; Koch et al., 1977,1978,1981,1982; Jones et al., 1978a,b; 1980a,b,c; 1985b,c; Levan et al., 1979; Nour et al., 1981; Rompala et al., 1984; Crouse et al., 1985; Shanin et al., 1985a,b,c; Robelin, 1986). These studies clearly demonstrate that there are significant differences in composition between British and continental European breeds. A number of researchers (Dikeman et al., 1975; Kempster, 1982; Kempster et al., 1986a,b,c) have called for further studies in order to determine whether the relationships established by the previously mentioned early observations with the British breeds hold true for the continental European breeds.

Methods of Measuring Growth and Body Composition. Meat animal production is dominated by two major considerations. The first is research concerns of nutrition, the efficient conversion of agricultural resources to meat, reproduction and animal genetics as they relate to the biological unit, the animal. The second is market considerations, which create an interrelationship between the scientists' interest in body composition and the ability to produce animals that conform to changing consumer demands. Estimation of changes in body composition through the development and use of cost effective methods can facilitate improvement in both of these areas. Measurement of body composition changes during growth have been attempted by a variety of methods

(Haecker, 1920; Hankins and Howe, 1946; Kraybill et al., 1951; Garrett et. al. 1959; Hedrick et.al. 1963; Byers, 1979 and Meissner, 1980a). By far the most common determination of changes in growth and composition is to compare animals at two or more points during their growth phase. However, quick, accurate, predictive techniques have yet to be developed (Kempster, 1986). Consequently, composition and changes in growth of an animal are determined by two very general classifications of methods: 1) either the animal is killed and the carcass or parts thereof analyzed, or 2) in vivo techniques are used. Each method, however, has problems and shortcomings with respect to expense (labor, isotope or loss of carcass value), precision, repeatability or commercial application. It is imperative that accurate, predictive, yet economical techniques for assessing live animal developmental changes be developed.

Estimating Live and Empty Body Composition

Serial Slaughter Techniques. Without the aid of accurate, repeatable, in vivo methods of assessing treatment effects on composition and tissue growth, serial slaughter techniques are usually employed. Numerous genotypically and phenotypically similar animals are randomly allotted to each treatment group for subsequent slaughter. These animals are assumed to be similar in

composition at the beginning of the trials and respond in like fashion throughout the treatment period. Each animal is assumed to represent the changes in body composition for all other animals in the study. The major problem with this method, however, is that it precludes any future measurement of growth. Large numbers of animals are also needed to reduce statistical variation among animals. Even in studies with large numbers of animals from the same breed, Ayola (1974) indicated there can be larger than expected biological variation. Thus, the animal selected for slaughter at a certain time point, may not represent the animal slaughtered earlier or later. Nevertheless, this method, although expensive, will continue to be useful. However, great care must be taken in the selection of animals for treatment groups.

Whole Body Physical Separation and Chemical Composition. Complete physical dissection and chemical analysis of whole body and carcass components is generally accepted as the most accurate procedure in determining animal composition (Powell and Huffman, 1968; Jesse et al. 1976). Studies on cattle, sheep or swine by Lawes and Gilbert (1859), Jordan, (1895), Trowbridge et al. (1919), Haecker (1920), Moulton (1922a,b) and, more recently, Brannang (1971), Jones (1985a) and Miller et al. (1988) have obtained data from which carcass and live body composition have been estimated by numerous equations.

Some workers actually separated individual tissues and muscles to provide more detailed information (Lawes and Gilbert, 1859; Haecker, 1920; Moulton, 1922a,b; McMeekan, 1941; Callow, 1947, 1948; Callow, 1962; Jesse, 1976; Brannang, 1971; Price and Berg, 1977; Jones, 1985).

In present day studies, whole body composition is preferred in small animal studies and can be obtained at relatively low cost. However, in large animal studies the cost of complete body and carcass dissection and analysis makes it nearly cost prohibitive. Also, dissection techniques may vary between studies and create erroneous variability in lipid or moisture content (Williams, et al, 1974). This problem has been addressed both in Europe and the U.S. by adoption of dissection procedures (Kempster, 1984; Cross, 1985). In light of changes in the types of animals demanded today, complete chemical analysis and physical dissection should be used when possible.

With beef carcasses, Butler et al. (1956) and Hedrick et al., (1965) and with pork carcasses, Breidenstein et al. (1964), determined that, although there may be small differences between right and left sides of carcasses, most differences were due to differences in separation or ribbing techniques. Thus since that time, most studies have generally involved one side of the carcass for research purposes which has reduced costs considerably. Use of data from more recent studies should serve as a

comparative endpoint for other rapid, but less accurate, indirect and less expensive methods of assessing body composition.

Use Of Carcass Cuts To Estimate Empty Body and Carcass Composition. Considerable effort has been expended in searching for carcass cuts, individual tissues, muscles or combinations of these which exhibit strong relationships either to the physical or chemical composition of the empty body or carcass (Hedrick, 1968). The early work of Hammond (1932) using parts of the body and their relationships to the whole body has resulted in considerable research on quantitative methods to estimate carcass composition. Research has been conducted on many carcass forequarter parts including the rib (Trowbridge et al., 1918; Moulton, 1922; Lush, 1926; Hopper, 1944; Callow, 1962; Morris and Moir, 1964; Busch et al., 1968; Moran, 1983), 9-10-11 rib section (Hankins and Howe, 1946; Wanderstock and Miller, 1948; Stoneker et al. 1952; King, 1954; Blumer et al. 1959; Moran, 1982,1983; Lunt et al., 1985b; Miller et al., 1988), 6-7-8 rib section (Alexander, 1961; Meyer, 1962; Hedrick et al. 1963), 12th rib section (Crown and Damon, 1960), rib core samples (Kennick and England, 1960), 10th rib section (Ledger and Hutchenson, 1962) and the foreshank (Butterfield, 1962, 1965; Callow, 1962; Hinks and Prescott, 1974). Most studies have attempted to focus on the use of forequarter cuts as these tend to be of lesser value.

Other studies have compared parts of the hindquarter including the flank (Hankins and Howe, 1946; Hedrick,1963; Allen et al., 1966) and the round (Cole et al., 1960b; Miller et al., 1965; Allen, 1966; Tuma et al., 1967).

Electronic Measuring Devices to Estimate Composition. The use of various electronic devices to estimate body composition has gained in popularity during recent years. The aim is to develop a nondestructive method of analyzing live animals and carcasses to predict composition. The principle behind many of these methods is to use the differences in density, ionic content, water content, dielectric natural radiation, electrical resistance, light reflection differences between muscle and fat, and electromagnetic properties between muscle, fat and bone to predict composition. Studies using more advanced technology such as near-infrared reflectance, (NIR; Eisen et al., 1984; Mitchell et al., 1986), nuclear magnetic resonance, (NMR), X-ray, gamma or electromagnectic radiation and electrical currents, (Miles, 1982) and total body electrical conductance, (TOBEC; Forrest et al., 1989) are currently being evaluated to determine their usefulness for measuring carcass or whole body composition.

Considerable effort has been expended in the development of fat depth indicators (FDI) in live cattle (Williams and Bailey, 1984) and carcasses (Kutsky et al., 1984; Phillips et al., 1987). Results of studies by

Williams and Bailey (1984) and Kutsky et al. (1984) led those researchers to conclude there have been insufficient improvement in the prediction of edible cuts from the live animal and carcass yield grades to warrant commercial application in the United States. Results of FDI studies by Ardnt (1983) and Phillips et al. (1984;1987) have led to the introduction and acceptance of this technology or modifications, as a tool for carcass grading in Australia, Europe and Canada.

A Video Image Analyzer (VIA) developed at Kansas State University was tested by Cross et al. (1983) on 9-10-11 rib sections of 44 carcasses and found to have considerable potential as a yield grading device. Briefly, the VIA determined: 1) average rib eye area, after three readings at the 12th rib interface; 2) fat thickness, at a point 3/4 of the distance of the lateral length of the longissimus muscle from the medial end (after up to 17 readings over a distance of 2.54 cm); 3) marbling, determined as particles of fat within the longissimus muscle completely surrounded by muscle and 4) a color lightness value of the lean tissue. Wassenberg et al. (1986) reported the VIA to be as reliable as a three member expert panel of U.S.D.A. meat graders in evaluating the percent beef carcass yield of primal lean. Development of this technology was slowed considerably in 1987 when the

major beef industry groups opted to pursue technology which could be used in live animals as well as carcasses.

Ultrasonic measurements have been the most extensively studied noninvasive method of predicting carcass composition. Wild (1950) was the first to report the use of this method which was followed by studies conducted by Stouffer et al. (1961, 1963), Wallace et al. (1977), Alliston and Hinks (1981) and Kempster and Owen (1981). Eveleigh et al. (1985) and Kempster (1986) have indicated subcutaneous fat, total fat and lean content can be accurately predicted in most species. Since the 1987 Beef Improvement Federation endorsement of ultrasound as the chosen method to estimate composition in beef cattle and carcasses numerous new studies have been reported (Sather et al., 1987;1988; Miller et al., 1988; Turner et al., 1988) in pigs and cattle.

Use of Creatinine as an Indicator of Muscle Mass. Borsook and Dubnoff (1947) showed that creatine phosphate is the immediate precursor of creatinine. Creatinine is theorized to be excreted in the urine proportionally to muscle mass. The usefulness of correlating creatinine, a physiological breakdown product of muscle, to empty body protein and lean body mass has been researched by several workers. Folin (1905) generated substantial interest in the use of creatinine as an indicator of muscle mass when he reported the amount of creatinine excreted in urine by

an individual receiving a meat - free diet remained constant. He also stated that creatinine excretion may be different for other individuals and independent of quantitative changes in the amount of total nitrogen excreted.

Beard (1943) presented a critical review of the metabolism of creatine and creatinine reporting that urinary creatinine excretion was highly variable and influenced by dietary factors. Walker (1960), showed the regulation of in vivo creatine synthesis was governed by the level of creatine in the muscles. Van Niekerk et al. (1963a,b) supported Walker's work and reported several major flaws from early work (e.g. Beard, 1943) that was made when making such claims, the major one being the incorrect inclusion of the highly variable urinary creatine excretion along with actual urinary creatinine.

Brody (1945) accumulated data from several studies suggesting that urinary creatinine excretion was related to body weight or to lean tissue in the animal body. Miller and Blyth (1952) developed an equation predicting lean body mass in humans from urinary creatinine excretion reporting that predicted lean body mass agreed within 13.1% of the densiometrically determined values in 90% of the cases. Forbes and Bruining (1976) found a high correlation (.988) between creatinine excretion and lean body mass estimated by ^{40}K counting in 21 human subjects and they developed an

equation to predict lean body mass. They also reported that daily urinary creatinine excretion did vary in their study. Their findings support previous reports including diurnal creatinine excretion (Lewis et al., 1975) and emphasized the necessity for complete 24 h collection periods extending over 3 to 4 days.

Dinning et al. (1949) reported that urinary creatinine excretion in steers was not affected by protein intake and that daily excretion remained relatively constant when compared to individual steer differences. Dinning et al. (1949) also reported that the loss of creatinine in urine samples of cattle could be prevented by lowering the pH to less than 6 and refrigerating the samples. Van Niekerk et al. (1963a) conducted several studies with sheep examining the stability and effects of diet on creatinine excretion. Their work supported the findings of Dinning et al. (1949) who reported the optimal conditions for handling urine to maintain creatinine concentration to be: a) storage at 4^{o} C, and b) lower pH to the range of 2.5 to 3.5 with 4 N H_2SO_4.

Lofgreen and Garrett (1954) examined the relationship between creatinine excretion and the lean content of steer carcasses. They used the 9-10-11 rib method of Hankins and Howe (1946) to predict the carcass lean in Hereford steers and reported a correlation of $r = .90 \pm .01$, and $r = .67$ for the relationship of creatinine to lean in the 9-10-11

rib. Van Niekerk et al. (1963b) reported even higher correlations than those of Lofgreen and Garrett (1954) for sheep. They derived prediction equations which estimate the quantity of protein, water and fat-free mass of the empty body of sheep. They also found body weight to be an accurate predictor of protein content in sheep containing less than 28% fat and weighing less than 55 kg. However, creatinine excretion proved to be a better indicator of protein content in sheep containing 28 to 47% fat than body weight. McCarthy (1981), Benner (1983), Golpinath and Kitts (1984) and Hayden (1987) found creatinine excretion in steers and heifers to increase with increasing live weight. However, they reported creatinine excretion per kilogram of body weight to plateau and(or) decrease slightly. This dilution of creatinine per unit body weight is to be expected as an animal begins to reach maximum muscle mass after which increases in live weight are mainly due to increases in fat.

Potassium 40 (^{40}K) Counting. Among noninvasive, nondestructive methods for predicting body composition, considerable efforts have been devoted to studies with ^{40}K (Zobrisky et al., 1959; Lohman et al. 1966; Frahm et al., 1971; Clark et al. 1976; Stiffler et al., 1980; Rider et al., 1981). Potassium 40 is a naturally occurring radioactive isotope, that represents a relatively constant

proportion of .011% of the total potassium, with a half life of 1.3×10^9 years (Anderson, 1959). During homeostasis, the concentration of potassium in the cell is constant. The presence of ^{40}K in the tissue provides an assessment of total muscle mass, since the majority of potassium present in the body is in muscle tissue (Kulwich et al.,1958; Kirton and Pearson, 1963; Forbes, 1963; Lohman et al., 1966).

A number of studies have been reported in which positive relationships were observed between ^{40}K counting for muscle in live animals and negative correlations for fat in sheep (Judge et al., 1963), cattle (Clark et al., 1972; Stiffler et al., 1980; Rider et al., 1981) and pigs (Stant et al., 1969). Recent studies by Stiffler et al. (1980) and Rider et al. (1981) address the problems of background interference and(or) depression, self absorption, accuracy of measurement, calibration of the equipment and repeatability. These studies report high correlations ranging from .92 to .97 using mutiple regression equations and they give at least as high or higher correlations as those reported by McKellan (1969) and Frahm et al. (1971).

Early studies suggested that changes over time, e.g., weight, age and organ potassium concentrations may alter total body potassium. This was thought to be significant enough to render the procedure unreliable. Data of Stiffler

et al. (1980) and Rider et al. (1981), while displaying decreased counting efficiencies, do not support this postulation. They found high correlations between ^{40}K counts and total body lean. These studies, as well as those of Johnson et al. (1973), showed an increase in total potassium content in the body. Potassium concentration in muscle, however, decreased as weight increased.

Distribution of potassium in the body tissues of cattle was studied by Lohman and Norton (1968). Trimmed muscle tissue contained 53.4 percent of the total potassium, with 12.4 and 16.4% in skeleton and gastrointestinal tract and contents, respectively. Fat depots are devoid of potassium except that from blood and the connective tissues in adipose tissue. The remaining potassium in the body is in other organs and blood.

Whole body counting has been shown to quite accurately estimate total body fat-free lean. However, certain constraints will limit the use of this procedure, e.g., availability, cost of equipment and extended time of counting to obtain measurements.

Dilution Techniques and Total Body Water Space. Shebaita (1977a,b) and Sheng and Huggins (1979) discussed the relationships between body water, body fat and the weight of the fat-free body in animals. Numerous researchers have reported data using various dilution techniques to estimate total body water in humans, rats,

cattle, pigs, sheep, and several other species. The most commonly reported tracers used are, antipyrine (and its derivatives), urea, and isotopes of water, notably tritium and deuterium oxide.

The underlying assumption associated with dilution technique is that the fat-free body is relatively constant in water, protein and ash (Panaretta and Till, 1963; Widdowson, 1968). Thus, when chemical maturity is attained (Moulton, 1923) in vivo measures of water can be useful in determining composition. The tracers mentioned above are easily analyzed and can be used to estimate body water, protein and fat. In the application of this technique, a measured amount of a tracer is injected (IV) into the animal, and allowed to become distributed in the body. Once equilibration into the body pools has occurred, blood is sampled to determine the tracer concentration. The volume of fluids (water) is calculated by dividing the known quantity of tracer injected by the concentration of the tracer at the time of equilibration (Shipley and Clark, 1972).

Several considerations must be kept in mind when using tracer chemicals. The compound must remain stable, be distributed quickly and uniformly in the body, be nontoxic and excreted slowly. Complications in using the dilution techniques are also numerous. Of greatest concern in the ruminant, is the dynamic flux of water in and out of the

rumen. Nutritional state is also a concern (Farrell and Reardon, 1972), since animals which are undernourished have a significantly higher water content. Although fat can be estimated, there is no measure of distribution in the body or actual thickness of some measured depots (e.g., backfat). Finally, these tracer methods cannot be used immediately before slaughter according to government inspection regulations.

Antipyrine Dilution. Brodie et al. (1949) described methods to determine antipyrine concentrations in biological fluids. Soberman et al. (1949) successfully applied these principles to humans to measure total body water. Application of antipyrine to animal studies was accomplished by Kraybill et al. (1951), on 30 cattle, to determine total body water. He found good agreement between this method and specific gravity observation. Kraybill et al. (1951) concluded that the fat-free body contains 73.2 percent water.

Wellington et al. (1956) found high relationships between antipyrine and water, fat estimates and actual cutout data. Further studies by Reid et al. (1957) with cattle; Kraybill et al. (1953) with pigs; Keys and Brozek (1963) with human subjects and Panaretto (1963a) with rabbits also showed high relationships.

This technique however, is not without problems as mentioned by Wellington et al. (1956) and discussed by Whiting et al. (1960). The major shortcoming of antipyrine dilution in ruminants is the uneven distribution and equilibration of antipyrine with the gastrointestinal tract water (Wellington et al., 1956; Hansard, 1963; Bensadoun et al., 1968). Others have confirmed the limitations with this procedure and reported unusually high values for body water between identical twin dairy heifers (Swanson and Neathery, 1956). Several chemical analogs of antipyrine have been employed for similar research, e.g., N-acetyl-4-aminoantipyrine (Reid et al.,1957; Panaretto and Till, 1963) and radioactive antipyrine (Hansard, 1963). Use of these derivatives also indicated unusual activities involved in equilibration between metabolic pools, further suggesting limitations of this technique.

Urea Dilution. The advantages of repeated growth measurements in nutritional and growth studies is well documented. San Pietro and Rittenberg (1953) suggested urea would be a satisfactory tracer, meeting all the requirements described by Soberman et al. (1949). Preston and Koch (1973) were among the first to use urea in dilution studies in cattle as a method for estimating body compostion. A distinct advantage of urea dilution as a marker is the minimal handling and single sampling time to arrive at an estimate of urea space (US). Several workers

(Preston and Koch, 1973; Bennett et al., 1975; Koch and Preston, 1979) examined the differences in urea equilibration times in blood and body water. They found urea and cellular water equilibration times to be optimal between 12 and 15 minutes post-injection. In recent studies (Bennett et al., 1982; Hammond, 1984;1988) sampling at 12 minutes post-infusion was used to determine US.

Preston and Koch (1973) and Koch and Preston (1979) used carcass specific gravity as an index of composition with which to compare US composition estimates. They found high correlations ($r^2 > .68$) between US, rib water, protein and fat and with carcass specific gravity.

Comparisons of US dilution with noninvasive electronic measuring devices have been examined by Bennett et al. (1982) and Jones et al. (1982). Jones et al. (1982a) used ultrasonic measures of backfat thickness in lambs, mature cows and steers to compare them with US determinations of carcass lean. Their low correlations of $r^2 < .30$ for lambs, $r^2 < .55$ in cows and $r^2 < .14$ in steers raised considerable doubt as to the effectiveness of this method. Bennett et al. (1982), on the other hand, found US to be a better predictor of composition than ultrasonic measurements in uniform animals, adjusted to constant weights. However, they concluded that ultrasonic measurements and US were equally reliable as indices of body composition over a wide range of breeds.

Meissner et al. (1980a,b,c) used urea and tritium to estimate body composition in young bulls. They found that tritium was more accurate in predicting body composition than US. When additional variables (i.e., body weight) were included, the reliability of US as a predictor of composition was increased. Bartle et al. (1983) examined the use of live weight US versus empty body weight in mature beef and dairy cows. US of live weight was poorly correlated with composition as determined by specific gravity and 9-10-11 rib composition. However, empty body US correlations were improved for both types of animals. Further refinement of the multiple regression equations with inclusion of plasma urea-nitrogen (PUN) changes improved correlations to r^2 = .66 and .62 for beef and dairy types, respectively. Inclusion of initial PUN values improved correlations for dairy animals only. These studies indicate the usefulness of US dilution is improved when other independent variables are included in the multiple regression equations. Hammond et al., (1984,1988) recently evaluated the urea dilution technique by comparing US to actual direct measurement of empty body water in steers. They reported correlations of $r^2 > .96$ between US and empty body water with multiple regression analysis. Inclusion of other independent variables predicted empty body water in similar ways.

In general, these studies suggest urea dilution is a

useful method for estimating body composition. The most useful application of predicting composition by US, appears to be in conjunction with other variables in developing predictive multiple regression equations.

Hydrogen Isotope Dilution. Since water comprises the largest component of the lean empty body, logic would suggest this ought to be the method of choice for measurements in growth and nutritional studies. Several hundred references report information and analyze the advantages, disadvantages and differences between deuterium oxide (D_2O) and tritiated water (TOH) in dilution studies.

Water labeled with either D_2O or tritium serves as an ideal tracer with which to measure water fluxes since they cross the barriers in the body at the same rate as body water (Pinson, 1952). The hydrogen isotope dilution technique was introduced by Hevesy and Hofer (1934) in studies in humans. Tritium, (t1/2 = 12.3 years), the radioactive isotope of hydrogen with the atomic mass of three, has been the favorite isotope for use until recently. Tritium has been relatively inexpensive and can be measured at low concentrations, especially with the increased sensitivity of liquid scintillation counters. However, the concerns with disposal costs and safety have limited the use of TOH in large animals. Deuterium (D2),

on the other hand, is a stable, nonradioactive isotope of hydrogen. Natural occurring concentration ratios of D2 to hydrogen are about 150 ppm. D2 combines with oxygen to form D_2O which is about 10% denser than pure water. D_2O has become the hydrogen isotope of choice in tracer studies of large animals even though it is relatively expensive. This increased cost is more than offset by the salvage value of the carcasses, otherwise lost in TOH studies. Also, improvements have been made in measuring sensitivity at low concentrations by Byers (1979a) and Zweens et al. (1980), with further modifications described by Ferrell and Philips (1980).

Many authors have reviewed the use of the biological tracers to measure body water (Pinson, 1952; Widdowson and Dickerson, 1964; Panaretto, 1968; Ward and Johnson, 1972; Sheng and Huggins, 1979 and Nagy and Costa, 1980.). Lifson and McClintock (1966) list several assumptions made when using the labeled water method. These include: 1) constant body water volume, 2) constant water flux rates, 3) tritium only labels body water, 4) tritium leaves the body in the form of water, 5) the specific activity in water leaving a labeled animal is the same as that in the animal's body water and 6) water in the environment does not enter animals through their skin or lung surfaces. Nagy and Costa (1980) evaluated these assumptions and concluded that although there are problems with each of these assumptions

and exaggerated values could result, the heavy water methods provide a reasonably accurate measure of body water. These findings are in general agreement with equations for isotope dilution analysis and validation presented by Gest et al. (1947) and Radin (1947). Pinson (1952) examined the use of D_2O and tritium in water exchange studies and Edelman (1952) studied the relationship of D_2O equilibration with body water. Because of the unique properties of both D_2O and TOH, research workers have found exchanges of D2 with the hydrogen of water to generally overestimate body water both in pregnant ewes (Trigg et al., 1978) and in cattle (Robelin, 1982) and Arnold et al., (1985). Tritium has also been found to both overestimate (Sheng and Huggins, 1979; +4 to 15%) and underestimate (Donnelly and Freer, 1974; Trigg et al. 1978; -2.4%), body water.

The use of these techniques for determining body composition in farm animals has been reviewed by Reid et al. (1955) and Pearson (1965). The majority of studies used D_2O or TOH to determine total body water followed by estimates of body composition. TOH has been used extensively in sheep (Till and Downes, 1962; Panaretto, 1963; Panaretto and Till, 1963; Panaretto, 1964; Reardon, 1969; Searle, 1970a,b,c; Smith and Sykes, 1974; Donnelly and Freer, 1974; Trigg et al., 1978) to determine either total water, body composition or both. Donnelly and Freer

(1974) used data collected from 149 Merino and Merino crossbred sheep to develop prediction equations for estimation of body composition. They found that inclusion of the variable, maturity, in the regression equations decreased residual standard deviations to a large enough degree so that the equations could be used across a wide range of ages. Searle (1970b) evaluated TOH space in 33 wethers as a predictive tool in previously published equations (Searle, 1970a). Refinement of the equations reduced variances of individual body components from the earlier study (Searle, 1970a) to the point that Searle proposed tritium dilution as a reliable method to measure body composition from 3 days of age to the adult stage in sheep. Furthermore, Trigg et al. (1978), although finding TOH space to underestimate body water by 2.4%, stated the results for body composition were more precise than those obtained by either ^{42}K dilution or D_2O techniques.

In cattle, TOH space has been used to estimate body water and composition by Carnegie and Tulloh (1968), Meissner et al. (1980a,b,c), Chigaru and Topps (1981), Little and McLean (1981). Meissner et al. (1980a,b,c) physically separated the body components of 20 cattle and performed chemical analysis. TOH could be used to estimate water, protein and ash, but the variation at 400 kg live weight ranged from 4 to 10%. However, ether extract showed a 25 to 30% variance with that predicted from TOH space.

Little and McLean (1981) also dissected and analyzed the whole body components of TOH infused animals, using chemical analysis and TOH space to derive equations. They included gut water as a part of whole body weight. Correlation coefficients between actual and predicted values for total body water (TBW), total body fat (TBF) and total body protein (TBP) were .984, .997 and .956, respectively. They indicated that, since TBW was being estimated, it is important to accurately measure fasted live weight (FLW), which includes gut water, immediately before slaughter. Accurate measures of FLW are closely related to the sum of TBW plus TBF along with TBP. They found, as did Haecker (1920) and Foot and Tulloh (1977), that gut contents were 87% water with the total dry matter in the gut being 1.75% of FLW. Suggestions of the need for further research into repeated measurements of body water in the same animal, to quantify body composition differences between animals is supported by these data and others.

In early studies with D_2O in sheep (Till and Downes, 1962; Foot and Greenhalgh, 1970; Farrell and Reardon, 1972; Trigg et al. 1978) and cattle (Little and Morris, 1972; Crabtree et al., 1974; Robelin, 1977), body water space was treated as a single pool including both actual body water and gut water as one component. This extra gut water, which is not related to any gut or carcass tissues, can

fluctuate on the average from 3 to 5 % or more per day due to dietary, environmental and animal differences (Nagy and Costa, 1980; Robelin, 1982). This variation can introduce substantial error in predictions of total body water if not accounted for.

Crabtree et al. (1974) found high correlations between D_2O space (DS), fat-free mass and empty body water (EBW) in six Fresian (F) and six F x Hereford steers. Robelin (1982) used a similar approach, with some modification, when he attempted to estimate gut content and correct for it in the final equation. He found a high correlation between predicted body fat and "mean" body weight. Measures of body weight are needed, however, when the animal is in a normal unstressed environment. His findings supported the use of D_2O to predict other components of body composition as well. Arnold et al. (1985) evaluated the one compartment model, (1P). He found that empty body protein (EBP) was overestimated by 3.6% and gastrointestinal tract water (GITH2O) was also overestimated by 13.4% with this method. Further improvements are necessary to develop consistently accurate equations.

Shipley and Clark (1972), after examining body water tracer kinetics, proposed numerous predictive equations which utilize dilution principles. In an effort to solve the problem of overestimation of body water due to variable

gut water, Byers (1979b) proposed separating body water and GITH2O into two pools. As pointed out by Smith and Sykes (1974), the majority of the variation in fat content can be accounted for by variations in empty body weight and water content either with or without GITH2O included. Theoretically then, accurate elimination of gut water by a dilution curve peeling process should improve prediction equations which can assess body composition.

Byers (1979b) applied his system to a diverse group of cattle ranging from calves to cows. D_2O dilution predictions were shown to be correlated with actual chemical analysis (r2=.965) and specific gravity (r2=.952). McCarthy (1983b) used the same procedure comparing small and large frame steers. He found high correlations for DS derived values with 9-10-11 rib section analysis, but low relationships between DS values and specific gravity, and between specific gravity and 9-10-11 rib section for water and fat. Ferrell and Jenkins (1984) applied the D_2O space technique to mature cows. They found that the relationship between D_2O pool size A (empty body water space) and the weight of body fat to be low (r2=.08). Modifications of the regression analysis to include EBW greatly improved the relationship (r2=.86) to estimate body fat. Empty body weight was highly predictable from live weight and D_2O pool B (GITH2O). However, due to high residual standard deviations in estimating weight of body fat, they found the

usefulness of D_2O space to be limited. Martin and Ehle (1986) reported body composition changes in dairy animals during and between lactations and ages large enough to merit further work and refinement. This observation also supports work by Odwongo et al. (1984) in dairy cattle.

Lunt et al. (1985b) used D_2O space to predict carcass composition in 32 Brahman, Angus and Brahman x Angus steers slaughtered after various gains in live weight. They found USDA yield grade (YG), specific gravity (SG), 9-10-11 rib section (RIB) analysis and chemical composition to more accurately predict carcass composition than D_2O dilution. This should be expected, since YG, SG and RIB evaluate only a portion (carcass) of the total body components. D_2O dilution, on the other hand, predicts the composition of the entire animal (carcass, hide, head, and viscera) of which a substantial amount of body fat and protein may be associated with noncarcass components. Miller et al. (1988) used 50 cattle ranging in age from calves to cows and found results similar to those of Lunt et al. (1985b).

Arnold et al. (1983,1985) compared body composition as estimated by the one pool (1CM) system of Loy (1983), the two pool (2CM) model (Byers,1979b) and a three comparment (3CM) model which consisted of intracellular, extracellular and GITH2O components for the direct measurement of body composition in 30 steers. They indicated each method has shortcomings for estimating body composition. The 1CM

method appears to more accurately estimate empty body ether extract (r=.82) than the 2CM method (r=.59). The 2CM method, however, more accurately predicted total body water, r2=.90 vs .84. The 3CM method showed no improvements over the 2CM method in estimatimg body water. Byers (1986) used 50 cattle ranging from calves to mature cows to assess the applicability of the D_2O dilution technique and other procedures to estimate body composition in beef cattle. In addition to standard curve peeling techniques, a simplified biexponential regression procedure was presented. Predictions of EBW, GITH2O and fill were all highly correlated (r^2=.97,.86,.90, respectively). Empty body weight, water, protein and lean body mass were also highly predicted, r2=.98 +/- about 2% for EBW and 7% for the other lean body components. As expected, fat was more variable when predicted (r2=.88, CV=24.6%) but inclusion of ultrasonic measurements reduced variation and increased precision.

The literature contains numerous conflicting comparisons which suggest the need for further studies and refinement of these procedures to increase the precision of their predictive value. Further studies evaluating these techniques which measure body and carcass composition using cattle differing in sex, age, fatness, muscling, breed and diet are needed to establish well proven and accepted techniques for use by scientists interested in

body composition, particularly with todays leaner, later maturing animals.

Methods of Estimating Carcass Composition

Whole Rib Composition. Hall and Emmett (1912) and Moulton et al. (1922) reported close relationships between wholesale rib composition and that of the beef carcass after dissection. Lush (1926) and Hopper (1944) reanalyzed the same data on 92 cattle and agreed with Trowbridge (1918) and Moulton (1922) that composition of wholesale ribs was representative of the entire carcass. Hopper (1944) presented prediction equations comparing muscle, fat and bone components as well as chemical composition of the wholesale rib to that of the carcass. The rib was selected for its ease of removal and higher correlation to carcass composition compared to other cuts. Berg and Butterfield (1976) and Moran (1982,1983) pointed out, however, that due to genotypic differences among animals and different management systems, proportions of carcass muscle and fat in different cuts may lead to erroneous conclusions. Further refinements of the wholesale rib section analysis have decreased costs and economic loss through the use of portions of the rib.

9-10-11 Rib Section. The work of Hopper (1944) stimulated research on the wholesale rib, or parts of the rib (Hankins and Howe, 1946) to determine the relationship

of the 9-10-11 rib to that of the entire rib and dressed carcass. In their studies, the 9-10-11 rib sections from 197 cattle were separated into muscle, fat and bone. Chemical analysis was performed on these tissues. High correlations between separable fat and lean, along with chemical fat and protein, with both the wholesale rib and the carcass were found. Hankins and Howe provided detailed procedures for separating the 9-10-11 rib section to improve consistency between investigators. This method has routinely been followed, supplying relatively accurate results in most serial slaughter trials and reduced expense compared to the wholesale rib. This method, however, has several drawbacks which many researchers ignore (Moran, 1982). Among the problems with this procedure is the decreased ability to accurately predict the amount of lean in the carcasses of heifers. The major concern originates from the fact that these equations have been developed from animals of a specific species (Bos taurus) produced under a specific management system which can influence composition. Moran (1982, 1983) and Berg and Butterfield (1976) point out these variables can lead to less accurate predictive ability. Since the publication of the equations by Hawkins and Howe, numerous investigators have successfully applied them or developed similar equations which use the separable and chemical components of the 9-10-11 rib from animals of different breeding or management

systems (Jones, 1982,1985c; Lunt et al., 1985b; Miller et al., 1988). These researchers evaluated several commonly used methods of estimating carcass composition and consistently report the 9-10-11 rib to be the method of choice with the highest correlations.

Alhassan et al. (1975) used the 9-10-11 rib section and carcass weight to predict empty body composition. These researchers concluded that prediction of body water and ash from weights of 9-10-11 rib moisture, ash and carcass weight were unacceptable. They also noted a difference in maturity between the Angus and Hereford steers used in the experiment. Their findings suggest that the rib section was more acceptable in predicting body composition across breeds than body weight measurements.

10th and 12th Rib Sections. Limited information is available on the use of the 10th and 12th rib section separable components to predict carcass composition. Crown and Damon (1960) found correlations of .96, .82 and .75 for percentage separable fat, lean and bone, respectively, of the 12th rib and corresponding carcass components. On the other hand, Ledger and Hutchison, (1962), found low relationships between separable and carcass components. Due to descrepancies in findings this procedure has not received much attention.

6-7-8th Rib Section. Several researchers (Alexander, 1961; Meyer, 1962; Hedrick et al., 1963) related the separable components of the 6-7-8th rib section to the yield of trimmed wholesale cuts. While the correlation coefficients were significant (r^2 >.6) for muscle and (r^2 > -.6) for fat, they are lower than those reported by Hankins and Howe (1946) for the 9-10-11 rib section.

Rib Core Section. Kennick and England (1960) explored the use of a smaller rib section to determine carcass composition. They used a core sample from between the 8-9th and 9-10th rib to relate to carcass composition. They suggested this method could be useful with large number of animals, but it has never gained support.

Wholesale Flank. Separable components of the flank were reported by Hankins and Howe (1946), Hedrick et al. (1963), Knapp (1964), Miller et al. (1965), and Allen et al. (1966) to be highly related to total carcass muscle and fat. Hankins and Howe (1946) actually found the correlation between flank separable fat and percentage ether extract to be higher than the 9-10-11 rib section, (.95 vs .93). Hedrick et al. (1963) reported the percentage fat in the wholesale flank was significantly correlated with percentage trimmed wholesale cuts (r=-.86) and trimmed primal wholesale cuts (r=-.80). Additionally, Miller et al. (1965) indicated percentage retail yield of

the flank was highly related to percentage boneless retail cuts (r=.78) and partially boneless retail cuts (r=.81) of the carcass. Knapp's (1964) findings were in agreement with these observations for the flank (r=.75). Allen et al. (1966) compared various carcass cuts including the flank from carcasses of several weight and fat thickness groups. Correlations between separable muscle, fat and bone in the flank and the carcass were .91, .91 and .32, respectively. These reports consistently showed higher relationships for the flank than the round. Thus, components of the flank have been shown to be highly correlated to muscle and fat in the entire carcass.

Since the flank is one of the less valuable cuts in the carcass, the monetary loss from each carcass makes this an attractive method of predicting carcass composition. However, use of this method is limited by potential differences in technique of flank removal and the possibility of excessive errors.

Wholesale Round. High correlations between separable muscles in the round and the yield of the carcass have been reported. Cole et al. (1960b) indicated that muscles in the round account for 90% of the variation in total carcass muscle. Miller et al. (1965) and Cahill (1966) showed significant relationships (r>=.80) between the round (trimmed and boneless) and partially boneless cuts of the carcass, primal cuts or weight of retail cuts (Tuma et al.,

1967).

Tissue Sawdust Techniques. Use of meat tissue sawdust has been examined by several researchers to evaluate its value for prediction of carcass composition. Vance et al. (1970) reported significant correlations ($P < .01$) between chemical components of beef carcass sides and meat sawdust obtained by sawing through the round, loin, rib and chuck of frozen sides at 2.54 cm sections. Williams et al. (1974) used Vance's technique in three trials with bull carcasses averaging 282 kg; Holstein calves averaging 138 kg and frozen carcasses from Holstein bull calves which averaged 338 kg live weight. They found that frozen carcasses, as compared to chilled carcasses, yielded the most reliable results when sawed at 2.54 cm intervals. Correlations between sawdust composition and carcass chemical composition ranged from .72 to .94 for carcass moisture and fat. Correlations of carcass protein and carcass ash with sawdust composition ranged from .64 to .68. Sawdust from chilled sides was considerably less reliable than sawdust from frozen sides as a predictor of carcass chemical composition, thus limiting the application of this technique, since the majority of beef carcasses are merchandised in the fresh chilled state.

Specific Gravity. Application of the carcass density principles to live subjects and tissues has been popular

over the past 50 years. Studies with humans by Behnke et al. (1942), as well as by Keys and Brozek (1953), were successful in measuring body fatness. As pointed out by Pearson et al. (1965, 1968) however, application of this procedure is virtually impossible with live animals. Therefore, use of specific gravity has generally been limited to postmortem components in animal studies.

Conceptually, specific gravity separates the carcass into two pools. The lean tissue has a density of 1.10 and fat is about .90. By weighing the carcass or cut in air and then in water, the density of the entire carcass can be determined. Numerous considerations must be taken into account, in developing equations, as outlined by Garrett (1968) and reviewed by Pearson et al. (1968) and more recently by Jones et al. (1978a). Briefly, the temperature of the water and the carcass, degree of hydration or dehydration of the carcass and the amount of trapped air in the carcass or cuts influence specific gravity.

In studies by Pace and Rathbun (1945) with guinea pigs, and Kraybill et al. (1953) with pork, Kirton and Barton (1958) along with Field et al. (1963) with lambs, demonstrated the usefulness of specific gravity as an index for measuring fat. Studies by Kraybill et al. (1952), Garrett et al. (1959), Kelly et al. (1968), Garrett and Hinman (1969), Preston et al., (1973), Ferrell et al., (1976) and Jones and Rompala (1985a) have provided high

correlations between specific gravity (density) and fat in beef carcasses. Additional studies have also been conducted with the use of specific gravity on certain carcass cuts and(or) muscles to assess carcass composition (Hopper, 1944; Lofgreen and Garrett, 1954; Orme et al., 1958; Cole, 1960a; Field et al., 1963; Latham et al., 1966; Ledger et al., 1973; Mata-Hernandez et al., 1981). Hedrick (1983) pointed out that studies by Waldman et al. (1969) and Gil et al. (1970) determined that specific gravity is not accurate for carcasses with low amounts of fat (< 20%). Garrett et al. (1968) and Riley (1969) indicated that the equations using specific gravity as an index of composition are likely to be more accurate with fatter carcasses since higher proportions of fat have lower specific gravity values. These reports are supported by the work of Preston et al. (1974) and Fortin et al. (1980a;1981) which indicate that measurement of specific gravity for individual carcasses is highly variable, but if compared between groups of carcasses, relatively large differences in composition can be detected.

Recent studies by Kempster et al. (1982a) and Jones et al. (1985a) using simple carcass measurements (e.g., fat thickness measurments) in conjunction with specific gravity provide a better prediction of carcass lean. Powell and Huffman (1968) found specific gravity results similar to those found by Kraybill, Bitter and Hankins (1952) and

Garrett and Hinman (1969). On the other hand, Lunt et al. (1985b) using Brahman, Angus and Brahman x Angus crossbred steers, found specific gravity accounted for a suprisingly low amount of variation (63 to 80%) in the percentages of separable lean, fat and bone in carcasses varying widely in composition. Miller et al. (1988), using a group of cattle from diverse biological types and mature sizes, concluded that specific gravity was not a useful tool for predicting composition in any age class from calves to cows. Miller cited problems caused by hide pullers, which entraps extra air between the fat and muscle, as one of the major reasons for unexplained differences in hindquarter and forequarter weights in water. This resulted in the inability of specific gravity to adequately estimate carcass composition in their study. It should be pointed out, that in early studies, as well as in studies today that attempts to use specific gravity as a tool to measure composition, carcasses should be dressed using the cradle methods. This prevents entrapment of excessive air under the fat. Also, past studies have repeatedly shown poorer predictive values in carcasses with less than 20% chemical carcass fat. These considerations should be taken into account when designing studies or interpreting results.

Relationships of Marbling Score to Carcass Composition, Ether Extractable Lipid Content of other Major Muscles and

Changes in Muscle to Bone Ratios. Intramuscular or intrafascicular adipose tissue (IFAT) commonly called marbling, has been examined by several researchers observing developmental increases in IFAT and its affects on muscle:bone ratios. Others have evaluated the usefulness of marbling score (Brackebush et al., 1988; Savell et al., 1986) and(or) content (Kauffman et al., 1975), in predicting carcass composition and ether extractable lipid (EEL) or fat of the longissimus dorsi (LD) and other muscles.

Johnson et al. (1972) conducted a feeding study in which about 10 percent of total fat was found in the intramuscular adipose tissue site. This relationship appeared to be constant when total side fat was about 16 kg. Whether 10 percent of total fat in IFAT is a general figure for most cattle remains unanswered, but Berg and Butterfield (1976) indicated there is an indication of genetic differences in quantities of IFAT and subsequent differences in the EEL found in IFAT. Berg and Butterfield (1976) also cited studies by Damon et al. (1960) and Kauffman et al. (1968) which relate increases in subjective marbling score to increases in fat thickness. This has generally become accepted as dogma in the beef industry.

Still others have examined the effect of IFAT development on muscle:bone ratio. Berg and Butterfield (1976), after reviewing several studies, observed that in

cattle with a muscle:bone ratio of 4:1 at 110 kg muscle plus bone weight, IFAT contributes .27 to the muscle in the ratio of 4:1. In the same cattle with 40 kg muscle plus bone weight and a muscle:bone ratio of 3.80:1, .14 of the muscle in the ratio was contributed by IFAT. They summarized their findings by suggesting a large part of the changes in muscle:bone ratio associated with increased weights could be explained by changes in fat within the muscles.

Cross et al. (1975) examined variations in marbling content in different muscles of beef carcasses. They compared the differences between marbling score required to quality grading the entire carcass versus the marbling score needed to quality grade individual carcass wholesale cuts. These researchers found lower marbling scores in the cross section of the round/loin and chuck/rib interfaces than the 12-13th rib interface. Also, as marbling content in the 12-13th rib decreased, marbling scores in the round and chuck also decreased in almost all cases. These findings contrast with those of Cook et al. (1964) who found an increase in marbling from the 12th to 6th thoracic vertebra. Doty and Pierce (1961) also reported variations in marbling scores and chemical fat content in the longissimus muscle from the 11-12th rib to the 7th/8th rib cross section.

Kauffman et al. (1975) suggested marbling score be used not only as an index for quality, but, in conjunction with U.S.D.A. yield grade, as a quantitative measure to predict fat - free muscle in beef carcasses. They developed regression equations using numerous carcass traits including marbling score to estimate percent fat standardized muscle.

Brackebush et al. (1988) found the fat content of all muscles in their study to be linearly related to LD fat content. The R^2 values ranged from a low of .81 for the supraspinatus, to a high of .92 for the spinalis dorsi. They concluded that percentage fat (EEL) in the LD can be used to predict the composition of other major muscles of the beef carcass.

Savell et al. (1986), responding to consumer concerns about fat content in beef, collected longissimus samples from the 13th rib of 518 beef carcasses ranging in marbling score from moderately abundant to practically devoid. They determined EEL and moisture content which ranged from 10.42 and 68.14 percent, respectively, for moderately abundant, to 1.77 and 75.37 percent, respectively, for practically devoid marbling scores. They developed a regression equation which predicts the percentage EEL of the longissimus at the different marbling scores. The equation:

% EEL =(marbling score x .0127) - .8043, (R^2 =.779),

appears to adequately estimate EEL of the longissimus with external adipose tissue and epimysium removed.

Relationships of Individual Muscles or Groups of Muscles to Carcass Composition and Carcass Lean. As previously mentioned, several researchers have reported that either entire wholesale cuts or parts of wholesale cuts can be used to estimate carcass composition, usually with high predictability, particularly for carcass muscle in hogs (Lush, 1926; Hammond, 1932; McMeekan, 1941) and beef (Hankins and Howe, 1946; Hankins et al., 1959; Crown and Damon, 1960; Cole, 1960a; Butterfield, 1962; Callow, 1962). Numerous muscles or groups of muscles have been excised to examine relationships between muscle weight and total separable carcass lean. Orme et al. (1960) dissected carcasses of mature Hereford cows, removing the longissimus dorsi (LD), semimembranosus and adductor (SM and AD), semitendinosus (ST), biceps femoris (BF), quadriceps (Q), psoas major (PM), triceps brachii (TB), and infraspinatus (INS). They found significant relationships, to varying degrees, between muscle weights and total carcass lean. Butterfield (1962) used the same muscles and the shin group from purebred Hereford or Brahman and Hereford x Brahman cattle to predict total muscle. He observed even higher correlations than did Orme et al.

(1960). Butterfield (1962) also indicated little effect of genetics on the relationship of muscles or groups of muscles to total muscle. He stated further that the influence of age on muscle content appears to be insignificant after six months of age. Price and Berg (1977) also used a group of muscles similar to Butterfield (1962) to predict total carcass muscle, stating that the relationship between predictor muscles and total muscle of the side can give meaningful estimates of total muscle of the side in a wide range of carcass types.

Recent work by Lunt et al. (1985a) with Angus, Brahman and crosses of these breeds, showed high relationships between certain muscles and(or) groups of muscles with total carcass lean. Their study, however, disagrees with earlier findings of Orme et al. (1960) and Butterfield (1963), exhibiting high variations between breeds when using muscles to predict total carcass lean.

Relationship of Longissimus Dorsi Area to Predict Total Muscle. Measurement of the cross section of the longissimus dorsi (LD) muscle at the 12th rib interface has received some interest over the past 50 years as an estimate of carcass muscle mass. Mackintosh (1937) used a sheet of parchment paper to trace an outline of the muscle and then measured area with a planimeter. Stull (1953), Schoonover and Stratton (1957) and Shrewsbury and Wideman

(1961) described techniques to measure the LD by photographing the muscle and then using either a wire grid or a planimeter to obtain the area. Henderson et al. (1966a) were among the first to refine the present plastic grid system for measurement. While not as precise as a planimeter, the differences were small. Ribbing differences between sides or carcasses are responsible for the majority of cross sectional area discrepancies (Hedrick et al. (1965).

Several researchers (Cole et al., 1960; Goll et al., 1961; Cole et al., 1962; Abraham et al., 1968) related the LD area to the separable lean in the carcass. They found the LD area to be associated with only about 18% or less of the variation in total carcass lean. Theoretically, use of LD area to predict muscle is sound, since the impetus for growth of this muscle, described by Berg and Butterfield (1976), is average. Unfortunately, numerous environmental and genetic variables exist which limit the usefulness of this measurement as a reliable predictor of total muscle in beef carcasses.

Prediction of Empty Body and Carcass Composition by Linear and Multiple Regression. Hopper (1944) and Hankins and Howe (1946) were among the first to develop linear regression equations for predicting beef carcass composition from the physical and chemical components of the wholesale rib and the 9-10-11 rib section. It is

beyond the scope of this dissertation to review all methods. Hedrick (1983), however, reviewed the literature citing a vast number of studies in which equations are available to predict body and carcass composition.

The major problem a researcher encounters when developing prediction equations includes identification of the "best" equation (MacNeil, 1983). At best, the definition of "best" could be considered nebulous. A commonly cited definition is (MacNeil,1983):

a) the equation must be unbiased or without discernible trends in the errors of the prediction, and;

b) the accumulated squared errors of prediction should be maximized.

Interpretation of results using prediction equations to estimate composition should be a major concern of scientists working in studies which measure changes in animal composition by prediction equations.

Correlation coefficients (r) and coefficients of determination (r^2) have traditionally been the major index referred to determining usefulness of equations. r^2,

$$r^2 = \frac{\text{sum of squares due to regression } (SS_r)}{\text{corrected total sum of squares } (SS_y)} ,$$

is usually maximized which provides a convenient statistic identifying the models (equations) having the largest sum

of squares due to regression within that study. Maximum r^2 is commonly interpreted to mean that the equation with the highest r^2 accounts for the greatest percentage of total variation in Y (the dependent variable) of all equations. MacNeil (1983) demonstrated that an equation with a maximum r^2 can in fact, have prediction error variance larger than the other equations derived from the same data.

In determining the correlation coefficient (r) between the assumed random variables X and Y, r is influenced by the range of values in the sample on which it is based. Correlation coefficients derived from biologically diverse populations will be considerably higher than those from a less variable population and potentially lead to erroneous conclusions.

Cross (1982) provides a classic example of misinterpretation of correlation coefficients derived from data between two groups of animals, which is presented in Table 1. The r^2 for group I is much higher than group II, suggesting the predicting equation from group I is more accurate. However, considerably <u>less</u> variation exists in group II carcass lean percentage resulting in a low r^2 value. Prediction of carcass lean percentage in group II would have no more error than group I, since the residual standard deviations (RSD) are equal. Cross suggests that since RSD accounts for the variation in Y, this would be a better equation selection criterion. Ideally, an equation

having a high r^2, as well as a low RSD, would be preferred.

TABLE 1. Comparison of Predictive Accuracy Between Two Groups of Pigs

Trait	Group I	Group II
Backfat thickness, cm (X), standard deviation	5.1	2.99
Percentage lean, % (Y), standard deviation	4.1	2.29
R^2	.75	.21
Residual s. d., %	2.05	2.05

MacNeil (1983) and Moran (1983) discussed the evaluation, selection and use of prediction equations for various scientific objectives. Accuracy should be the ultimate concern when selecting an equation and precision should only be a secondary factor in choosing the final equation.

The ultimate test of a prediction equation's usefulness for future experiments is the validation of the equation in several independent samples. Successful validation requires measurement of the trait to be predicted (Y) and the predictors (X's), in the independent samples, just as in the original population from which the equation is generated. Validation over a wide range of conditions (including different genotypes, management procedures and environments) is critical to prevent bias. The regression

of predicted Y on the observed Y should have an intercept not significantly different from zero and a slope not significantly different from one. Failure to meet these criteria, indicates that the prediction equation could be biased (Gill et al, 1978).

The utility of a prediction equation can be compared to an untested hypothesis until it is validated with independent data sets. Previously published prediction equations should be applied to new data sets generated by researchers collecting composition data and then publish the results. MacNeil (1983) states; "results should be published regardless whether they support validation or discourage future use of the equation. Until the prediction equations are validated on animals other than those from which the original equation was formulated, their utility remains questionable."

Chapter 1

Changes in Empty Body, Carcass Composition and Relationships between Moisture, Fat and Protein of Major Tissues in Large Framed Beef Steers at Four Different Weights

ABSTRACT

Developmental changes in empty body, carcass composition and composition of gain was determined on 20 continental European crossbred steers representing four slaughter groups. Five steers were slaughtered at each weight group (G1:300; G2:390; G3:480 and G4:560 kg live weight). Average number of days on feed between slaughter groups was 64, 64 and 55. Complete physical dissection and chemical composition of all individual empty body (EB) and carcass tissues were conducted on each steer. EB weight as a percentage of live weight was 91.8, 91.9, 91.7 and 92.7% for G1 to G4, respectively. Percentage EB moisture (EBH_2O) and protein (EBP) decreased from 60.9:19.0 in G1 to 52.3:16.5% in G1 to G4, respectively. Percentage EB fat (EBFAT) increased from 15.1 to 27.1% in G1 to G4, respectively. Carcass moisture and protein decreased from 63.9:18.11 in G1 to 52.64:14.51% in G4, respectively. Carcass fat increased from 16.87 in G1 to 32.01% in G4, respectively. Skeletal muscle as a percentage of live weight and EB weight decreased ($P<.05$) from 42.3:46.09 in G1 to 38.7:41.75% in G4, respectively. Carcass skeletal muscle decreased ($P<.05$) from 66.0 to 57.9% from G1 to G4, respectively. The ratio EBH_2O:lean body mass (LBM) did not differ (P.10) between groups averaging .72. The ratio

EBH_2O:EBP (3.2) did not differ (P>.10) between slaughter groups. EB fat gain (g/d) was 537.0 from d 0 to 183. EBP gain (g/d) was 178.7 from d 0 to 183. Carcass fat and protein gain (g/d) was 417;100.1, respectively, during the 183 d feeding period. EB skeletal muscle accretion (g/d) was 484.7 from d 0 to 183. Hide and the gastrointestinal tract as a percentage of EB weight did not differ (P>.10) between groups. The greatest change in composition of dissectible tissues occurred in the EB and carcass nonskeletal muscle soft tissues (mainly adipose tissue) which increased from 15.4 to 24.4% of EB weight.

INTRODUCTION

The early studies in beef composition conducted by Trowbridge (1919); Haecker (1920); Moulton (1922b); Hopper (1944); Hankins and Howe (1946); Callow (1961, 1962); Luitingh (1962) and Johnson et al. (1972), examined the composition of British bred beef cattle typically 18 to 24 months of age or older. Numerous relationships and growth patterns of empty body components have been derived from these studies.

During the past 15 to 20 years however, there has been an increased interest in continental European breeds of cattle for use in crossbreeding programs with British breeds. One of the main objectives in cross breeding has been to increase the muscle content in the carcasses. During the same period, the trend in beef production has moved toward marketing at younger ages. Some researchers (Cole et al., 1964; Brungardt, 1972; Berg and Butterfield, 1976 and Koch and Dikeman, 1977) have demonstrated that continental European breeds and their crosses have faster growth rates and heavier mature weights than British breeds.

With increased use of continental European genetics in crossbreeding and selection for larger framed British breeds, more information is needed examining the effect of

faster growth rates, younger slaughter ages and heavier mature weights on the distribution and relationships between major body tissues and empty body moisture, fat and protein.

Since empty body and carcass composition have been and are an increasingly important basis for treatment comparisons, this study was designed to examine the growth, development and distribution of major empty body tissues of continental European crossbred steers typical in today's feedlots. A second objective of this study was to gather data and relationships between moisture, fat, protein and mineral content on leaner, later maturing cattle which can be used to update and develop equations which more accurately predict the composition of today's leaner, heavier weight cattle.

MATERIALS AND METHODS

Experimental Animals. Twenty Simmental X Charolais X Angus steer calves were selected from one producer's calf crop of 350 genetically similar steer calves. The calves were selected specifically to represent the large frame size described in the official U.S. feeder cattle grade standards (USDA,1979) and muscle thickness designation No. 1, described by USDA (1976). Calves were selected on body condition score, weight, projected optimal final market fatness and projected market weight. Initial body weights of all animals was 260 kg (+/- 10 kg). Steers were housed unrestrained and exposed to ambient temperatures and photoperiods from January to September.

Animal Grouping. Animals were randomly allotted five per slaughter group to four groups. Group 1 (G1) steers were slaughtered when each steer weighed approximately 300 kg, G2 approximately 390 kg, G3 at 480 kg and G4 at 570 kg, fasted live weight. Steers were fed a typical complete feedlot grower diet (Schroeder, 1987; 13%CP, 1.88 Mcal NE_m/kg; 1.22 Mcal NE_g/kg) until all animals from G2 were slaughtered. At that time, the remaining steers were switched to a typical feedlot finishing diet (Schroeder, 1987; 11%CP, 1.98 Mcal NE_m/kg; 1.3 Mcal NE_g/kg) until the steers reached the designated slaughter endpoint. Average

days on feed between slaughter groups was 64, 64 and 55, respectively. Each steer was weighed every two weeks after feed had been withheld for 16 h. When steers approached the designated slaughter weight, each steer was weighed every 7 d after feed had been withheld for 16 h prior to weighing, until the slaughter date was determined. Immediately prior to slaughter, feed was again withheld for 16 h and each steer was weighed. Water was supplied ad libitum at all times. Animals were transported to the meat laboratory, immediately reweighed and hip height measurements taken. One steer was slaughtered each day according to common commercial procedures.

Tissue Collection, Dissection and Determination of Empty Body and Carcass Composition. At slaughter, all tissues (including blood) were collected as quickly as possible, weighed (to nearest gram) and subsampled. Blood was subsampled as bleeding occurred in heparinized containers to facilitate accurate determination of blood composition. Tissues requiring further dissection were placed in moisture impermeable bags to prevent water loss. Tissue samples were either immediately frozen in dry ice in their entirety or ground, subsampled and placed in a -40^{o} C freezer for later analysis of moisture (M), ether extractable lipid (EEL) and protein (P; N x 6.25) content (AOAC, 1980). A complete list of abbreviations for dissected empty body components, carcass tissues, muscles

and bones is found in Appendix Tables 1, 2 and 3. Upon removal of the intact hide, the hide was cleaned of any remaining subcutaneous adipose tissue (ScAT) and muscle. The hide was immediately weighed (to nearest .05 kg), split medially and one half sampled in ten different locations and ground for analysis. One front foot and one hind foot was removed weighed and dissected into bone and soft tissues. The tail was removed, ScAT removed, weighed, ground and later analyzed. The head (minus the tongue) had the brain removed, the remainder split into right and left sides and all soft tissue removed from the right side.

Immediately after removal of the hide, proportionate ScAT subsamples were removed from twelve different locations from the right side of the carcass. All remaining ScAT was rapidly removed from the right side of the carcass to minimize moisture loss. The ScAT was ground three times (3 mm plate) and subsampled. The gastrointestinal tract (GIT) was removed, weighed and emptied of contents. All GIT individual components listed in Appendix Table 3, were separated, re-weighed and later analyzed. All other abdominal and thoracic cavity noncarcass components were removed, separated, weighed and stored for later analysis.

Prior to splitting the carcass, the right and left kidneys were removed and weighed individually. Additionally, the right side kidney and pelvic adipose

tissue (KP) was removed, weighed and frozen for later analysis.

Care was taken in splitting the carcass to ensure minimal deviation from the medial plane of the vertebra. Any deviations were immediately corrected while splitting. Any unevenly split bone was removed from the corresponding side and added to the opposite side. Hot carcass weights from the right side were corrected to include all previously mentioned fat depot subsamples. The left side was weighed, shrouded and chilled for 24 h. Fat thickness measurements, (to the nearest mm), longissimus dorsi (LD) cross sectional area (REA) were determined and percentage KP fat estimated. USDA (1976) yield and quality grade data were obtained by trained university personnel.

After splitting and completion of right side ScAT removal, intermuscular adipose tissue (IMAT) subsamples were removed from the round, loin, rib, chuck, plate and brisket, (between the major groups of muscles), pooled and analyzed.

Eight individual muscles listed in Appendix Table 2, were quickly removed individually, dissected, cleaned of all external adipose tissue and weighed. Muscles were subsampled and analyzed for M, EEL and P. Twenty five muscles of the right side, listed in Appendix Table 2, were subsampled (proportionate to weight) and composited. The composited muscle sample was ground, powdered and analyzed

to determine the amount of intramuscular EEL in the carcass. Intramuscular adipose tissue (IFAT; 3 to 5 g) was dissected from a second subsample of the same twenty five muscles to determine M, EEL and P content of the IFAT, for later calculations of composition. Rapid dissection of the remaining skeletal muscle, adipose tissue, heavy connective tissues plus tendons and bone plus cartilage was completed.

Bones were dissected completely free of muscle, fat, tendons and ligaments, but not cartilage, and separated either into individual bones or groups of bones for later analyses. Individual and group bone weights taken included: femur, tibia/fibula, radius/ulna, humerus, 3rd and 10th rib, skull, vertebral column, lower leg (front and hind foot), hind limb (carcass), front limb (carcass) and rib cage (including sternum and costal cartilages). All bones were ground by groups using an Autio 801 whole body grinder at The Ohio State University, Columbus, OH. After grinding, 10% of the weight of each group was taken for analyses. All groups of bones from the carcass were combined for a composite sample and 10% of the total weight subsampled. In order to correct for removed bone subsamples, an extra 10% of noncarcass bone groups was removed before pooling all ground bone to arrive at the composite total body bone to be subsampled for analyses.

Determination of Skeletal Muscle, Marbling and Intermuscular Adipose Tissue from Right Sides and Total Body. All soft tissues (less Sc fat, tendons and ligaments) dissected from the right side (including the head) were weighed, ground 3 times (3mm plate) and subsampled. Appendix Table 4 contains a complete list of all abbreviations which follow for use in calculating fat-free muscle, skeletal muscle, etc. Percentage moisture (M), ether extractable lipid (EEL) and protein (P; N X 6.25) in the intermuscular and intramuscular AT (EELIMIF) and other soft tissues from the right side of the carcass were determined (AOAC, 1980). From this sample, the EELIMIF represented the lipid from the intermuscular (IMAT) and intramuscular (IFAT) adipose tissue. The remainder of the sample is referred to as the fat-free muscle (FFM). The FFM includes the moisture and protein associated with the muscle along with the IMAT and IFAT. The quantitative estimation of the weight of the empty body muscle, IMAT and IFAT can be determined using the following calculations which are diagrammed in Appendix Table 5.

The weight of FFM was divided by the difference of one minus the percentage EEL in the composite muscle sample taken from the previously mentioned 25 muscles of the right side (1- %EEL of composite muscle marbling determination sample). This resulted in the weight of the skeletal muscle, as well as marbling adipose tissue (includes

M,EEL,P) and the M and P associated with the IMAT, labeled FFMEE. The difference between FFMEE and FFM represents the EEL from the IFAT of the skeletal muscle (EEIFAT). The EEIF is subtracted from the EEIMIF which resulted in the EEL associated with the IMAT (EEIM). The EEIM is divided by the percentage EE of the IMAT sample which gives the total weight of the IMAT. To determine the M and P associated with the IMAT, the EEIM is subtracted from the IMAT giving the moisture and protein (MPIM) associated with the IMAT.

In order to determine the estimated muscle tissue, M and P associated with the IFAT, the MPIM is subtracted from the FFM giving the total estimated fat-free muscle and marbling adipose tissue M and P, (FFMIF). Adding the EEIFAT to the FFMMA gives the estimated total skeletal muscle and marbling adipose tissue (TMM). The total weight of the marbling adipose tissue (TIFAT) is derived by multiplying the TMM by the percentage of total marbling adipose tissue (T%IFAT). Determination of T%IFAT is accomplished by dividing the percentage of EEL in the composite muscle sample (represents IFAT EEL) by the percentage EEL of the dissected composite marbling sample. Skeletal muscle tissue without IFAT, (TM) can then be derived by subtracting the TIFAT from the TMM.

Conversion of the right side tissue weights (muscle, subcutaneous AT, intramuscular AT, intermuscular AT and bone) to total body tissue weights was performed since

earlier studies by Butterfield (1963), Briedenstein et al., (1964) and Hedrick et al., (1965) have shown that cattle and pigs to exhibit bilateral symmetry. The tail, kidneys, perirenal fat and any internal cavity tissues which do not exhibit bilateral symmetry were removed prior to converting all right side tissue weights, to left side tissue weights and then to total body tissue weights. The weights of all tissues (muscle, adipose tissue and bone, etc.) as a percentage of the right side were multiplied by the weight of the left side to give the weight of the tissues in the left side. Weights of tissues from both sides were summed to determine the total weight of muscle, adipose tissue (all depots), bones and other tissues in the body.

After completion of all individual tissue analyses, the weights and respective composition of major empty body organs and tissue groups listed in Appendix Table 1 were recombined to determine actual empty body (EB) composition in kilograms and percentage of the respective tissue groups, as well as kilograms and percentage EB water (EBH_2O), EB fat (EBFAT) and EB protein (EBP). Additionally, all carcass tissue weights and composition, also listed in Appendix Table 1, was recombined to determine actual kilograms and percentages of carcass water ($CARCH_2O$), carcass fat (CARCFAT) and carcass protein (CP). Empty body and carcass ash, EBASH and CARCASH, respectively, were determined as the difference of all

other EB and CARC components from 100%. The summation of all tissue weights was at least 98.5% of initial EB and carcass weight.

Statistical analysis. Group means and standard errors for weights and percentages of EB and carcass, respectively, and analysis of variance were performed according to SPSS Base Manual (Statistical Package for the Social Sciences, 1989).

RESULTS AND DISCUSSION

Live Performance and Carcass Data. Means and standard errors for the various carcass traits are presented in Tables 1-1 and 1-2. All steers were started on feed at the same time and fed until each steer reached the designated fasted slaughter weight, in each randomly assigned group. The average live weight of the initial slaughter group (G1) was 298.5 kg and increased by approximately 90 kg between G1 and group 2 (G2), and between G2 and group 3 (G3) but only 75.54 kg between G3 and group 4 (G4). This descrepancy was due partly to the difficulty in estimating amount of fill in the gastrointestinal tract (GI) and the increased weight loss associated with handling during transportation to the meat laboratory. As indicated in Table 1-1, the percentage empty body weight of the live weight was the same in G1, G2 and G3, while in G4 the empty body weight was 92.7% of the fasted live weight suggesting there was indeed more shrink in G4 steers between the time the steers were weighed at the research unit and the final weighing immediately before slaughter the next morning. The average final slaughter weight of 555.5 kg did not present any adverse effect on the final experimental outcome and carcass dissection, since all animals in G4 had attained the desired endpoint

of USDA quality grade of low Choice, fat thickness of at least 10 mm and yield grade of 3.0. Dressing percentage increased in G4, partially due to the increased shrink which resulted in the decreased fasted live weight previously discussed.

Fat thickness at the 12th and 13th rib interface increased ($P<.001$) between each group with the largest increase in fat thickness occurring between G2 and G3, as expected, the feeding period in which the steers were switched to a high concentrate diet. Ribeye area increased between each group with the largest increase observed between G1 and G2. Calculated yield grades, using the equations of Murphy et al., 1960, did not differ ($P>.10$) between G1 and G2, but did differ ($P<.01$) between G2 and G3 and G3 and G4. Marbling scores and USDA quality grade scores were not different ($P>.10$) between G1 or G2, and between G3 or G4, but differed ($P<.01$) between G2 and G3.

Live weight (LWT) gains and empty body (EB) weight gains (Table 1-2) between G1 and G2 and G2 and G3, respectively, did nor differ ($P>.10$). However, live weight gain between G3 and G4 was only 74.9 kg. Average days on feed (64d) for each group did not differ between G1 and G2 and between G2 and G3 but was 55 d between G3 and G4. The average total days on feed for the duration of the study was 183 d. Average daily gain between groups did not differ ($P>.10$) but did decrease numerically as expected.

TABLE 1-1. MEANS AND STANDARD ERRORS FOR LIVE WEIGHT, EMPTY BODY AND CARCASS WEIGHTS AND CARCASS TRAITS

	Group			
	1	2	3	4
No. of steers	5	5	5	5
Trait Age	10 mo	12 mo	14 mo	16 mo
Live fasted slaughter weight (LWT), kg	298.5	390.1	480.0	555.5
SE	2.99	2.09	.74	1.11
Empty body weight (EBWT), kg	273.9	358.4	440.0	514.9
SE	3.55	1.24	2.64	3.32
EB WT as % of live weight, %	91.76	91.89	91.68	92.69
SE	.29	.54	.54	.75
Hot carcass wt (HCWT), kg	188.1	247.5	303.7	365.7
SE	3.8	1.84	2.74	3.12
Dressing percentage, %	63.0	63.4	63.3	65.8
SE	.10	.15	.07	.22
12th rib fat thickness, mm	2.6	4.8	8.7	11.4
SE	.02	.03	.03	.05
Longissimus area, cm^2	60.3	75.2	80.8	86.6
SE	.98	1.93	3.71	3.60
Kidney fat, %	2.0	2.5	2.5	3.1
SE	.11	.16	.16	.19
Yield grade	1.74	1.82	2.39	3.01
SE	.12	.16	.13	.18
Marbling score[a]	Trace 58	Trace 74	Small 12	Small 58

a Minimum traces = 0, maximum = traces 100. Traces = USDA Standard. Small = USDA low choice.

TABLE 1-2. MEANS AND STANDARD ERRORS FOR LIVE ANIMAL PERFORMANCE TRAITS AND LINEAR MEASUREMENTS

	Group			
Item	1	2	3	4
LWT gain between groups, kg		91.6	89.9	75.5
SE		1.87	.88	1.01
EBWT gain between groups, kg		84.5	81.6	74.9
SE		1.22	2.14	2.89
Average days on feed between groups		64	64	55
Total days on feed per group		64	128	183
SE		2.28	2.6	2.37
Average daily gain (ADG), LWT, kg		1.43[a]	1.4[a]	1.37[a]
SE		.03	.11	.05
Average hip height, cm	122.05	128.4	130.68	134.75
SE	.43	.51	.55	.88
Frame score	5.4[a]	5.75[a]	5.5[a]	5.7[a]
SE	.06	.14	.10	.14

a Values within a row with a different superscript differ ($P<.01$).

Average hip height (a measure of growth used in conjunction with age to determine frame score) increased between groups. Frame score did not differ (P>.10) between groups G1 to G4, respectively.

Empty body composition by percentages and weight is presented in Table 1-3. Mean percentage EB moisture (EBH_2O) decreased from 60.9 (G1) to 52.3% in G4. Percentage EB fat (EBFAT) increased while percentage EB protein (EBP) decreased between each group through G3 but neither fat nor protein differed (P>.05) between G3 and G4. Percentage EB protein (EBP) decreased from 19.0 to 16.5% between G1 to G4, respectively. Percentage EB mineral (EBM) was 4.8% in G1 and decreased in each successive slaughter group to 4.0% in G4. The values for empty body composition of the steers in this study are similar to those reported by Haecker (1920) and Moulton (1922), however steers having similar EB composition in this study were 150 to 250 kg heavier than the cattle reported in their studies.

As expected, the absolute weight of EBH_2O, EBFAT, EBP and EBM (Table 1-3) increased between each group. However, as is apparent in Table 1-3, EBFAT changed the most dramatically, increasing 238% in weight, compared to a 61.5 and 63.1% increase in EBH_2O and EBP, respectively. EBM increased in weight by 56.1% between G1 and G4.

TABLE 1-3. GROUP MEANS AND STANDARD ERRORS FOR EMPTY BODY COMPOSITION COMPONENTS

	Group			
Item	1	2	3	4
Empty body H^2O, %	60.9[a]	58.0[b]	54.0[c]	52.3[c]
SE	.33	.57	.70	.37
Empty body fat, %	15.1[a]	19.5[b]	24.6[c]	27.1[c]
SE	.33	.85	.95	.49
Empty body protein, %	19.0[a]	18.1[b]	16.8[c]	16.5[c]
SE	.20	.20	.18	.12
Empty body mineral, %	4.8[a]	4.3[b]	4.2[b]	4.0[b]
SE	.16	.12	.11	.12
Empty body H^2O, kg	166.8	208.0	237.5	269.4
SE	2.76	1.55	3.48	3.27
Empty body fat, kg	41.3	70.0	108.2	139.6
SE	.52	3.28	4.18	2.06
Empty body protein, kg	52.0	64.8	73.9	84.8
SE	1.04	.54	.88	1.04
Empty body mineral, kg	13.2	15.4	18.2	20.6
SE	.51	.40	.38	.70

a,b,c Values within a row with different superscripts differ ($P<.05$).

Changes in carcass composition listed in Table 1-4 were similar to changes in EB composition. The absolute weight of carcass moisture ($CARCH_2O$) increased 69.3%, however, percentage $CARCH_2O$ decreased from 63.93 to 52.64% between G1 to G4, respectively. Absolute weight (kg) of carcass fat increased 290% and the percentage carcass fat increased from 16.87 to 32% between G1 and G4, respectively. Carcass protein increased 64.9% in absolute weight, but decreased as a percentage of carcass soft tissues from 18.1 to 14.5% between G1 and G4, respectively.

Skeletal muscle increased in absolute weight (Table 1-5) by 70.3% between G1 and G4. Skeletal muscle as a percentage of live weight and empty body weight (Table 1-5) decreased from 42.27;46.1% to 38.7;41.75% between G1 and G4, respectively.

Carcass soft tissues (CST), as expected, increased with increasing carcass weight (Table 1-6). CST as a percentage of hot carcass weight increased between each group from 82.9 to 87.7% in G1 to G4, respectively. The increased CST retained in the carcass is an indication that adipose tissue and skeletal muscle increased at a more rapid rate than carcass bone. Carcass muscle increased in weight between each group, however, carcass muscle as a percentage of hot carcass weight decreased from 66.0 in G1 to approximately 58.0% in G4. The percentage carcass muscle of the steers in this study was similar to carcasses of

TABLE 1-4. GROUP MEANS AND STANDARD ERRORS FOR CARCASS COMPOSITION

	Group			
Item	1	2	3	4
Carcass H_2O, %	63.93[a]	59.53[b]	54.8[c]	52.64[c]
SE	.53	.77	.93	.68
Carcass EEL, %	16.87[a]	23.18[b]	29.28[c]	32.01[c]
SE	.40	.96	1.16	.77
Carcass Protein, %	18.11[a]	16.46[b]	15.11[c]	14.51[c]
SE	.30	.18	.25	.19
Carcass H_2O, kg	99.70	124.91	144.09	168.81
SE	3.09	.55	2.15	3.13
Carcass EEL, kg	26.3	48.66	76.99	102.62
SE	.55	2.61	3.44	2.34
Carcass P, kg	28.21	34.56	39.7	46.53
SE	1.03	.31	.52	.66

a,b,c Values within a row with different superscripts differ ($P<.05$).

TABLE 1-5. GROUP MEANS AND STANDARD ERRORS FOR TOTAL SKELETAL MUSCLE, CARCASS SOFT TISSUE, CARCASS SKELETAL MUSCLE AND PERCENTAGE SKELETAL MUSCLE

	Group			
Item	1	2	3	4
Total skeletal muscle, kg	126.25	156.95	182.68	214.97
	3.72	.58	2.81	2.69
Muscle percent of live weight, %	42.27[a]	40.24[a]	38.06[b]	38.70[b]
SE	.84	.36	.55	.53
Muscle percent of EB WT,%	46.09[a]	43.79[b]	41.51[c]	41.75[c]
SE	.56	.44	.54	.68

a,b,c Values within a row with different superscripts differ ($P<.05$).

similar carcass composition reported by Callow (1961), Hendrickson et al. (1965) and Berg and Butterfield (1976). Carcass weights in their studies however, were 50 to 125 kg less than carcass weights in this study.

The EB was comprised of 13.2% bone (actual bone and cartilage) in G1 (Table 1-7). EB soft tissues, as expected, increased more rapidly than EB bone between each slaughter group resulting in total EB bone accounting for 9.9% of the EB weight in G4. Carcass bone, as typically reported in the literature, consists of actual bone, cartilage, heavy connective tissue, ligaments and tendons. The absolute weight (kg) of carcass bone comparable to carcass bone reported in the literature, is shown in Table 1-7. Actual carcass bone and cartilage (without heavy connective tissue, ligaments and tendons) for steers in each group in this study was reorted by Schroeder (1987). Percentage carcass bone (including heavy connective tissue, ligaments and tendons) was 17.07% in G1 decreasing to 12.3% in G4, respectively. These data follow similar patterns of development for British-bred cattle as discussed by Callow (1961), Lawrence and Pearce (1964), Henrickson et al., (1965) and Berg and Butterfield (1976).

Carcass muscle to bone ratios (carcass bone including heavy connective tissue, ligaments and tendons) in this study were 3.88, 4.15, 4.4 and 4.7 for G1 to G4, respectively. These data were similar to reports in the

TABLE 1-6. GROUP MEANS AND STANDARD ERRORS FOR CARCASS SOFT TISSUE, CARCASS SKELETAL MUSCLE, PERCENTAGE SKELETAL MUSCLE, CARCASS BONE AND PERCENTAGE CARCASS BONE

	Group			
Item	1	2	3	4
Carcass soft tissues (CST), kg	156.0	209.9	262.9	320.7
SE	3.99	2.43	2.28	2.66
CST % of HCWT,	82.87	84.93	86.51	87.69
SE	.47	.59	.37	.38
Carcass skeletal muscle, kg	124.20	154.49	179.72	211.74
	3.68	.46	2.76	2.72
Carcass muscle percent of carcass weight, %	66.0[a]	62.51[b]	59.19[c]	57.89[c]
	.72	.52	1.01	.47

a,b,c Values within a row with different superscripts differ ($P<.05$).

literature by Luitingh (1962), Henrickson et al. (1965), Berg and Butterfield (1966;1976), Jones (1985b,c) and Lunt et al. (1985a,b), but are consistently lower than those reported by Shanin and Berg (1985a,b,c,) for double muscled, "synthetic" beef (Galloway x Angus x Charolais crossbreds) and small framed British breeds.

Complete physical dissection of the entire EB and carcass allowed for determinations of numerous relationships found in Table 1-8 between skeletal muscle, skeletal muscle protein, empty body protein and carcass protein. Dissection and chemical analyses of the skeletal muscle and EB determined that across all slaughter groups, G1 to G4, respectively, the percentage of the EB protein pool attributable to skeletal muscle protein was constant ($P>.10$) between groups averaging 52% for all steers. Protein content in all skeletal muscle free of external fat was constant ($P>.10$) at 21.0% (Table 1-8), although there was a slight numerical decrease in protein content as each slaughter group increased in weight.

Dissection and chemical analyses of the carcass skeletal muscle and other carcass soft tissues (CST) showed that when protein content of the CST was determined in each group, 95.0% of all protein present in the CST was accounted for in the carcass skeletal muscle. These relationships can be useful in predicting EB and carcass composition as described in later chapters.

TABLE 1-7. GROUP MEANS AND STANDARD ERRORS FOR PERCENTAGE TOTAL EMPTY BODY BONE, TOTAL CARCASS BONE WEIGHT[a], AND PERCENTAGE BONE IN THE CARCASS AND MUSCLE TO BONE RATIO

	Group			
Item	1	2	3	4
Total bone only of EBWT, %	13.20[a]	11.48[b]	10.46[bc]	9.87[c]
SE	.18	.32	.18	.22
Total carcass bone, kg[d]	32.06	37.27	40.80	45.04
SE	.46	.94	.74	1.35
Total carcass bone, %[d]	17.07[a]	15.08[b]	13.43[bc]	12.31[c]
SE	.47	.44	.18	.32
Carcass bone[e] %	15.1[a]	13.31[b]	12.05[bc]	11.14[c]
SE	.31	.42	.13	.31
Carcass muscle/bone ratio[f]	3.88[a]	4.15[b]	4.41[c]	4.71[c]
SE	.15	.09	.05	.11

a,b,c Values within a row with different superscripts differ (P<.05).
d Includes heavy connective tissue, ligaments and tendons.
e Includes only carcass bone and cartilage.
f Carcass bone including heavy connective tissue, etc.

TABLE 1-8. GROUP MEANS FOR PERCENTAGE PROTEIN IN SKELETAL MUSCLE AND PERCENTAGE OF SKELETAL MUSCLE PROTEIN IN TOTAL CARCASS PROTEIN

	Group			
Item	1	2	3	4
Percentage of EB protein from skeletal muscle, %	52.0[a]	51.4[a]	51.41[a]	52.9[a]
SE	1.27	.61	.44	.23
Protein in skeletal muscle, %	21.4[a]	21.2[a]	20.8[a]	20.9[a]
SE	.24	.20	.14	.20
Skeletal muscle protein as % of carcass P	95.0[a]	95.03[a]	94.3[a]	95.2[a]
SE	.14	.12	.29	.13

ab Values within a row with different superscripts differ ($P < .05$).

Percentage lean body mass decreased with increasing live weight (Table 1-9). However, consistent with reports by Byers (1979b) and Arnold et al. (1985) the ratio of EBH_2O to lean body mass remained relatively constant (P>.10) averaging .72 in steers weighing 300 to 555 kg. Likewise, the EBP:EBH_2O and EBH_2O:EBP ratios remained constant averaging .312 and 3.21, respectively, across all slaughter groups. Interestingly, the carcass moisture to carcass protein ratio did not differ (P>.10) averaging 3.62 in steers with greater than 20% carcass fat (G2 to G4, respectively). The skeletal muscle moisture:protein ratio also remained constant (P>.25) at 3.55 across all groups.

Composition of gain. Steers in this study gained the least amount of EBF (Table 1-10) and the most EBP during the first 64 d feeding period. EBF gain per day was 446 g, accounting for 33.8% of the EB average daily gain (ADG). EBP gain per day was about 200 g which accounted for about 15% of the EB ADG for the feeding period. EBF gain was the greatest during the second 64d averaging 597 g/d, about 47% of the EB ADG. During this same period, EBP gain was the least averaging 142 g/d, only 11.1% of EB ADG. This is not totally unexpected since the steers were switched from a high protein, lower energy diet to a lower protein, high concentrate diet during this period. The switch to lower protein and higher energy in the diet may have partially accounted for more lipid being synthesized and accumulating

TABLE 1-9. GROUP MEANS AND STANDARD ERRORS FOR ACTUAL LEAN BODY MASS AND RELATIONSHIPS OF WATER TO PROTEIN IN THE EMPTY BODY, CARCASS AND SKELETAL MUSCLE

	Group			
Item	1	2	3	4
Actual lean body mass, %	84.69	80.41	74.91	72.78
SE	.32	.85	.88	.49
EBH_2O:LBMASS	.719[a]	.7216[a]	.7204[a]	.7188[a]
SE	.003	.002	.002	.002
EBP:EBH_2O	.3119[a]	.3117[a]	.3113[a]	.3147[a]
SE	.004	.002	.002	.003
EBH_2O:EBP	3.21[a]	3.21[a]	3.21[a]	3.18[a]
SE	.04	.02	.02	.03
Carcass moisture: carcass protein ratio	3.53[b]	3.61[a]	3.63[a]	3.63[a]
SE	.04	.05	.02	.03
Skeletal muscle moisture:protein ratio	3.54[a]	3.55[a]	3.55[a]	3.52[a]
SE	.03	.04	.03	.06

a Means in a row with different superscripts differ (P<.05).

in the abdomen and carcass. During the final 55 d feeding period (d 128 - 183), the steers gained 573 g/d of EBF accounting for 42% of the EB ADG, slightly less than the previous period. EBP gains, however, were higher than during the previous 64 d period, probably due to compensatory protein deposition when the temperatures in the feeding period of late summer were more temperate and growth performance was enhanced. When EBF deposition per day was calculated during the last 119 d of feeding (typical of many feeding trials), grams of EBF gained per day was 585.9 g and EBP gained per day was 167 g. These values were in a range consistent with the estimated daily values of McCarthy (1981) and Anderson (1987).

Table 1-11 contains the carcass composition of gain data for the steers in this study. During the first 64 d period, steers gained approximately 349 g of carcass fat per day which was 78% of EBF gain for this feeding period. Carcass protein gain was about 100 g/d or about 50% of the EBP gain. Interestingly, the deposition of carcass fat during the second 64 d period was reduced to 443 g/d, 74.1% of the EBF gain. This decrease in the rate of carcass fat deposition seems abnormal, however, little information exists in the literature which examines by physical carcass dissection, the effects of switching to a high concentrate diet during the feeding of cattle. Closer examination of the data indicates that during the feeding period in which

TABLE 1-10. EMPTY BODY FAT AND PROTEIN ACCRETION BETWEEN SLAUGHTER GROUPS AT DIFFERENT DAYS ON FEED

	Days on feed					
Item	0-64	64-128	128-183	0-128	0-183	64-183
EB fat, kg	28.56	38.23	31.49	66.79	98.22	69.72
EB fat gain, g/d	446.25	597.34	572.5	521.8	537.05	585.9
% EB ADG	33.81	46.67	42.1	40.14	40.69	44.56
EB protein, kg	12.79	9.09	10.83	21.88	32.71	19.92
EB protein gain, g/d	199.8	142.03	196.91	170.94	178.74	167.4
% EB ADG	15.14	11.1	14.48	13.15	13.54	12.73

the steers were switched to a high concentrate diet more fat was deposited in the other EB tissues, namely the gastrointestinal tract viscera. The deposition of carcass protein during the same period was also lower during the second 64 d feeding period. The carcass protein deposited, however, accounted for 56.5% of the EBP deposited per day. Carcass fat deposited was 466 g/d, 81.4% of the EBF deposition during the final 55 d period. As with EBP deposition, carcass protein deposition increased over the second 64 d period to 124 g/d; 63.1% of the daily EBP deposition.

Skeletal muscle deposition rates varied as would be expected over the duration of the study (Table 1-12). Over the entire study (183 d) the average skeletal muscle deposited per day averaged 484.7 g. Closer examination of Table 1-12, however, indicates that during the second period (d 64 - 128) skeletal muscle accretion was reduced at the time when EBF depostion (Table 1-10) was greatest. During the final 55 d feeding period skeletal muscle deposition was increased to the highest rate of 587.3 g per day. During this period there appeared to be compensatory muscle deposition. Part of this increased skeletal muscle deposited, however, was actually fat being deposited in the muscle in the form of intramuscular adipose tissue. During the final feeding period, skeletal muscle deposition accounted for 43.2% of the EB ADG.

TABLE 1-11. CARCASS FAT AND PROTEIN ACCRETION BETWEEN SLAUGHTER GROUPS AT DIFFERENT DAYS ON FEED

Item	Days on feed					
	0-64	64-128	128-183	0-128	0-183	64-183
Carcass fat, kg	22.33	28.33	25.63	50.66	76.32	53.96
Carcass fat gain, g/d	348.9	442.66	466.0	395.78	417.05	453.4
% EB fat accretion	78.18	74.11	81.4	75.95	77.66	77.39
Carcass protein, kg	6.35	5.14	6.83	11.49	18.32	11.97
Carcass protein gain, g/d	99.22	80.31	124.2	89.8	100.11	100.59
% EB protein accretion	49.7	56.5	63.1	52.5	56.0	60.1

Table 1-13 contains the composition makeup as a percentage, of the EB by each major tissue. As previously discussed, skeletal muscle as a percentage of the EB decreased in each successive group, however, skeletal muscle was the largest portion of the EB in each group. Total bone (cartilage and bone) also decreased as a percentage of the EB. Hide as a percentage of the EB remained relatively constant at about 8% of the EB weight in each slaughter group. Blood decreased slightly as a percentage of the EB in each successive group. Accurate quantitation of blood, however, is difficult since a portion of the blood is retained in capillaries causing an underestimation of blood and overestimation of other tissues which had trapped blood. The gastrointestinal tract remained relatively constant between 9.5 and 10.0% of the EB weight in each group. Nonskeletal muscle EB soft tissues (EBST),(EB and carcass), comprised mainly of adipose tissue, not surprisingly, showed the largest change as a percentage of EB weight. EBST increased from 15.4 to 24.4% of the EB weight as the steers increased in weight and degree of fatness. The composition of each previously mentioned EB tissue and the percentage each tissue contributed to EB moisture, fat and protein is found in Appendix Tables 6, 7, 8, 9 and 10.

TABLE 1-12. EMPTY BODY SKELETAL MUSCLE ACCRETION BETWEEN SLAUGHTER GROUPS AT DIFFERENT DAYS ON FEED

Item	Days on feed					
	0-64	64-128	128-183	0-128	0-183	64-183
EB skeletal muscle, kg	30.7	25.7	32.3	56.4	88.7	58.0
EB skel muscle gain, g/d	479.7	401.6	587.3	440.6	484.7	487.4
% of EB ADG	36.3	31.38	43.18	33.9	36.7	37.1

TABLE 1-13. MEANS OF PERCENTAGE OF EMPTY BODY COMPOSITION FROM MAJOR EMPTY BODY TISSUES

Item	Group 1	2	3	4
Skeletal muscle, %	46.09	43.79	41.51	41.75
SE	.56	.44	.54	.68
Total EB bone, %	13.2	11.48	10.46	9.87
SE	.18	.32	.18	.22
Hide, %	7.97	8.65	8.09	8.15
SE	.29	.22	.14	.11
Blood, %	5.74	5.5	5.27	4.56
SE	.19	.20	.28	.06
GI tract, %	9.48	9.62	10.0	9.76
SE	.27	.34	.28	.48
Empty body and carcass nonskeletal muscle soft tissues, %	15.4	18.98	22.93	24.37
SE	.47	.51	.29	.46
Respiratory tract, %	.93	.87	.73	.70
SE	.06	.03	.04	.04
Heart, %	.54	.52	.48	.43
SE	.02	.02	.02	.02
Central nervous system, %	.21	.18	.17	.14
SE	.02	.015	.03	.02
Urinary/ reproductive tract, %	.41	.40	.36	.27
SE	.03	.007	.002	.004

SUMMARY

Complete physical dissection and chemical analysis of all EB and carcass tissues of 20 genetically similar steers at four developmental stages was conducted in this study. The continental European crossbred steers in this study were heavier in weight but similar in composition to studies reported earlier. Five steers were slaughtered per weight group when the fasted live weight was estimated to be 300, 390, 480 and 570 kg for G1, G2, G3 and G4, respectively. EB weight as a percentage of live weight was 91.8, 91.9, 91.7 and 92.7% for G1 to G4, respectively. Average daily gain, although decreasing slightly, did not differ (P>.10) between slaughter groups. Frame scores for steers in each group did not differ (P>.10) ranging from 5.4 to 5.75.

Percentage EB moisture (EBH^2O) and protein (EBP) decreased from 60.9:19.0 in G1 to 52.3:16.5% in G1 to G4, respectively. Percentage EB fat (EBFAT) increased from 15.1 to 27.1% in G1 to G4, respectively. Carcass moisture and protein decreased from 63.9:18.11 in G1 to 52.64:14.51% in G4, respectively. Carcass fat increased from 16.87 in G1 to 32.01% in G4, respectively.

Total skeletal muscle increased from 126.25 in G1 to 215 kg in G4, respectively. Skeletal muscle as a

percentage of live weight and EB weight decreased (P<.05) from 42.3:46.09 in G1 to 38.7:41.75% in G4, respectively. Carcass skeletal muscle decreased (P<.05) from 66.0 to 57.9% from G1 to G4, respectively. Carcass soft tissue (includes muscle and fat) as a percentage of hot carcass weight increased from 82.9 to 87.7% from G1 to G4, respectively.

Percentage empty body bone (connective tissue, ligaments, tendons, etc. not included) decreased from 13.2 to 9.87% from G1 to G4, respectively. Total carcass bone (including connective tissue, ligaments, tendons, etc.) increased in weight from 32.06 to 45.04 kg from G1 to G4, but decreased as a percentage of the carcass between G1 and G4 (17.07 vs 13.43%), respectively. The carcass muscle to bone ratio also increased from 3.88 in G1 to 4.71 in G4 indicating that skeletal muscle was increasing in weight at a more rapid rate than carcass bone.

Percentage lean body mass (LBMASS) decreased from 84.7 to 72.8% between G1 and G4, respectively. EBH_2O:LBMASS remained constant across all groups at .72. Likewise, EBH_2O:EBP remained constant across all groups at 3.2. The carcass H_2O:carcass protein ratio was 3.53 in G1 but increased and remained constant at about 3.63 in G2 to G4, respectively. The skeletal muscle moisture:protein ratio did not differ (P>.10) between groups ranging from 3.52 to 3.55.

Several previously unreported relationships were determined from this study. 1) 52% of empty body protein is derived from skeletal muscle and 2) 95% of carcass soft tissue protein is accounted for in the skeletal muscle of the carcass. These relationships and others identified in this study can be useful in understanding and predicting changes in empty body and carcass composition of cattle typical of today's feedlot.

EB fat gain (g/d) was greatest and EB protein gain (g/d) was the least during the feeding period d 65 to 128 averaging 597.3 and 142.03 g, respectively. EB fat gain (g/d) was 537.0 from d 0 to 183. EBP gain (g/d) was 178.7 from d 0 to 183. EB fat gain as a percentage of EB ADG was about 40-41% for the 183 d feeding period. EBP gain as a percentage of ADG was 13.5% for the 183 d feeding period. Carcass fat gain increased between each group with the greatest carcass fat gain (g/d) during the 128-183 d period averaging 466.0 g. Carcass fat gain (g/d) as a percentage of EB fat accretion during the 0-183 d period was 77.7%. Carcass protein gain (g/d) was 100.1 g during the 0-183 d feeding period, but varied considerably during the individual feeding periods. Carcass protein as a percentage of EB protein accretion was 56.0 for the 0-183 d feeding period. Skeletal muscle gain (g/d) was 36.7% of EB ADG for the entire feeding period.

The hide and gastrointestinal tract as a percentage of EB weight did not differ (P>.10) between groups. The hide accounted for about 8% of the EB weight in each group. The gastrointestinal tract (including associated fat) accounted for between 9.5 and 10% of the EB weight in each group. The greatest change in composition of dissectible tissues occurred in the EB and carcass nonskeletal muscle soft tissues (mainly adipose tissue) which increased from 15.4 to 24.4% of EB weight. All other tissues decreased as a percentage of EB weight between groups.

Chapter 2

Use of Deuterium Oxide Dilution Techniques to Estimate Skeletal Muscle Protein

ABSTRACT

Body composition estimated by one and two pool compartment deuterium oxide (D_2O) dilution techniques was compared with body composition determined directly on twenty large framed continental European crossbred steers. Five steers were infused with D_2O before slaughter at one of four weights (300, 390, 480 and 560 kg live weight). Empty body water (EBH_2O) was overestimated by both the one compartment (1CM, using slope, intercept method) and the two compartment kinetic (2CM) method in steers at 300 to 390 kg. At 480 and 560 kg, EBH_2O was overestimated by 2.5 to 5.0% by both the 1 CM and 2 CM methods, however, the 1CM did not differ statistically from the direct method. Empty body protein (EBP) estimated by the 1CM did not differ statistically from direct methods, however, EBP was overestimated by 1.5 to 6.5% across all weight groups. In most cases the 2CM overestimated ($P<.05$) EBP in most cases from 2.0 to 10.0%. Empty body ether extract (EBFAT) was underestimated ($P<.01$) by both the 1CM and 2CM methods at 300 and 390 kg. EBFAT estimated by 1CM in steers at 480 and 560 kg was not statistically different from actual empty body fat, due to large standard errors, but was 8 to 9% less than actual. The 2CM method underestimated ($P<.05$) EBFAT in all groups by 13 to 30 %. Percentage gut fill did

not differ (P>.05) between direct and estimated fill in 300, 390 and 480 kg steers, however, large estimated variation was found at 560 kg steers. In general, both the 1CM and 2CM were not useful in accurately estimating empty body composition in crossbred steers at 300 to 390 kg. Both the 1CM and 2CM methods were somewhat more useful, although not accurate, in estimating empty body composition in steers at 480 or 560 kg.

The assumptions that the amount of EBH2O associated with EBP and ash were valid, however, values from this study differed slightly from previous studies. In animals with empty body weight greater than 175 kg, the calculated values from the literature for the ratios of protein and ash to water are .302 and .0668, respectively. In this study the ratio of EBP:EBH_2O and EB ash:EBH_2O was .312 and .0755, respectively. The ratio of skeletal muscle protein to empty body protein was constant in all weight groups with a value of .52. The relationship between EBH_2O and skeletal muscle protein can be useful in future studies investigating skeletal muscle growth using repeated indirect methods for estimating EBH_2O and EBP. Skeletal muscle protein (kg) can be estimated by the following equation: -2.11 + .172 x EBH_2O (kg) with R^2=.97 and RSD = 1.18. Results of this study suggest developmental changes occur in EBH2O to D_2O relationships as cattle mature and fatten. In order to accurately predict EBP, developmental

interactions between EBH2O and D2O space must be accounted for when developing prediction equations.

INTRODUCTION

The accurate estimation of body composition and skeletal muscle of live animals has understandably attracted much attention. An accurate estimate of body composition and muscle mass would be extremely useful in studies to examine the rate of accretion and changes in chemical components in the body. Whole body analysis, while most accurate, is laborious, expensive and does not allow for repeated measurements. As indicated by Ferrell and Jenkins (1984), an ideal method of predicting body composition should be accurate, repeatable, easily performed, relatively inexpensive, applicable to animals of diverse ages and done with minimal distress to the live animal.

Numerous research studies efforts have been attempted and methods developed to estimate carcass composition of cattle and other species. The most widely used include: component parts which have been examined for potential use as composition predictors (Hopper, 1944; Hankins and Howe, 1946; Hinks and Prescott, 1974; Ferrell et al., 1976) and specific gravity (Garrett and Hinman, 1969; Preston et al., 1974, Jones, 1985a) which have had varying success.

Concurrently, substantial efforts have been made to measure composition of the live animals using a variety of

procedures. Numerous measurements of body composition involve the relationships between the chemical components water, protein and fat. While protein and mineral mass have been measured by creatinine excretion (Boileau et al., 1972; Aulstad, 1970) and isotopes, e.g., potassium (^{40}K, ^{42}K Lohman et al., 1966; 1968; McLellean et al., 1969; Frahm et al., 1971), the relationships involving water, the largest component in the empty body, especially the lean empty body, have been the most frequently studied.

A number of investigators have conducted experiments using urea dilution (Preston and Kock, 1973; Hammond, 1984), ^{42}K dilution (Trigg et al., 1978), dye dilution (Panaretto and Till, 1963), antipyrine (Wellington et al., 1956) and other infusates which are based on dilution principles to estimate body water and (or) fat. Further technological advances have allowed for use of the hydrogen isotopes, namely, tritium (TOH) and deuterium oxide (D_2O) as more ideal tracers for estimating body water (Foot and Greenhalgh, 1970; Searle, 1970a; Crabtree et al., 1974; Donnelly and Freer, 1974; Robelin, 1977; Byers, 1979b; Little and McLean, 1981; Arnold et al., 1985, Miller et al., 1988). However, none of these methods is without problems, which has been thoroughly discussed in the review of literature.

Application of the biological nonradioactive tracer D_2O, is frequently used today in body composition studies.

However, use of this technique is complicated by the direct passage of D_2O into the ruminal water in the gastrointestinal tract (GITH2O) of cattle and sheep, thus causing overestimations of total empty body water. Sheng and Huggins (1979) discussed the relationship between tissue water and the lean body mass (LBM). Because tissue water is mainly associated with the lean body, generally accepted relationships between empty body water (EBH2O), empty body protein (EBP), fat (EBFAT) and ash (EBM) have been established and used to calculate the water, protein, fat and ash in the empty body (Byers, 1979b; Loy, 1983).

Several authors have reported successful development of hydrogen isotope dilution techniques to estimate EBH_2O and digestive tract fill of cattle from calves to cows and in cows of various breeds. Other studies report variable results and minimal ability to predict carcass fat (Byers, 1979b; Ferrell and Jenkins, 1984; Odwongo et al., 1984; Arnold et al., 1985; Martin and Ehle, 1986, Miller et al., 1988).

Arnold et al. (1985) discussed three approaches used in developing mathematical models to determine body water after injection of a tracer. The commonly used methods in ruminants are modifications of the one pool technique of Robelin (1975) and the two pool technique developed by Byers (1979b). Further refinement of the previously mentioned techniques is necessary in order to validate the

procedures to gain widespread acceptance.

Berg and Butterfield (1976) recommended that muscle mass be the logical endpoint for the beef industry. While considerable data exist which examine the yield of saleable retail cuts from carcasses (Harrington, 1971; Abraham, 1968,1980; Parrett et al., 1985; Johnson et al., 1989) and to a lesser extent the total separable muscle from carcasses (Butterfield, 1962; Cole et al., 1960b;1962; Allen, 1966; 1968; Berg and Butterfield, 1966; Jones, 1985a; Shanin and Berg, 1985a,b,c), relatively limited amounts of data exist which examine the relationship between muscle mass, skeletal muscle protein and EBP. Haecker (1920) performed extensive dissections of the whole body of cattle, reporting EBP found in the "flesh" (muscle and fat) of cattle ranging from 45 kg calves to 682 kg steers. Other more recent work (Byers, 1979b; Little and McLean, 1981; Ferrell and Jenkins, 1984) has been limited to the determination of EBP without detailed dissection of skeletal muscle and determination of protein associated with skeletal muscle.

The objective of this study was to determine the relationship between skeletal muscle protein and empty body protein. A second objective of this study was to examine the use of one pool and two pool isotopic dilution methods and existing equations, utilizing D_2O as a tracer, for estimating empty body protein and skeletal muscle of steers

at four developmental stages of growth.

MATERIALS AND METHODS

Twenty genetically similar continental European cross-bred beef steers were used in this study. Animals were randomly allotted to one of four slaughter weight groups, G1 to G4, (300, 390, 480, 560 kg, live weight), designed to represent animals at four developmental stages. The final weight group was to represent the finished market weight and amount of fat which is considered within the optimal range for steers in today's market. The management and diets of the animals was the same as that previously described.

Predicted empty body composition of the steers in this study was determined using a modification of the procedure described by Byers (1979b). When the animals reached the designated weight they were restrained in a squeeze chute, haltered and catheterized. Animals were held off feed 16 h before the time of infusion to reduce excessive fill, but water was never restricted. A 50 cm length of polyethylene tubing (PE200, I.D. 1.4mm) was passed through a 12 gauge needle into the jugular vein. The needle was removed, the tubing fitted with a 17 gauge adapter, flushed with either 3% citrate solution or heparinized saline and plugged. Deuterium oxide (D_2O, 99.8%, Cambridge Laboratories, MA) was used as the tracer

after 9 g NaCl per liter were added to give a physiological infusate. The quantity infused was 10 g/ 45 kg body weight, which was sufficient to give an initial D_2O concentration of 400 to 650 ppm. Sixty ml syringes were filled with D_2O and weighed. Prior to infusion an initial blood sample was drawn (T_0), to determine background concentrations of D_2O in each animal. Blood was stored in labeled 15 ml plastic heparinized tubes with rubber stoppers or plastic caps. After collections were completed each day, the samples were frozen at -30^{o} C for later processing.

At the beginning of each initial infusion, the catheter was flushed and D_2O quickly infused with the beginning and ending times recorded (to the nearest .01 min). The times were averaged to arrive at an initial infusion and all subsequent samplings determined from this time. To ensure complete delivery of D_2O the catheter was flushed with 50 ml of saline solution. To prevent clotting, 10 to 15 ml of 3% citrate solution were infused and then the catheter was plugged. Syringes were weighed immediately after infusion to the nearest .01 g to determine actual dosage.

After the infusion procedure was completed, blood samples were drawn at 10, 15, 20, 25, 30, 45, 60, 75, 90, 105, 120, 180, 240 and 300 min. The remaining samples were taken at 24 h (1440 min), 48 h (2880 min), 72 h (4320 min). The 120 min and later samples were taken by venipuncture.

For all samples, an initial 15 ml blood sample was drawn and discarded to remove residual H_2O and citrate from the tubing. The start and end of bleeding times were averaged to arrive at an actual bleeding time. After the 120 min sample was taken, the animals were returned to the pens and allowed access to feed and water. Animals were weighed at the beginning of the infusion and when the 3, 4, 5, 24, 48 and 72 h samples were taken to obtain an average live weight. All frozen blood samples were thawed, transferred to 100 ml volumetric flasks and lyophilized. Recovered D_2O samples were refrozen at 0^oC in 20 ml serum bottles until analyzed. All samples were analyzed for D_2O via infrared spectrophotometry, using procedures described by Byers (1979a). Water kinetics were examined by two methods. The two pool (2CM) standard curve peeling process of Byers (1979b) was used with several modifications. The doses of D_2O infused were corrected for NaCl by multipling the infused amount by .991. Further adjustment to the pool sizes was made for the difference in the density of D_2O to H_2O by dividing by 1.1044 to determine QAW (defined as EBH2O) and QBW (defined as gastrointestinal water, GITH2O). These corrections increased the accuracy of the procedures. The second method was a one pool method (1CM) described by Loy (1983) and evaluated by Arnold et al. (1985). Modifications and adjustments to this procedure were the same as previously mentioned for the two pool method.

Examples of the equations for the two pool kinetics system were presented by Byers (1979b) and McCarthy (1981).

Following completion of the sampling at 72 h the animals were transported to the meat laboratory and slaughtered. All tissues were individually collected, weighed and later analyzed for moisture, protein (nitrogen x 6.25) and ether extractable lipid (EEL). The right side of each carcass was physically separated into muscle, fat depots, heavy connective tissue and bone. The soft tissues were ground three times through a 3 mm plate, subsampled and powdered. All bones (including skull and feet) were weighed individually and as groups, and then frozen. Bones were ground through an Autio 801 grinder at The Ohio State University, subsampled and analyzed. The tail was weighed and ground through an 8 mm plate, subsampled and powdered. One side of the hide was ground for analyses. Viscera was emptied of contents which were then pooled, weighed and subsampled. Individual viscera components, organs, internal (noncarcass) fat depots and all other internal body cavity components were ground, powdered and analyzed. All tissues collected were summed after analyses to derive empty body weight (EBWT). Empty body and carcass composition components were determined from the weight of each individual sample and the resulting percentage composition. Skeletal muscle weight and moisture, EEL and protein percentages were determined.

Means and standard errors for all EB and skeletal muscle components were calculated for each group of animals. Analysis of variance was used to examine differences in composition between dilution methods. Equations predicting skeletal muscle, empty body water, empty body protein and empty body fat were derived using stepwise regression procedures according to the SPSS Base Manual (1989).

RESULTS

Empty body weights (EBWT) and EB composition data for the four slaughter groups (G1 to G4) are shown in Table 2-1. As expected as the weight of all components increased during development, the percentage of empty body moisture (EBH_2O), protein (EBP) and mineral (EBM) decreased ($P<.001$) while EBFAT increased.

Table 2-2 contains the lean body mass (LBM;kg) and percentage LBM for each group. As the steers matured, the absolute weight of the LBM increased but the percentage of LBM decreased 5.05, 6.8 and 2.8%, respectively, indicating each successive group deposited an increasing amount of fat. The ratio of EBH_2O to LBM did not differ ($P<.001$) between groups and remained constant for all groups at 72.0%. The relationship of EBP:EBH_2O and EBH_2O:EBP also remained constant ($P<.001$), averaging .312 and 3.21 for all steers.

Table 2-3 gives the means and standard errors of the actual and predicted EBWT for 1CM and 2CM methods. EBWT in G1 was slightly overpredicted ($P<.05$) by the 1CM and 2CM method, by 1.4 and 2.7%, respectively. As weight increased, both methods improved (statistically) in accuracy (except in G3 for 1CM; $P<.05$) to estimate EBWT. However, both methods overestimated EBWT in G2 and G3 from

TABLE 2-1. GROUP MEANS AND STANDARD ERRORS FOR ACTUAL EMPTY BODY COMPOSITION COMPONENTS

	Group			
Item	1	2	3	4
Actual empty body weight, kg	273.9	358.4	440.0	514.9
SE	3.55	1.24	2.64	3.32
Empty body H_2O, kg	166.8	208.0	237.5	269.4
SE	2.76	1.55	3.48	3.27
Empty body H_2O, %	60.9	58.0	54.0	52.3
SE	.33	.57	.70	.37
Empty body fat, kg	41.3	70.0	108.2	139.6
SE	.52	3.28	4.18	2.06
Empty body fat, %	15.1	19.5	24.6	27.1
SE	.33	.85	.95	.49
Empty body protein, kg	52.0	64.8	73.9	84.8
SE	1.04	.54	.88	1.04
Empty body protein, %	19.0	18.1	16.8	16.5
SE	.20	.20	.18	.12
Empty body mineral, kg	13.2	15.4	18.2	20.6
SE	.51	.40	.38	.70
Empty body mineral, %	4.8	4.3	4.2	4.0
SE	.16	.12	.11	.12

TABLE 2-2. GROUP MEANS AND STANDARD ERRORS FOR ACTUAL LEAN BODY MASS AND RELATIONSHIPS OF EMPTY BODY PROTEIN TO EMPTY BODY WATER[a]

	Group			
Item	1	2	3	4
Actual lean body mass, kg	231.97	288.21	329.64	374.74
SE	3.87	2.31	4.23	4.58
Actual lean body mass, %	84.69	80.41	74.91	72.78
SE	.32	.85	.88	.49
EBH_2O:LBMASS	.719[a]	.7216[a]	.7204[a]	.7188[a]
SE	.003	.002	.002	.002
EBP:EBH_2O	.3119[a]	.3117[a]	.3113[a]	.3147[a]
SE	.004	.002	.002	.003
EBH_2O:EBP	3.21[a]	3.21[a]	3.21[a]	3.18[a]
SE	.04	.02	.02	.03

[a] Means in a row with different superscripts differ ($P<.05$).

.8 to 2.6%. In G4 the 1CM tended to overestimate EBWT (P>.05) by 1.05% and the 2CM method tended to underestimate (P>.10) by .9%. Group means and standard errors for the percentage of EBH_2O from actual and prediction methods are presented in Table 2-4. The 1CM overestimated (P<.05) EBH_2O in G1 and G2 by 8.2 and 7.5%, respectively. Estimation of EBH_2O by the 1CM method tended to improve as the EBWT increased (P>.05). However, EBH_2O was still overestimated by 5.0 and 2.5% in G3 and G4, respectively. The 2CM overestimated EBH_2O (P<.05) in all groups by 8.9, 8.9, 11.9 and 6.35%, respectively.

Predicted EBP (Table 2-5) using 1CM was not statistically different from direct measurements, although EBP was overpredicted in each group by 1.5, 2.3, 2.7 and .7%, respectively. The 2CM method did not accurately predict EBP in the young, lean steers in G1, G2 and G3, as it overestimated EBP by 5.3, 5.4 and 8.5%, respectively. The 2CM estimated EBP did not differ (P>.05) from the actual EBP in G4 but was overestimated by 1.9%.

Estimated empty body fat (EBFAT) presented in Table 2-6 was underestimated (P<.01) by both prediction methods. The 1CM underestimated EBFAT by 27.1, 21.4, 8.2 and 9.1% for the respective group. The 2CM method underpredicted EBFAT to a greater extent in each group by 39.3, 31.5, 29.9 and 12.6%, respectively. It is interesting to note, however, that as the steers fattened, both methods improved in the ability to estimate fat content.

TABLE 2-3. GROUP MEANS AND STANDARD ERRORS FOR ACTUAL EMPTY BODY WEIGHT AND EMPTY BODY WEIGHT DETERMINED BY D2O METHODS[a]

	Group			
Item	1	2	3	4
Actual empty body weight, kg	273.9[a]	358.4[a]	440.0[a]	514.9[a]
SE	3.55	1.24	2.64	3.32
D2O 1 pool empty body weight, kg	277.7[b]	365.5[a]	451.4[b]	520.3[a]
SE	3.39	2.83	1.43	1.42
D2O 2 pool empty body weight, kg	281.3[b]	361.1[a]	445.96[a]	510.5[a]
SE	3.19	4.63	3.96	3.96

[a] Means in a column with different superscripts differ ($P<.05$).

TABLE 2-4. GROUP MEANS AND STANDARD ERRORS FOR PERCENTAGE AND WEIGHT OF EMPTY BODY WATER DETERMINED BY DIRECT AND D2O METHODS[a]

Item	Group 1	2	3	4
Actual empty body H2O, %	60.88[a]	58.03[a]	53.97[a]	52.31[a]
SE	.33	.57	.70	.37
D2O 1 pool empty body H2O, %	65.84[b]	62.38[b]	56.68[a]	53.61[a]
SE	.93	1.25	1.56	.66
D2O 2 pool empty body H2O, %	66.28[b]	63.20[b]	60.38[b]	55.63[b]
SE	.59	.87	1.31	.89

[a] Means in a column with different superscripts differ ($P<.05$).

TABLE 2-5. GROUP MEANS AND STANDARD ERRORS FOR PERCENTAGE AND WEIGHT OF EMPTY BODY PROTEIN DETERMINED BY DIRECT AND D2O METHODS[a]

	Group			
Item	1	2	3	4
Actual empty body protein, %	18.99[a]	18.09[a]	16.80[a]	16.46[a]
SE	.20	.20	.18	.12
D2O 1 pool empty body protein, %	19.27[a]	18.51[a]	17.25[a]	16.57[a]
SE	.21	.28	.35	.15
D2O 2 pool empty body protein, %	20.0[b]	19.07[b]	18.22[b]	16.78[b]
SE	.18	.26	.39	.27

[a] Means in a column with different superscripts differ ($P<.05$).

TABLE 2-6. GROUP MEANS AND STANDARD ERRORS FOR PERCENTAGE AND WEIGHT OF EMPTY BODY FAT DETERMINED BY DIRECT AND D2O METHODS[a]

	Group			
Item	1	2	3	4
Actual empty body fat, %	15.09[a]	19.52[a]	24.58[a]	27.12[a]
SE	.33	.85	.95	.49
D2O 1 pool empty body fat, %	10.96[b]	15.35[b]	22.56[a]	24.64[a]
SE	1.18	1.59	1.98	1.84
D2O 2 pool empty body fat, %	9.16[b]	13.37[b]	17.24[b]	23.76[b]
SE	.81	1.19	1.79	1.22

[a] Means in a column with different superscripts differ ($P<.05$).

In Table 2-7, percentage empty body mineral (EBM) was underestimated ($P>.05$) to a greater extent using the 1CM method than the 2CM. EBM was underestimated using the 1CM method by 10.4, 3.7, 7.0 and 7.3% for each group, respectivly. EBM predicted using the 2CM method was underestimated in G1 by 6.0%, overestimated in G2 and G3 by 1.2 and .2%, respectively and underestimated by 4.3% in G4.

Table 2-8 contains the actual weight and percentage of gut fill predicted by the 2CM method. Although not statistically significant, percentage gut fill differed from actual percentage fill by -14.5, +3.5, -3.5 and +20.7% for the respective groups. Quantity of fill (kg) differed by -22.1, -6.9, -12.3 and +9.9% for G1 to G4, respectively. While the magnitude of difference from actual percentage and weight of gut fill appears to be great, the difference in water associated with gut fill does not completely account for the overestimation in EBH_2O.

Table 2-9 contains the means and standard errors for the actual weight of skeletal muscle (SKM) from the EB, percentage muscle of the EB, protein content of the EB skeletal muscle and percentage EBP originating from skeletal muscle. Skeletal muscle mass increased ($P<.001$) between each group, however, percentage SKM of the EB decreased ($P<.05$) from G1 to G3 but did not differ ($P>.10$) between G3 and G4. SKM protein content, while numerically decreasing slightly, did not differ ($P>.10$) from G1 to G4,

TABLE 2-7. GROUP MEANS AND STANDARD ERRORS FOR PERCENTAGE AND WEIGHT OF EMPTY BODY MINERAL DETERMINED BY DIRECT AND D2O METHODS[a]

	Group			
Item	1	2	3	4
Actual empty body mineral, %	4.81[a]	4.30[a]	4.15[a]	4.00[a]
SE	.16	.12	.11	.12
D2O 1 pool empty body mineral, %	4.31[a]	4.14[a]	3.86[a]	3.71[a]
SE	.05	.06	.08	.03
D2O 2 pool empty body mineral, %	4.57[a]	4.35[a]	4.16[a]	3.83[a]
SE	.04	.06	.09	.06

[a] Means in a column with different superscripts differ ($P<.05$).

TABLE 2-8. ACTUAL AND PREDICTED WEIGHT AND PERCENTAGE GUT FILL FROM DISSECTION AND D_2O DILUTION TECHNIQUES[a]

Item	Group 1	2	3	4
Actual GI fill, kg	33.51[a]	39.34[a]	48.24[a]	43.85[a]
SE	1.13	3.03	2.28	3.93
D2O 2 pool GI fill,kg	26.11[a]	36.63[a]	42.32[a]	48.19[a]
SE	3.93	3.24	5.30	3.21
Actual GI fill, %	10.91[a]	9.87[a]	9.88[a]	7.84[a]
SE	.41	.69	.47	.69
D2O 2 pool GI fill, %	9.33[a]	10.18[a]	9.53[a]	9.46[a]
SE	1.45	.98	1.27	.70

[a] Means in a row with the same superscripts do not differ (P>.05).

TABLE 2-9. GROUP MEANS AND STANDARD ERRORS FOR ACTUAL EMPTY BODY SKELETAL MUSCLE TRAITS USED WITH D2O PROCEDURES TO ESTIMATE SKELETAL MUSCLE

	Group			
Item	1	2	3	4
Actual empty body skeletal muscle, kg	126.25	156.95	182.68	214.97
SE	3.72	.58	2.81	2.69
Skeletal muscle protein, %	21.4	21.20	20.80	20.88
SE	.24	.20	.14	.20
Actual protein from total skeletal muscle, kg	27.06	33.27	38.00	44.88
SE	1.09	.30	.61	.61
Actual percentage of EB protein from skeletal muscle, %	52.00	51.4	51.41	52.9
SE	1.27	.61	.44	.13
Percentage muscle of EB WT,%	46.09	43.79	41.51	41.75
SE	.56	.44	.54	.68

averaging 21.0% for all animals. Quantity of protein (kg) in SKM increased with each group, however, the ratio of SKM protein to EBP did not differ (P>.10) between slaughter groups averaging 52% across all animals and groups. Since this relationship remains constant over the period of time in which an animal is rapidly developing and fattening it can be useful in predicting skeletal muscle protein and ultimately SKM.

Table 2-10 contains the regression equations developed from the data collected from the steers in this study to estimate EBH_2O, EBFAT, SKM protein, EB LBM and EBP. In equation 1, 92% of the variation in EBH_2O was accounted for by the D_2O pool A, suggesting that reasonably accurate determinations of EBH_2O can be obtained by using a 1CM method. Equation 2 and 3 estimate EBFAT (%;kg) from EBH_2O (%;kg) which accounts for 99% and 91% of the variation in EBFAT, respectively. Predicting EBFAT by regression equation appears to be more accurate than estimating EBFAT by differences since errors in each method compound the problems and will reduce the accuracy of estimation of EBFAT. Equations 4, 5 and 6 appear to be useful in predicting the weight of SKM protein, explaining 97, 98 and 87% of the variation in skeletal muscle protein by using the relationships between EBH_2O, EBP and D_2O pool A and SKM protein. Equations 7 and 8 predict skeletal muscle quantity (kg) in the EB from EBH_2O and EBP, respectively,

TABLE 2-10. EQUATIONS TO PREDICT EMPTY BODY WATER, SKELETAL MUSCLE PROTEIN EMPTY BODY FAT AND GUT FILL

Eqn #	Dependent Variable	Independent Variable	Intercept	Regression coefficient	R^2	RSD
1	EBH^2O, kg	D_2O pool A	-21.85	.967	.92	11.66
2	EBFAT, %	EBH_2O (%)	98.82	-1.372	.99	.45
3	EBFAT, kg	EBH_2O (kg)	-117.78	.942	.91	11.85
4	Skeletal muscle protein, kg	EBH_2O (kg)	-2.11	.172	.97	1.18
5	Skeletal muscle protein, kg	EBP (kg)	-1.606	.543	.98	1.00
6	Skeletal muscle protein, kg	D_2O pool A	-5.439	.1647	.87	2.51
7	Skeletal muscle, kg	EBH_2O (kg)	-19.58	.861	.99	3.6
8	Skeletal muscle, kg	EBP (kg)	-16.1	2.705	.99	3.96
9	EB lean body mass	= EB H_2O / .72				
10	EB protein	= EB H_2O * .312				

accounting for 99% of the variation in SKM. Equations 9 and 10 are simply the equations used by Byers (1979b) substituting the constants for EBH_2O:LBM and EBP:EBH_2O from this study.

DISCUSSION

The studies of Lawes and Gilbert (1859); Haecker (1920); Moulton (1922a,b); Reid et al., (1963) are the most complete body composition studies and they have been the basis for comparisons of numerous later studies examining cattle growth. The empty body (EB) chemical composition of steers from the present study generally correspond to the 273, 364, 409 and 454 kg empty body weight groups from the studies mentioned above. In this study the chemical composition of the EB of animals from G1 and G2 are in agreement with the data of Haecker, 1920; Moulton, 1922a,b; Maynard and Loosli, 1962. The change in empty body composition in the steers from G3 and G4 in the present study were not as large as the change in composition of the comparable 364 to 454 kg groups in the earlier studies of Haecker. Changes in EB composition between G2 and G3 from this study were not as dramatic for all components, and the composition of G3 in the present study closely represented the 409 kg EBWT group in the Haecker study; and G4 closely corresponded to the composition of the 454 kg live weight group of Haecker. These data exemplify the changes in composition which have occurred during the past 75 years with changing demands for leaner beef. Selection of later maturing, leaner, more muscular cattle and the use of

continental European breeds of cattle have effectively extended the lean growth and delayed the fattening phase of the steers, compared with conventional domestic beef breeds. These data support the work by Koch et al. (1976) in which cattle from various biological types were examined.

The data and relationships given in Table 2-2 show that the developmental changes in lean body mass (LBM) are consistent with previously published work by Haecker (1920); Moulton (1922a,b); Callow (1962), Reid et al., (1963). The relationship of water to LBM has been generally accepted to remain constant over time (Pace and Rathbun, 1945; Babineau and Page, 1955; Panaretto and Till, 1963; Byers, 1979b; Arnold et al., 1985). Panaretto and Till (1963) as well as the previously mentioned workers have shown the relationship to be constant at about 73.2%. Prediction equations from dilution studies for estimation of EB components were derived asssuming this relationship to be constant. Many studies are conducted using this assumption, never determining the actual ratio. Numerous deviations from the constant 73.2% have been discussed by Widdowson (1968) and Sheng and Huggins (1979). Reports of values other than the reported constant have been reported for Holsteins (Wellington et al., 1956), goats (Panaretto, 1963a,b), Angus cattle (Carnegie and Tulloh, 1968), Jerseys (Carnegie and Tulloh, 1968), dogs (Sheng and Huggins,

1971), rats (Tisavipat et al., 1974), and Holstein cattle (Odwongo et al., 1984) which are 67.9, 75.6, 68.9, 66.5, 63.0, 75.8, 72.0 to 76.5%, respectively. Changes in the H_2O/LBM ratio as indicated, can have very profound effects on the resulting data, which in turn can lead to invalid conclusions. In this study the H_2O/LBM was constant (72.0), but slightly lower than the reported 73.2. These values are in agreement with those derived from the data of Trowbridge et al. (1918), Haecker (1920), Moulton et al. (1922a,b, 1923), Ellenberger (1950), Reid et al. (1963, 1968) and Garrett and Hinman (1969), lending support to the use of constant relationship values in subsequent prediction equations. However, the values differ from those of Byers (1979b) and Arnold et al. (1980, 1985) which ranged from 72.4 to 73.9%. The EBP/EBH_2O and H_2O/EBP ratios derived in the present study were slightly higher but still in general agreement with published data as well as the more recent studies by Williams and Bergstrom (1980), Arnold (1980) and Arnold et al., (1985).

The standard equation used in the 1CM and 2CM method consistently overestimated the EBWT for all groups. This suggests that modifications in the equations may more accurately predict EBWT using the 1CM method. It is puzzling, to find the 2CM most accurately predicts EBWT for the G3 and G4, while overestimating the EBWT for G1 and G2. This suggests that the relationships used in the 1CM and

2CM equations to predict EBWT and EBH_2O in later groups (fatter) may not account for developmental changes in $GITH_2O$ and D_2O : H_2O interactions, in young, lean animals thus overestimating EBWT.

The 1 CM EBH2O is overestimated as calculated from the total body water (TBH_2O) by the equations TBH_2O = .968 (D_2O space), EBH_2O = TBH_2O -$GITH_2O$ and $GITH_2O$ = GITF (gut fill) x .847 as presented by Loy (1983) and Arnold et al., (1985). The overestimation appears to be due in part to TBH_2O:D_2O space relationships and the %$GITH_2O$ from which the EBH_2O is derived. The EBH_2O from the 2CM method on the other hand is derived from the equation kg (EBH_2O) = 1.038 x QAW -17.92, (QAW is pool A, the large EBH_2O pool measured by the kinetics model presented by Shipley and Clark, 1972 and discussed by Byers, 1979b). Nagy and Costa (1980) discussed possible sources of errors in measuring body water and water fluxes using hydrogen isotopes. The EBH_2O for both methods in this study differs from those of Byers (1979b; 1986) and Arnold et al., (1985), overestimating ($P<.05$) EBH_2O, especially in G1, G2 and G3. Data and relationships derived from this study suggest the present equations of Loy (1983), Arnold et al., (1985) and Byers (1979b) will not adequately estimate the EBH_2O of young, lean animals. There appears to be a developmental change in the H_2O to D_2O relationship which is greatest, causing the highest overestimation, in the young, lean animals (G1

and G2) in this study, becoming less significant as the cattle fatten, (G3 and G4).

The 1CM method EBP is derived from EBH_2O by the equation %EBP = (100 -%EBFat - %EBH_2O)(.831) and %EBFat = 94.32 - (1.266)(%EBH_2O). Thus, the importance of accurate estimation of EBH_2O becomes obvious. Since EBP in the 2CM is also derived from EBH_2O, it is obvious that EBP would be overestimated in G1, G2 and G3 and most accurately estimated in G4.

The constant used in the 2CM method (Byers,1979) equation was .3017 multiplied by EBH_2O to give EBP. This protein constant value is in general agreement with that determined by numerous researchers (Trowbridge et al., 1918,1919; Haecker, 1920; Haigh et al., 1920; Moulton et al., 1922a,b, 1923; Ellenberger et al., 1950; Garrett and Hinman, 1969; Garrett et al., 1971; Simpendorfer, 1973; Foot and Tulloh, 1977; Williams et al., 1974; Byers, 1979b;1986; Arnold, 1980, 1985). The protein constant determined in this study was .312, which was slightly higher than the value commonly used in the dilution techniques for the two pool method. Substitution of this value into the present equations would result in an even larger deviation from actual EBP, thus emphasizing the need to accurately determine EBH_2O.

EBM is also calculated from EBH_2O using the constant .183 and .0689 for the 1CM and 2CM methods, respectively.

These constants agree with those cited by Martin and Ehle (1986) and Ferrell and Jenkins (1984). Predicted mineral values in this study were slightly higher (due to overestimation of EBH_2O) than those published in the literature.

Limited amounts of information exist in which workers measured the weight of muscle in the empty body or in carcasses of cattle. Haecker (1920) reported weight of "flesh" which included muscle and fat. Berg and Butterfield (1976) reported data from others who estimated the percentage of muscle in the carcass from the amount in rib sections (Lawrence and Pearce, 1964; Henrickson et al., 1965). Callow (1961) measured muscle in carcasses of cattle from different planes of nutrition. Berg and Butterfield (1976) also presented data from a study by Berg comparing the quantity and growth of muscle from bulls, steers and heifers. The growth patterns of cattle in the present study were similar to that of published work. However, empty body muscle weights were greater in the present study, probably as a result of the increased lean growth traits common in continental European crossbred cattle.

The percentage protein in the composite muscle sample from the present study was the same as that reported by Berg and Butterfield (1976) and USDA (1986) and only slightly higher than that reported by Brannang (1966)

(20.33 to 20.64%). The slight decrease in protein over time due to the dilution of the protein by increased intramuscular fat was not significant (P>.1).

Calculations to determine the weight of protein associated with the skeletal muscle and subsequent determinations of the percentage of EBP from skeletal muscle are similar to those of Haecker (1920) and Moulton (1922a,b). Protein determined in these earlier studies was determined from "flesh" as described previously. Since protein associated with fat was included in their calculations, removal of "fat associated protein" would reduce their values of the %EBP (58%0 from SKM to be similar to those in the present study. Haecker's study showed a narrow range for the percentage EBP from carcass flesh for the cattle that ranged in weight from 318 to 454 kg, which closely resembles the composition of the steers in the present study. While the percentage of EBP from skeletal muscle was decreased slightly in G2 and G3 in this study, it was likely due to individual animal variation. One animal in G1 was slightly above average in muscling (compared to others in G1) thus increasing muscle protein and one steer in each of G2 and G3 was slightly below average in muscle, thus causing lower muscle protein. Regardless, the values for EBP from SKM derived from cattle in this study, are similar to those derived from published data. The relationships can ultimately be useful in

predicting skeletal muscle mass as long as EBH_2O can be accurately determined.

SUMMARY

Skeletal muscle protein. As the steers grew, the percentage of skeletal muscle protein of the empty body protein remained constant at about 52%. Percentage protein in the skeletal muscle, while becoming slightly diluted due to fattening (intramuscular fat), remained relatively constant at 21% across groups. These data suggest that skeletal muscle protein can be predicted if empty body protein can be accurately estimated or directly determined.

Empty body water relationships. Empty body water as a percentage of lean body mass remained constant at 72.0% across all groups. Furthermore, the relationship of empty body protein to empty body water remained constant at .312. These data suggest that empty body protein and lean empty body mass can be predicted if empty body water can be accurately estimated.

Dilution techniques. Equations from the one compartment dilution technique consistently overestimated empty body weight. The one compartment method showed a developmental change in accuracy of estimating empty body weight, overestimating empty body weight in lean animals and more accurately estimating empty body weight as the steers fattened. The two compartment equations overpredicted empty body weight in young, lean steers but

underpredicted EBWT in the final weight group.

Prediction of empty body chemical components. Both methods overestimated empty body water and thus empty body protein which is calculated from empty body water. The one compartment method equations more closely predicted empty body water in the leaner animals. These data suggest that equations used in this study do not adequately estimate empty body water and thus should not be utilized alone to accurately estimate empty body protein and in turn skeletal muscle especially in large frame, lean crossbred cattle. Furthermore, refinements and modifications of existing prediction equations and dilution principles are needed to account for the developmental changes in empty body water, fat and protein relationships, in order to more accurately estimate empty body composition of cattle.

Chapter 3

Estimation of Lean Body Mass, Empty Body Protein and Skeletal Muscle Protein from Urinary Creatinine Excretion in Continental European Crossbred Steers

ABSTRACT

The relationship of urinary creatinine excretion (UCE) with lean body mass (LBM), empty body protein (EBP) and skeletal muscle protein (SMP) was studied. Genetically similar crossbred steers (Simmental X Angus X Charolais) were randomly allotted (5 per group) to one of four final slaughter groups (300, 390, 480 and 560 kg, respectively). Six days prior to slaughter, steers were acclimated to collection crates and total urine collected each day for 3 d. Individual day urine collections were measured, subsampled, pooled and analyzed for UCE at the termination of the collection period. Steers were slaughtered 2 d later with complete physical and chemical analysis conducted on all empty body components. Mean daily UCE (g/d) per slaughter group were 7.83, 11.42, 12.29 and 13.42, respectively. UCE was highly correlated to weight of LBM, EBP and SMP (r=.92, .90 and .87, respectively). Equations predicting LBM, EBP and SMP were derived using stepwise regression procedures. Equations predicting LBM, EBP and SMP from UCE had R^2 and RSD values of .84, .81, .75; 22.19, 5.46, 3.43, respectively. Accuracy of prediction equations was greatly improved with the addition of fasted live weight (LW) into each equation. Prediction equations for LBM, EBP and SMP follow:

$$LBM = 59.37 + 4.915 \times UCE\ (g/d) + .445 \times LW\ (kg)$$

$$EBP = 13.261 + .814 \times UCE\ (g/d) + .1078 \times LW\ (kg)$$

$$SMP = 6.338 + .161 \times UCE\ (g/d) + .0642 \times LW\ (kg)$$

These data suggest that UCE may be useful as a research tool for estimating developmental changes in LBM, EBP and SMP in beef steers.

INTRODUCTION

Waterlow (1969) referred to the urinary metabolite of creatine phosphate, creatinine, as a valid global index of muscle mass. Past research data support this claim in humans, beef cattle and sheep, however, very little recent information is available which has quantified the relationship between urinary creatinine excretion and lean body mass in steers.

Folin (1905) stimulated early interest in creatinine excretion during studies in which he found no change in the creatinine excretion from an individual receiving a meat - free diet. Brody (1945), Dinning et al. (1949), Lofgreen and Garrett (1954) and Van Niekerk et al. (1963a) each accumulated data from studies in beef cattle and sheep which showed high correlations ($r > .65$) between creatinine excretion and lean body mass. However, these researchers did not totally dissect the carcass and quantify the lean body mass. Recently McCarthy (1981), Benner (1983), Golpinath and Kitts (1984) and Hayden (1987) reported creatinine excretion increased as live weight increased indicating muscle mass was increasing. Each of these studies attempted to use creatinine excretion as a tool to assess the effects of exogenous growth promoting agents and changes in frame size on muscle mass in beef.

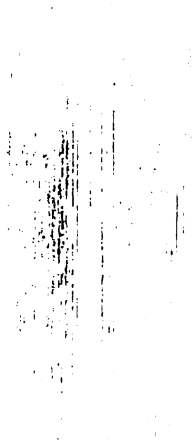
In the present study, the objective was twofold. 1) investigate the relationship between developmental changes in daily creatinine excretion and empty body composition. Secondly, develop equations which can be utilized to predict lean body mass, empty body protein and skeletal muscle protein and other live measurements in steers from daily creatinine excretion.

METHODS

Urine Collection. Urine was collected by placing steers in individual 85 x 142 cm collection crates. Steers were placed into the collection crates 1-2 d before actual collection in order to allow them to acclimate to the restraining chute and collection crates. Total urine was collected for 3 d from a 66 x 66 cm plexiglass collector under the collection crate. During the collection process, the urine passed through 2 layers of fine mesh steel screening and 2 layers of cheese cloth before entering the collector to minimize fecal and hair contamination. Urine was collected in 20 liter plastic containers to which 4 N H_2SO_4 was added to lower the pH of the urine to 2-3. The containers were emptied daily and total volumes recorded. A 10% aliquot was obtained each day, passed through 3 layers of cheese cloth and stored at 2^{o} C until the 3 d collection was completed. The 3 aliquots were composited and frozen at -20^{o}C. Approximately 100 ml of composited urine were filtered and analyzed.

Creatinine Analysis. Creatinine concentrations were determined in urine samples by a colormetric procedure (Sigma Chemical Co., 1978).

Statistical Analysis. Group means, standard errors of creatinine excretion, total urine excretion, lean body



mass, empty body protein and skeletal muscle protein were determined. Analysis of variance was conducted on all variables between slaughter groups. Prediction equations were developed using stepwise multiple regression procedures. All analyses were conducted according to SPSS Base Manual (1989).

RESULTS AND DISCUSSION

Mean values for urinary creatinine excretion (mg/d), creatinine per kilogram live body weight (Cr/WT) and total urine output (TUR) for each group are presented in Table 3-1. As expected, urinary creatinine excretion (UCE) increased with increasing live weight. UCE significantly increased ($P<.001$) from G1 to G2 and G3. However, while UCE increased ($P>.1$) from G2 to G3, large variations in individual animal outputs were noted. Such variations are consistent with data from humans, rats and sheep (Forbes and Bruining, 1976). As expected, UCE was significantly higher in G4 than all other groups.

Forbes and Bruining (1976) demonstrated the usefulness of using UCE as an index of LBM as long as care is taken in collecting samples. In this study, urine output varied as much as 4 liters from day to day, however, UCE concentration also varied accordingly. Scrimshaw et al. (1966) reported that among other things, stress and strenuous excerise can each introduce a 5 to 10% variation in daily creatinine excretion. Paterson (1967) and Zorab et al. (1969) have demonstrated that daily UCE can vary and they stressed the importance of collecting several days urine output in order to accurately assess UCE. After examining available UCE data in cattle and sheep, these and

Table 3-1. GROUP AVERAGE DAILY URINE OUTPUT, URINARY EXCRETION OF CREATININE AND CREATININE PER KILOGRAM BODY WEIGHT IN CATTLE OVER TIME

	Group			
Item	1	2	3	4
No. of Animals	5	5	5	5
Average creatinine excretion, mg/day	7827.6[a]	11423.5[b]	12292.2[b]	13399.2[c]
SE	332.0	212.0	393.8	582.2
Average daily creatinine excretion per unit of body weight, mg/kg	26.36[b]	29.22[a]	25.47[b]	24.71[b]
SE	1.13	.48	.84	1.04
Average daily urine output, ml	3341.1	4539.1	6314.7	3684.0
SE	761.5	1262.0	1667.2	172.0

[a]Means in the same row with different superscripts differ (P<.01).
[b,c]Means in the same row with different superscripts differ (P<.05).

other factors most likely are also applicable to livestock. Thus, potentially relatively large errors (5 to 20%) or larger are possible if one would rely strictly on a single day's UCE or single point UCE to predict lean body mass.

Researchers in several recent studies each collected urine in cattle and determined daily UCE. They referred to increasing UCE as an indicator of differences in muscle mass or an index of increasing muscle mass. McCarthy (1981) reported significant differences in UCE between small and large frame beef steers of 6352 to 8705 mg/d and 6732.5 to 11982 mg/d, respectively. UCE values for comparable live weight, large frame steers in McCarthy's study were similar to steers of similar live weight, composition and UCE values in the present study. TUR and Cr/WT values in this study were similar to those reported by McCarthy (1981) and Hayden (1987) in steers of similar weights.

Gopinath and Kitts (1984) investigated muscle protein metabolism and UCE in Hereford steers with a beginning weight of approximately 380 kg. After 24 d and approximately 33.6 kg gain, they reported similar UCE values (11,460 mg/d) to G2 steers in the present study. Throughout the duration of their study at collection days 56 and 63 (live wt of approximately 450 to 465 kg), UCE values were similar to G3 steer UCE values in the present study.

Benner (1983) and Hayden (1987) each investigated the effects of trenbolone acetate and estrogenic implants on muscle protein metabolism and changes in body composition in continental European crossbred heifers (Benner) and steers (Hayden). These researchers reported increasing UCE values with increasing live weight and also higher UCE values for implanted animals. They concluded that increased UCE values of implanted animals indicated increased muscle mass. Each supported their findings using either deuterium oxide or urea space dilution, estimating that the treated animals contained more empty body protein and thus more skeletal muscle protein than controls.

Table 3-2 contains values for weight of lean body mass (LBM), weight of fat-free muscle (FFM), percentage FFM of LBM, weight of empty body protein (EBP) and weight of skeletal muscle protein (SMP) for each group. Weight of LBM, FFM, EBP and SMP each increased from G1 to G4. However, percentage FFM of LBM remained relatively constant at about 53.5%. This supports the finding of Forbes and Bruining (1976) in which they concluded that fat-free muscle comprised about one-half of the lean body mass in humans. Knowledge of LBM, the percentage of FFM of LBM and the ability to predict each is useful in measuring rates of protein turnover i.e., synthesis and degradation studies in cattle.

TABLE 3-2. ACTUAL AVERAGE LEAN BODY MASS, FAT FREE MUSCLE, PERCENTAGE FFM OF LBM, EMPTY BODY PROTEIN AND SKELETAL MUSCLE PROTEIN IN GROUPS OF STEERS

	Group			
Item	1	2	3	4
No. of Animals	5	5	5	5
Actual lean body mass, kg	232.0	288.2	329.6	374.7
SE	3.87	2.31	4.22	4.58
Fat free muscle mass, kg	124.13	153.06	174.66	205.25
SE	3.62	0.66	2.87	3.14
Percentage FFM of LBM, %	53.5^{ab}	53.1^{b}	53.0^{b}	54.8^{a}
SE	0.74	0.25	0.40	0.25
Empty body protein, kg	52.0	64.8	73.9	84.8
SE	1.01	0.54	0.88	1.04
Skeletal muscle protein, kg	27.1	33.3	38.0	44.9
SE	1.09	.30	.61	.61

[ab] Values within a row with the same superscript differ ($P < .05$).

Table 3-3 contains regression eqautions which predict LBM for steers in this study using UCE and other easily obtainable live animal traits. UCE (R^2 = .84; eqn #1) was useful in predicting LBM. However, since live weight (LWT; kg) and 12th rib fat (12FT; cm) are highly related to body composition, equation #2 which includes UCE and LWT, accounted for 98% of the variation in LBM and dramatically reduced the residual standard deviation (RSD), from 22.2 to 6.6 kg. Equation #3 which included UCE, LWT and 12FT also accounted for 99% of the variation in LBM and only slightly improved the RSD (6.2 vs 6.6). A fourth equation which included only LWT and 12FH was also useful, but slightly less accurate, in predicting LBM (R^2 = .98; RSD = 7.3). The high R^2 and low RSD indicate these measurements allow for relatively easy determination of LBM with or without using UCE as an independent variable. From the standpoint of predicting LBM from UCE and with as few number of other easily obtained independent variables as possible, use of UCE and LWT require the least amount of time and equipment necessary. Inclusion of 12FT marginally improved the estimation of LBM. However, accurate 12th rib backfat measurements must be obtained by ultrasound which would necessitate a trained operator and thus an increase in labor and expense.

TABLE 3-3. REGRESSION EQUATIONS TO PREDICT WEIGHT OF LEAN BODY MASS

Equation number	Independent variables	Intercept	Regression coefficient	R^2	RSD
1	Creatinine excreted (g/d)	60.9506	21.82	.84	22.19
2	Creatinine excreted (g/d)	59.3706	4.915	.98	6.633
	+ live weight (kg)		.44501		
3	Creatinine excreted (g/d)	32.9461	3.92	.99	6.20
	+ live weight (kg)		.5874		
	+ 12th rib fat thickness (cm)		- 35.006		
4	Live weight (kg)	26.674	.73464	.98	7.311
	+ 12th rib fat thickness (cm)		- 54.11		

Table 3-4 contains equations which predict weight of EBP in steers from this study. As with equations predicting LBM, equation #5, using only UCE was useful (R^2 = .81, RSD = 5.455) in estimating EBP. However, as previously mentioned, addition of LWT and (or) 12FT as independent variables into equations with UCE increased R^2 to .98 and significantly reduced the RSD, improving the ability of equation #6 and #7 to accurately estimate EBP. Equation #8 also adequately estimated EBP without the need to analyze urine for creatinine content.

Table 3-5 contains equations which predict weight of skeletal muscle protein. Equation # 9 using UCE as the sole indepedent variable in predicting weight of SKP had a coefficient of determination (R^2) of only .76 and RSD of 3.43. Addition of LWT to equation #10 again greatly improved the ability to estimate SMP (R^2 = .95, RSD = 1.6). Inclusion of 12FT into equation #11 marginally improved the ability to predict SMP (R^2 = .96, RSD = 1.56), as did the elimination of UCE as an independent variable in equation #12 (R^2 = .95, RSD = 1.51). Elimination of UCE as a variable related to muscle mass, may however, sufficiently bias the estimation of SMP, if an animal's actual weight is considerably exaggerated due to excessive fill.

Table 3-6 contains the summary of significant differences using the Student's T-Test comparing results of actual group values for LBM, EBP and SMP versus predicted

TABLE 3-4. REGRESSION EQUATIONS TO PREDICT WEIGHT OF EMPTY BODY PROTEIN

Equation number	Independent variables	Intercept	Regression coefficient	R^2	RSD
5	Creatinine excreted (g/d)	13.6441	4.916	.81	5.455
6	Creatinine excreted (g/d)	13.2613	.814	.98	1.871
	+ live weight (kg)		.1078		
7	Creatinine excreted (g/d)	4.8329	.504	.98	1.695
	+ live weight (kg)		.1532		
	+ 12th rib fat thickness (cm)		-11.1655		
8	Live weight (kg)	4.0262	.1722	.98	1.729
	+ 12th rib fat thickness (cm)		-13.623		

TABLE 3-5. REGRESSION EQUATIONS TO PREDICT WEIGHT OF SKELETAL MUSCLE PROTEIN

Equation number	Independent variables	Intercept	Regression coefficient	R^2	RSD
9	Creatinine excreted (g/d)	6.5662	2.6	.75	3.43
10	Creatinine excreted (g/d)	6.3384	.161	.95	1.597
	+ live weight (kg)		.06416		
11	Creatinine excreted (g/d)	1.4952	-.0164	.95	1.559
	+ live weight (kg)		.09025		
	+ 12th rib fat thickness (cm)		-6.416		
12	Live weight (kg)	1.521	.0896	.95	1.513
	+ 12th rib fat thickness (cm)		-6.336		

TABLE 3-6. SUMMARY OF STUDENT'S T-TEST COMPARISONS BETWEEN ACTUAL AND PREDICTED LEAN BODY MASS, EMPTY BODY PROTEIN AND SKELETAL MUSCLE PROTEIN

	Group			
Item	1	2	3	4
No. of Animals	5	5	5	5
LBM Eqn no.				
1	NS	.003	NS	.08
2	NS	NS	NS	NS
3	NS	NS	NS	NS
4	NS	NS	NS	NS
Kg EBP eqn no.				
5	NS	.004	NS	.08
6	NS	NS	NS	NS
7	NS	NS	NS	NS
8	NS	NS	NS	NS
Kg SMP eqn no.				
9	NS	.02	NS	.05
10	NS	NS	NS	NS
11	NS	NS	.10	NS
12	NS	NS	.10	NS

values. Predicted values were determined by applying the equations derived using all animals in the study to each group of five animals. Equations using only UCE as the only independent variable significantly ($P<.05$) overpredicted values when compared to actual values in G2 and G4. Equations 2, 6 and 10 consistently accounted for 95 percent or more of the variation in the weight of lean body mass, empty body protein and skeletal muscle protein. These equations were nearly as accurate as all other equations, with the least amount of labor and expense, for predicting LBM, EBP and SMP. Equations 3, 4, 7, 8 and 10 also provided values which did not differ from actual values. However, equations 11 and 12 provided values for SMP which approached being significantly different from actual values and therefore can not be recommended for use.

SUMMARY

Urinary creatinine excretion appeared to be excreted proportionately (r=.87) to muscle mass. Lean body mass, empty body protein, skeletal muscle and skeletal muscle protein were determined by physical dissection and chemical analyses at four stages of development. Regression equations using creatinine excretion alone can be useful to predict lean body mass, empty body protein and skeletal muscle protein. Inclusion of live weight however, as a second variable in regression equations significantly improved the ability to predict LBM, EBP and SMP muscle protein, accounting for at least 95% of the variation in LBM, EBP and SMP.

Chapter 4

Comparisons of Commonly Used Methods of Estimating Beef Carcass Composition in Continental European Crossbred Steers

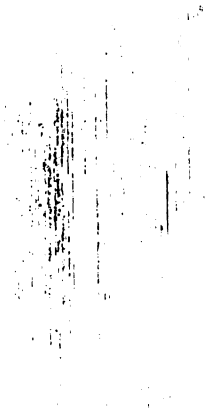
ABSTRACT

To assess the accuracy and usefulness of current carcass composition prediction methods, 9-10-11 rib sections (RIB) and carcass specific gravity, (SG, with KP fat included), at different degrees of fatness, 20 genetically similar steers were randomly allotted to one of four slaughter weights. Weight and percentage (kg:%) of carcass water (CH_2O), protein (CP), fat (CFAT) were directly determined by physical separation and chemical analyses of carcass soft tissues. Equations developed by Hankins and Howe (1946) overestimated carcass water and protein and underestimated carcass fat ($P<.01$). Using equations developed by Garrett and Hinman (1969) specific gravity underestimated ($P<.05$) carcass water in carcasses with less than 24% carcass fat, underestimated ($P<.05$) carcass fat and overestimated ($P<.05$) carcass protein in carcasses with greater than 17.0% carcass fat. Specific gravity of the carcass with kidney and pelvic fat removed to reduce trapped air, and specific gravity of the 9-10-11 rib were examined and equations developed to predict carcass composition. All methods were highly correlated to actual carcass components ($r>.85$, $P<.001$) for all steers suggesting that refinement of prediction equations is needed to utilize these prediction methods with lean, large frame cattle today.

INTRODUCTION

The most accurate determination of carcass composition as stated by Powell and Huffman (1968) is the complete chemical analysis of the entire carcass. However, budgetary constraints, time, labor expenses and the loss of carcass value limit the use of this procedure. Therefore, researchers are forced to rely on convenient, indirect methods and procedures to obtain reliable composition information at reasonable cost.

Numerous methods to indirectly estimate carcass chemical composition of cattle have been suggested (Hankins and Howe, 1946; Kraybill et al., 1952; Yeates, 1965; Garrett and Hinman, 1969; Ledger et al., 1973; Miller et al., 1988). Since carcass composition is the index for many research treatment comparisons, highly correlated estimation methods are essential to give meaningful treatment results. Today, the most commonly used methods of estimating carcass chemical composition is that introduced by Hankins and Howe (1946) which uses the composition of the 9-10-11 rib section to predict the composition of the entire carcass. Specific gravity as first discussed by Kraybill et al., (1952) and later reviewed by Pearson et al., (1968), Garrett and Hinman (1969), has also been used as a predictor of carcass



composition with both favorable (Garrett and Hinman, 1969; Ledger et al., 1973) and unfavorable results (Powell and Huffman, 1968; Lunt et al., 1985a; Jones and Rompala, 1985a; Miller et al., 1988). Fat thickness over the longissimus muscle at the 12 - 13 rib interface also has been examined and found to be highly correlated to the chemical composition of the carcass (Crouse and Dikeman, 1974).

Development of the aforementioned methods to predict carcass composition was conducted using predominantly domestic-bred cattle notably Angus, Hereford, Shorthorn, Brahman or crosses of each. The biological and developmental nature of these breeds, when fed normal ad libitum diets, predisposes them to the accumulation of large quantities of subcutaneous adipose tissue at market weights as indicated by Haecker, 1920; Trowbridge, 1922a,b; Callow, 1962 and thoroughly discussed by Berg and Butterfield, 1976. Interestingly however, Cole, Ramsey and Epley (1962) tested the equations of Hankins and Howe for predicting separable components (fat, lean and bone) in cattle of British, dairy and Zebu genetic background and they found them to be accurate predictors.

The interest and increasing emphasis on lean beef production has been a driving force behind research efforts to produce less fat and more muscle in carcasses of domestic breeds of cattle. The introduction of continental

European breeds has proven to be genetically a much faster, easier method in which to significantly alter carcass composition of beef produced today than by altering the domestic breeds. Numerous research papers have documented the findings that continental European crossbred cattle produce leaner carcasses than domestic breeds of cattle. Recent studies by Charles et al. (1976a), Jones et al. (1982,1985b,c) and Shanin et al. (1985a,b,c) have shown that both the amount and distibution of fat in the carcasses of continental European bred cattle differs from that of British breeds.

Today's crossbred cattle marketed at 13 to 16 mo of age typically have larger, heavier carcasses and less subcutaneous fat. These studies suggest that the established equations which estimate carcass composition by 9-10-11 rib section, specific gravity and fat thickness, may be less reliable in leaner carcasses from today's feedlot cattle.

Since cattle frame - types have changed since the time when estimating equations were developed, the present study was designed to evaluate the application of existing prediction equations to carcasses from continental European crossbred animals at four developmental stages and body weights. Relationships between the prediction of percentage of carcass water, ether extractable lipid and protein using the composition and SG of the RIB and SG of

the carcass were compared with actual carcass composition to determine usefulness of these equations in cattle of very uniform composition within each group as well as the diverse carcass composition between weight groups. New equations were generated if present equations proved to be inadequate. Furthermore, the relationships between the specific gravity of the 9-10-11 rib section and specific gravity of the carcass without kidney and pelvic fat and carcass composition also were examined.

MATERIALS AND METHODS

Experimental Animals. Twenty, genetically similar, large framed (frame score 5 to 6), Simmental x Charolais x Angus crossbred beef steers previously described in Chapter 1 were used in this study comparing predicted carcass compostion with the actual chemical composition of the carcass. The chemical composition of the entire right side of the carcass was determined by the procedures outlined in chapter 1. The left side of each carcass was weighed, shrouded and chilled for a minimum of 24 h. Left sides were ribbed, fat measurements taken at the 12-13 rib interface (to the nearest .01 mm), ribeye areas measured and USDA grades obtained by trained MSU personnel. Each side was quartered with each quarter weighed in air to the nearest .05 kg on a platform scale. Each quarter was then immediately suspended in 4 C water and the weight (to the nearest gram) recorded, after any trapped air was removed from the carcass and kidney fat area. Specific gravity of the left side (SG) was determined by dividing the total of the forequarter and hindquarter weights by the difference between weight in air and the weight in water (Garrett and Hinman, 1969). Carcasses were allowed to drip for 5 min during which time the kidney and pelvic fat (KP) was removed and weighed. The hindquarter was then reweighed in

water without kidney and pelvic fat (SG2). This was done to reduce any variation in the amount of trapped air in and around the KP on specific gravity and the resulting predicted carcass composition. Prediction of carcass composition components was obtained from the equations of Garrett and Hinman (1969) found in Appendix Table 4.

The 9-10-11 rib section (RIB) was removed by the procedures described by Hankins and Howe (1946). The rib section was separated into soft tissues and bone with weights recorded and adjustments made for water loss. Soft tissues were ground three times through a 3 mm plate and subsampled. The samples were powdered and moisture, ether extractable lipid (EEL) and protein were determined by AOAC methods (AOAC, 1980). T-test comparisons were conducted between actual carcass composition and 9-10-11 rib estimated carcass composition using the equations reported by Hankins and Howe (1946) for steer carcasses, and those reported by Crouse and Dikeman (1974) and Miller et al. (1988). A complete list of equations developed by Hankins and Howe (1946), Crouse and Dikeman (1974) and Miller et al., (1988) can be found in Appendix Table 13. Prior to dissection of the rib section, the specific gravity of the rib (SGR) was determined in the same manner as described for carcasses.

Statistical analyses. Means and standard errors of actual carcass composition and predicted composition were

calculated for each group of five carcasses. Analysis of variance was used to analyze differences between weight groups and the influence of development on carcass components. Stepwise linear multiple regression procedures were used to develop equations to predict carcass composition. All statistical analysis were conducted using the Statistical Package for the Social Sciences (SPSS, 1989).

RESULTS AND DISCUSSION

Group means and standard errors of the carcass and 9-10-11 rib section (RIB) chemical composition are presented in Table 4-1. Specific gravity means and standard errors for the left side of carcasses and the RIB of each group are also presented in Table 4-1. Additionally, the overall means and standard errors of the chemical composition of the carcass and RIB of all animals as one group is displayed in Table 4-1.

The composition of the carcasses and RIB within each group from this study were well within the range of the carcasses and rib sections sampled by Hankins and Howe (1946). Carcass moisture from the overall group however, was 2.6% (absolute percentage points) higher than that of the Hankins and Howe (1946) study and 8.1% higher than the mean carcass moisture in the study by Crouse and Dikeman (1974). Overall carcass fat was 2.4 and 9.9 percentage points lower than the Hankins and Howe (1946) and Crouse and Dikeman (1974) studies, respectively. Similar values were true for the RIB with moisture being 1.0 and 12.0 percentage points, higher than reported in the Hankins and Howe (1946) and Crouse and Dikeman (1974) studies, respectively. RIB fat was 7.2 and 15.2% lower in the present study than the RIB fat reported in the earlier

studies mentioned. Interestingly, overall group mean carcass protein did not differ between the present study and the work reported by Hankins and Howe (1946) but was 1.75% higher than in the study of Crouse and Dikeman (1974). The decrease in fat and increase in moisture is not surprising since during the past 10 - 15 yr there has been an effort to reduce fat in beef carcasses by selection, nutrition and use of cattle from continental European genetic lines in this country.

Table 4-2 contains the actual and predicted group means and standard errors for percentage carcass moisture. Predicted carcass moisture was derived using the equations of Hankins and Howe (1946) and Crouse and Dikeman (1974) found in Appendix Table 4. As seen in Table 4-2, both prediction methods overestimated carcass moisture ($P<.05$) in groups 1, 2 and 4, and while not statistically significant, also tended to overestimate carcass moisture in G 3. It is interesting to note that as the carcasses increased in fat content and decreased in moisture both equations tended to more accurately predict carcass moisture.

When comparing methods of predicting ether extractable lipid (EEL) of the carcass soft tissues in Table 4-3, EEL was underestimated ($P<.01$) in each group by the Hankins and Howe (1946) equation and also by the equation of Crouse and Dikeman (1974) in groups 1 and 2. Predicted carcass fat

TABLE 4-1. GROUP MEANS AND STANDARD ERRORS FOR CARCASS, 9-10-11 RIB COMPOSITION AND SPECIFIC GRAVITY

Item	Group 1	2	3	4	Overall Groups
Carcass H_2O, %	63.93	59.53	54.8	52.64	57.72
SE	.53	.77	.93	.68	1.06
Carcass EEL, %	16.87	23.18	29.28	32.01	25.34
SE	.40	.96	1.16	.77	1.40
Carcass protein, %	18.11	16.46	15.11	14.51	16.05
SE	.30	.18	.25	.19	.34
9-10-11 rib H_2O, %	66.96	61.27	53.24	50.6	58.02
SE	.58	.88	.36	.96	1.53
9-10-11 rib EEL, %	15.19	20.98	31.15	34.75	25.53
SE	.39	.94	.38	1.4	1.84
9-10-11 protein, %	17.47	17.14	14.94	14.17	15.93
SE	.26	.10	.25	.36	.34
Carcass SG with KP	1.0747	1.0694	1.0585	1.0528	
SE	.0018	.0024	.0019	.0009	
Carcass SG without KP	1.0828	1.0734	1.0638	1.0585	
SE	.002	.002	.002	.001	
RIB SG	1.1116	1.085	1.0758	1.0664	
SE	.005	.0018	.0025	.0015	

[ab] Values within a column with different superscripts differ ($P < .05$).

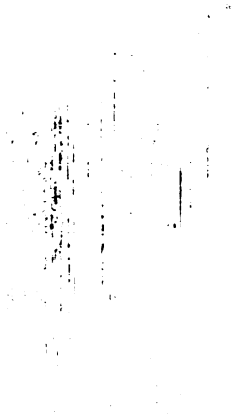


TABLE 4-2. COMPARISONS OF ACTUAL CARCASS MOISTURE WITH PREDICTED CARCASS MOISTURE

	Group			
Item	1	2	3	4
Actual				
H_2O, %	63.93[a]	59.53[a]	54.8[a]	52.64[a]
SE	.53	.77	.93	.68
Hankins/Howe[c]				
H_2O, %	67.05[b]	62.79[b]	56.76[a]	54.77[b]
SE	.43	.66	.27	.72
Crouse/Dikeman[d]				
H_2O, %	65.18[a]	61.14[a]	55.44[a]	53.56[b]
SE	.41	.62	.26	.68

ab Values within a column with different superscripts differ ($P < .05$ or less).
c Equation from Hankins and Howe (1946).
d Equation from Crouse and Dikeman (1974).

tended (P>.10 or greater) to be lower in groups 3 and 4. Estimation of carcass fat by equations reported by Miller et al. (1988) derived from fed (finished) steers (equation 1) and equation 2 from all types (calves, feeders, yearlings, fed steers and cows) overestimated (P<.05) carcass fat in group 1 but did not differ (P>.15) from actual carcass fat in groups 2, 3 and 4. The Miller equations when tested on other data sets in addition to this study may come to be widely accepted for predicting carcass fat.

Table 4-4 contains the group means and standard errors of the actual and estimated percentage carcass protein using the percentage protein in the RIB and the prediction equations of Hankins and Howe (1946) and Crouse and Dikeman (1974). Both equations did not differ (P>.05) in predicting carcass protein from actual carcass protein in G 1. As the carcasses increased in fat and decreased in percentage protein the Hankins and Howe (1946) equation overestimated (P<.05) carcass protein. The equation developed by Crouse and Dikeman (1974) overestimated (P<.05) carcass protein in G 2 but did not differ (P>.15) from actual carcass protein in groups 3 and 4. The equation developed by Crouse and Dikeman (1974) while presently not widely used, appear to be valid for .he 170 predicting carcass protein in cattle with greater than 24% carcass fat.

Table 4-5 contains a summary of the student's t-test statistical analysis using each equation and comparing the predicted composition to actual composition. As indicated in the footnotes of each table, nonsignificance is indicated when P is greater or equal to .15. In several cases the reported P value approached significance. If more animals were included in the present study significant differences between the actual and predicted composition would be expected.

Table 4-6 is a summary of the differences in the means between actual and predicted carcass moisture, ether extractable lipid and protein. It is interesting to note that of all reported prediction equations used in the comparisons in the present study, no equation accurately predicted the carcass composition of the carcasses highest in moisture and protein and lowest in fat. It may be necessary to establish an accepted prediction equation for carcasses less than approximately 20% carcass fat or conduct total dissection and grinding in order to establish baseline carcass data if needed. As the basis for comparison in many research studies involving beef cattle, carcass composition must be easily and reliably obtained with carcass loss, labor and expenses kept to a reasonable cost. The results of the present study indicate that although the 9-10-11 rib may be a widely accepted method of estimating carcass composition, it appears that enough

TABLE 4-3. COMPARISONS OF ACTUAL AND PREDICTED CARCASS ETHER EXTRACTABLE LIPID[a]

	Group			
Item	1	2	3	4
Actual				
EEL, %	16.87[b]	23.18[b]	29.28[b]	32.01[b]
SE	.40	.96	1.16	.77
Hankins/Howe[d]				
EEL, %	14.73[c]	19.02[c]	26.54[c]	29.23[c]
SE	.29	.70	.28	1.04
Dikeman[e]				
EEL, %	15.58[c]	19.98[c]	27.70[b]	30.47[c]
SE	.29	.72	.29	.77
Miller 1[f]				
EEL, %	18.74[c]	22.79[b]	29.90[b]	32.45[b]
SE	.27	1.48	.60	.98
Miller 2[g]				
EEL, %	19.12[c]	22.83[b]	29.38[b]	31.66[b]
SE	.25	.61	.25	.90

abc Values within a column with different superscripts differ ($P < .05$ or less).
d Equation from Hankins and Howe (1946).
e Equation from Crouse and Dikeman (1974).
f Equation from Miller et al. (1988), fed cattle only.
g Equation from Miller et al. (1988), all cattle.

TABLE 4-4. COMPARISONS OF ACTUAL AND PREDICTED CARCASS PROTEIN

	Group			
Item	1	2	3	4
Actual Carcass Protein, %	18.11[a]	16.46[a]	15.11[a]	14.51[a]
SE	.30	.18	.25	.19
Hankins/Howe P, %	17.54[a]	17.33[b]	15.90[b]	15.40[b]
SE	.17	.07	.16	.23
Dikeman P, %	17.31[a]	17.06[b]	15.38[a]	14.80[a]
SE	.20	.08	.19	.27

[ab] Values within a column with different superscripts differ ($P < .05$).

TABLE 4-5. SUMMARY OF STUDENT'S T-TEST COMPARISONS BETWEEN ACTUAL AND PREDICTED CARCASS MOISTURE, FAT AND PROTEIN[a]

	Group			
Item	1	2	3	4
No. of Animals	5	5	5	5
% Carcass H_2O				
Hankins/Howe[b]	.004	.011	.12	.003
Crouse/Dikeman[c]	.08	.09	NS	.04
% Carcass EEL				
Hankins/Howe[b]	.003	.008	.05	.002
Crouse/Dikeman[c]	.02	.02	NS	.10
Miller 1[d]	.005	NS	NS	NS
Miller 2[e]	.002	NS	NS	NS
% Carcass Protein				
Hankins/Howe[b]	NS	.003	.01	.02
Crouse/Dikeman[c]	.07	.009	NS	NS

a Nonsignificance at P = .15 or greater.
b Equation from Hankins and Howe (1946).
c Equation from Crouse and Dikeman (1974).
d Equation from Miller et al. (1988), fed cattle only.
e Equation from Miller et al. (1988), all cattle.

TABLE 4-6. SUMMARY OF ABSOLUTE DIFFERENCES BETWEEN ACTUAL AND PREDICTED CARCASS MOISTURE, FAT AND PROTEIN

	Group			
Item	1	2	3	4
% Carcass H_2O				
Hankins/Howe[a]	3.12	3.26	1.96	2.13
Crouse/Dikeman[b]	1.25	1.61	.64	.92
% Carcass EEL				
Hankins/Howe[a]	-2.14	-4.16	-2.74	-2.78
Crouse/Dikeman[b]	-1.29	-3.20	-1.58	-1.54
Miller 1[c]	1.87	- .39	.62	.44
Miller 2[d]	2.25	- .35	.10	.35
% Carcass Protein				
Hankins/Howe[a]	- .57	.87	.79	.89
Crouse/Dikeman[b]	- .80	.60	.27	.29

a Equation from Hankins and Howe (1946).
b Equation from Crouse and Dikeman (1974).
c Equation from Miller et al. (1988), fed cattle only.
d Equation from Miller et al. (1988), all cattle.

change in the physical and compositional makeup of typical market cattle has occurred which suggests that the equations reported by Hankins and Howe (1946) are not accurate enough for use today. Continued use of equations reported by Hankins and Howe (1946) overestimates the carcass protein and underestimates carcass fat to such an extent that incorrect and costly conclusions may be made. The more recent studies by Crouse and Dikeman (1974) and Miller et al. (1988) have reported equations which were found to adequately estimate carcass fat and protein in steers which had in excess of 24% carcass fat in the present study. Further validation of either the previously mentioned equations or the equations derived from the present study using the 9-10-11 rib section needs to be more extensively studied.

Tables 4-7, 4-8 and 4-9 contain the group means and standard errors of actual carcass composition and carcass composition predicted using the specific gravity of each carcass and equations developed by Garrett and Hinman (1969). Specific gravity equations underpredicted ($P<.05$) carcass moisture in groups 1 and 2 and tended ($P>.05$) to slightly underpredict moisture in groups 3 and 4. Specific gravity estimated carcass fat in G 1 did not differ ($P>.05$) from actual, however, in groups 2, 3 and 4 carcass fat was underpredicted ($P<.05$) in all cases. Carcass protein in Table 4-9, was accurately predicted in G 1 but

TABLE 4-7. COMPARISONS OF ACTUAL AND PREDICTED CARCASS MOISTURE USING SPECIFIC GRAVITY

	Group			
Item	1	2	3	4
Actual				
H_2O, %	63.93[a]	59.53[a]	54.8[a]	52.64[a]
SE	.53	.77	.93	.68
Garrett/Hinman				
H_2O, %	59.42[b]	57.45[b]	53.36[a]	51.2[a]
SE	.67	.91	.71	.34

[ab] Values within a column with different superscripts differ ($P < .05$).

TABLE 4-8. COMPARISONS OF ACTUAL AND PREDICTED CARCASS ETHER EXTRACTABLE LIPID USING SPECIFIC GRAVITY

	Group			
Item	1	2	3	4
Actual				
EEL, %	16.87[a]	23.18[a]	29.28[a]	32.01[a]
SE	.40	.96	1.16	.77
Garrett/Hinman				
EEL, %	17.80[a]	20.59[b]	26.39[b]	29.41[b]
SE	.95	1.29	1.0	.48

[ab] Values within a column with different superscripts differ ($P < .01$).

TABLE 4-9. COMPARISONS OF ACTUAL AND PREDICTED CARCASS PROTEIN USING SPECIFIC GRAVITY

	Group			
Item	1	2	3	4
Actual Protein, %	18.11[a]	16.46[a]	15.11[a]	14.51[a]
SE	.30	.18	.25	.19
Garrett/Hinman Protein, %	18.27[a]	17.62[b]	16.26[b]	15.54[b]
SE	.22	.30	.24	.11

[ab] Values within a column with different superscripts differ ($P < .05$).

was overestimated ($P<.05$) in groups 2, 3 and 4.

These results are consistent with those of Powell and Huffman (1968), Lunt et al. (1985a), Jones and Rompala (1985) and Miller et al. (1988) all of which discouraged the use of specific gravity to estimate carcass fat. The results of the present study however, are contrary to those reported by Waldman et al. (1969) and Gil et al. (1970) both of which reported that specific gravity was not accurate for carcasses with <20% fat. More research data for carcasses from the U.S. cattle population with < 20% carcass fat are needed in order to determine the most reliable method of determining composition.

Specific gravity of the carcass may continue to be a useful tool, contrary to the findings of Powell and Huffman (1968), Lunt et al. (1985b) and Miller et al. (1988). Researchers must realize however, that any method of handling which increases the chance of entrapping excess air under the fat layer (as is done in hide pulling) can render this method of estimating carcass composition useless. Careful thought and planning needs to accompany design of experiments utilizing specific gravity. Use of specific gravity to estimate carcass composition should only be conducted on carcasses which have been skinned in the tradition cradle method. It is recommended that the equations developed by Garrett and Hinman (1969) not be used as the single estimate of carcass composition since

biased, inaccurate results may be obtained. The equations using carcass specific gravity with and without kidney and pelvic fat as derived in the present study, need to be validated with a different population of carcasses to further refine them.

Regression equations in Table 4-10, predicting percent carcass moisture, ether extractable lipid and protein from the RIB composition show that percentage chemical fat of the RIB accounted for a high proportion of the variation in carcass fat as indicated by an R^2 of .93 and residual standard deviation (RSD) of 1.65. Additionally, percent moisture of the RIB accounted for 91% of the variation in carcass chemical moisture across all slaughter groups. Equation 3 (Table 4-10) was derived from all carcasses in the present study. It showed that 76% of the variation in carcass protein was accounted for by the percent protein in the RIB from groups 1 to 4. Results of the earlier analyses comparing various prediction equations showed that since carcass protein was accurately predicted by the Hankins and Howe (1946) equation, it may be possible to improve the ability of the equation to estimate carcass protein by using only data from groups 2, 3 and 4. Equation 4 (Table 4-10) was derived from the percentage protein in the RIB from groups 2, 3 and 4. The R^2 value was improved to .82 and the RSD was decreased to .40, indicating that equation 4 did account for more of the variation and reduce the

TABLE 4-10. REGRESSION EQUATIONS TO PREDICT PERCENTAGE CARCASS MOISTURE, ETHER EXTRACTABLE LIPID AND PROTEIN

Eqn no.	Dependent variable	Independent variables	Intercept	Regression coefficient	R^2	RSD
1	Carcass % EEL	% EEL of RIB[b]	6.604	.7338	.93	1.65
2	Carcass % H_2O	% H_2O of RIB[b]	19.323	.6619	.91	1.44
3	Carcass % Protein	% protein of RIB[a]	2.361	.85923	.76	.73
4	Carcass % Protein	% protein of RIB[b]	5.8824	.6147	.82	.40

a calculated from all groups (G1 - G4).
b calculated from G2 - G4 only.

standard deviation of predicted carcass protein in carcasses from groups 2, 3 and 4.

Table 4-11 contains regression equations predicting percent carcass moisture from the specific gravity of the carcass with and without the kidney and pelvic fat. As is evident in equations 5 and 7, removing the kidney and pelvic fat improved the ability (R^2 = .83 vs .85) of specific gravity of the carcass to estimate carcass moisture. Addition of hot carcass weight (HCWT) as well as specific gravity further improved both equations 6 and 8 (R^2 = .88 and .89; RSD = 1.63 and 1.60, respectively).

As with the use of specific gravity to predict carcass moisture, Table 4-12 shows that removal of kidney and pelvic fat from the carcass improved the ability to predict percent carcass fat (R^2 = .84 and .86 for equations 9 and 11, respectively). Hot carcass weight as a second variable improved the equations even more as indicated by R^2 values of .90 and RSD of 2.00 and 1.94, respectively for equations 10 and 12.

Regression equations predicting percent carcass protein (Table 4-13) from carcass specific gravity accounted for less of the variation in carcass protein than equations previously discussed. This is not suprising since specific gravity is more highly associated with the degree of fatness and water content. Regardless, carcass specific gravity with and without kidney fat accounted for 77 and

TABLE 4-11. REGRESSION EQUATIONS TO PREDICT PERCENTAGE CARCASS MOISTURE USING CARCASS SPECIFIC GRAVITY

Eqn no.	Dependent variable	Independent variables	Intercept	Regression coefficient	R^2	RSD
5	Carcass % H_2O	Carcass SG w/KP	-421.49	450.45	.83	1.93
6	Carcass % H_2O	Carcass SG w/KP + HCWT	-153.92	208.76 -.038	.88	1.632
7	Carcass % H_2O	Carcass SG w/oKP	-396.7	424.84	.85	1.84
8	Carcass % H_2O	Carcass SG w/oKP + HCWT	-161.52	214.0 -.035	.89	1.60

TABLE 4-12. REGRESSION EQUATIONS TO PREDICT PERCENTAGE CARCASS ETHER EXTRACTABLE LIPID FROM CARCASS SPECIFIC GRAVITY

Eqn no.	Dependent variable	Independent variables	Intercept	Regression coefficient	R^2	RSD
9	Carcass % EEL	Carcass SG w/KP	658.85	-595.48	.84	2.54
10	Carcass % EEL	Carcass SG w/KP + HCWT	265.86	-240.5 .056	.90	2.00
11	Carcass % EEL	Carcass SG w/oKP	628.27	-563.68	.86	2.36
12	Carcass % EEL	Carcass SG w/oKP + HCWT	289.15	-259.67 .05	.90	1.94

79%, respectively, of the variation in carcass protein as indicated by equations 13 and 15. As with carcass moisture and fat, including HCWT as a second independent variable improved the R^2 values to .85 and reduced the RSD values to .59 and .58, respectively, for equations 14 and 16.

The specific gravity of the RIB may be a useful tool to predict RIB and carcass composition if money, labor and equipment are limited. As indicated in Table 14, specific gravity of the RIB accounted for about 77% of the variation in carcass moisture, fat and RIB fat, while 71% of the variation in carcass protein was accounted for by RIB specific gravity as indicated with equation 19. The minimal loss of carcass value appears especially promising when used with other carcass measurements.

TABLE 4-13. REGRESSION EQUATIONS TO PREDICT PERCENTAGE CARCASS PROTEIN FROM CARCASS SPECIFIC GRAVITY

Eqn no.	Dependent variable	Independent variables	Intercept	Regression coefficient	R^2	RSD
13	Carcass % protein	Carcass SG w/KP	-130.36	137.62	.77	.72
14	Carcass % protein	Carcass SG w/KP + HCWT	-23.64	41.218 -.015	.85	.59
15	Carcass % protein	Carcass SG w/oKP	-123.57	130.52	.79	.68
16	Carcass % protein	Carcass SG w/oKP + HCWT	-30.51	47.1 -.014	.85	.58

TABLE 4-14. REGRESSION EQUATIONS TO PREDICT PERCENTAGE CARCASS MOISTURE, eTHER EXTRACTABLE LIPID AND PROTEIN AND RIB ETHER EXTRACTABLE LIPID FROM 9-10-11 RIB SPECIFIC GRAVITY

Eqn no.	Dependent variable	Independent variables	Intercept	Regression coefficient	R^2	RSD
17	RIB %EEL	RIB SG	453.318	-394.386	.77	3.969
18	Carc $\%H_2O$	RIB SG	-188.35	226.86	.77	2.278
19	Carc % P	RIB SG	-58.98	69.17	.71	.81
20	Carc % EEL	RIB SG	352.92	-302.0	.78	2.92

SUMMARY AND CONCLUSIONS

The accuracy of existing prediction equations using the 9-10-11 rib section and carcass specific gravity were evaluated in the present study. Both methods were highly correlated ($r > .85$; $P < .05$) to actual carcass moisture, EEL and protein. Prediction equations developed by Hankins and Howe (1946) consistently underpredicted ($P < .05$ or less) percentage carcass EEL by 2.1 to 4.1 percentage points. Prediction equations reported by Crouse and Dikeman (1974) also underpredicted carcass EEL by 1.3 to 3.2 percentage points. Predicted carcass EEL using equations reported by Miller et al., (1988) did not differ ($P > .15$) from actual carcass EEL. Carcass protein was overpredicted ($P < .05$) using the equations of Hankins and Howe (1946) in group 2, 3 and 4 steers and underpredicted carcass protein in G 1 ($P > .15$). Equations developed by Crouse and Dikeman (1974) to estimate carcass protein appear to be valid for predicting carcass protein in carcasses with greater than 24% fat.

Although specific gravity of the carcass was highly correlated ($r > .85$) with carcass moisture, EEL and protein, the equations reported by Garrett and Hinman (1969) did not accurately predict carcass composition in carcasses with >20% fat in the present study. Results of the present .he

189 .op study did however, suggest that carcass specific can be used to accurately predict carcass composition in carcasses with <20% fat using the equations of Garrett anf Hinman (1969). Specific gravity of the carcass with the kidney fat removed was also highly correlated to carcass composition. It is concluded in the present study that enough of a change in the physical and compositional makeup of typical market cattle has occurred to justify development and validation of refined equations using the 9-10-11 rib section and specific gravity from cattle typical of the current U.S. cattle population.

Chapter 5

Estimation of Beef Carcass Skeletal Muscle from 9-10-11 Rib Section of Continental European Crossbred Steers

ABSTRACT

Growth of carcass soft tissues (CST) and changes in the relationships involving distribution of carcass moisture (CW), fat (CFAT) and protein (CP) in carcass muscle (CMUS) were examined in large frame (Simmental X Charolais X Angus) steers. Twenty steers, randomly allotted to one of four groups (n=5/group), were slaughtered when fasted live weights were 300, 390, 480 and 560 kg for the four groups, i.e., G1, G2, G3 and G4, respectively. CW, CFAT and CP were directly determined by physical separation and chemical analysis. Carcasses were dissected into CST (CMUS and adipose tissue, AT) and bone (CB). CW was 63.9, 59.5, 54.8 and 52.6%, for G1 to G4, respectively. CFAT was 16.9, 23.2, 29.3 and 32.0%, for G1 to G4, respectively. CMUS comprised 66.0, 59.2, 59.2 and 57.9% of hot carcass weight, respectively, in each group. Protein (P) content of the CMUS was not different (P>.10) between groups. Values ranged from 20.8 to 21.4%, with a mean of 21% across all groups. Percentage CP in G1 to G4 was 18.0, 16.5, 15.1 and 14.5, respectively. Total CMUS P as a percentage of CP did not differ between groups (95.0, 95.0, 94.3, 95.2; P>.10), averaging 95%. Bone content of the 9-10-11 rib section (RIB) was highly correlated (P<.001) to CB and can be used to predict CB. These data were used to develop multiple

regression equations to predict CST, weight and percentage of CMUS in beef carcasses from this study.

INTRODUCTION

Simple and accurate estimation of beef carcass composition by indirect methods continues to be a goal of animal scientists. Of current acceptable methods, Schroeder et al. (1987) and Miller et al. (1988) reported the 9-10-11 rib section method (RIB) described by Hankins and Howe (1946) to most accurately estimate carcass composition. Both studies, however, reported that although th RIB was the method of choice in estimating carcass composition, as carcass fat increased in moderate to large frame steers the RIB became less accurate for predicting carcass fat and protein. Updated prediction equations have been generated which more accurately estimate carcass fat and protein.

Selleck and Tulloh (1968) and Berg and Butterfield (1976) recommended that fat, bone and edible product, (skeletal muscle) should be the endpoint by which changes in beef carcass composition should be measured. Present research efforts attempt to respond to the demand for lean meat products and high saleable yields by concentrating on decreasing carcass fat and increasing skeletal muscle by genetic improvements or treatment with exogenous growth promotants. Present prediction equations, however, do not appear to adequately recognize and measure the full

magnitude of response obtained through genetic selection and use of exogenous growth promoting agents. Increased emphasis on measuring lean tissue (i.e., muscle mass) in beef cattle necessitates development of reliable research tools and prediction methods which can accurately and repeatably measure differences in skeletal muscle mass in beef carcasses.

The present study was designed to evaluate developmental relationships and changes in carcass protein and bone, skeletal muscle protein as a percentage of carcass protein, protein content of skeletal muscle and the composition of the RIB for use in development of prediction equations to estimate carcass skeletal muscle.

MATERIALS AND METHODS

Experimental animals. Twenty genetically similar Simmental X Charolais X Angus steers were randomly allotted to four slaughter groups as indicated in Table 5-1. All steers were fed ad libitum, a 13% crude protein corn silage - high moisture corn - soymeal concentrate diet during the growing phase (diet 1). After G 2 animals were slaughtered, the remaining steers (G 3 and G 4) were fed a 11 % crude protein corn silage - high moisture corn and soy concentrate diet during the finishing phase. When each steer reached the designated weight, it was slaughtered according to commercial practices.

Carcass Physical and Chemical Composition. Carcasses were split and the right side of each carcass was physically dissected into individual soft tissues which included: carcass skeletal muscle (CMUS), adipose tissues (AT) and carcass bone (CB). All carcass tissues were weighed and subsampled. Moisture, ether extractable lipid and protein (N x 6.25) were determined on each sample by AOAC methods. In order to obtain left side tissue weights, the weight of soft tissues in the right side (minus kidney, pelvic and thoracic cavity (KPH) adipose tissue) as a percentage of the right side, was multiplied by the weight of the left side (minus KPH). All weights were pooled to

TABLE 5-1. EXPERIMENTAL ALLOTMENT OF STEERS INTO SLAUGHTER WEIGHT GROUPS

	Group			
	1	2	3	4
Number per group	5	5	5	5
Fasted live weight, kg	300	390	480	560
Age, mo	10	12	14	16

obtain the physical and chemical composition of each carcass.

9-10-11 Rib Section Composition. Rib sections were removed from the left side of each carcass according to the methods described by Hankins and Howe (1946). Chemical analysis was performed on the soft tissues. Estimation of carcass chemical composition and percentage carcass bone was made using equations reported by Hankins and Howe (1946) for steers found in Table 5-2.

Statistical Analysis. Comparisons of estimated carcass composition using existing prediction equations with actual composition were reported in Chapter 4. Paired t-test analyses were used to evaluate differences between actual and predicted carcass composition. Stepwise linear regression procedures (SPSS/PC+ V2.0 Base Maual, 1989) were used to derive new prediction equations. Equations reported are those in which R^2 and RSD were optimized.

TABLE 5-2. PREDICTION EQUATIONS DERIVED BY HANKINS AND HOWE (1946) TO ESTIMATE CARCASS PROTEIN AND BONE

Carcass Protein:

%CP = 6.19 + .65 x % P of RIB

R^2 =.83 RSD = .79

Carcass Bone:

%CB = 5.52 + .57 x % Bone in RIB

R^2 = .80 RSD = 1.26

RESULTS AND DISCUSSION

Means and standard errors for actual carcass composition are presented in Table 5-3. The carcasses from the steers in the present study ranged in weight from 188.1 kg to 365.7 kg and had 12th rib fat measurements that ranged from 2.6 to 11.4 mm, typical of the current cattle population in the U.S. Table 5-4 contains more detailed carcass dissection data including dissectible soft tissues which consists of skeletal muscle and fat. As one would expect, the percentage of soft tissues (CST) of the hot carcass weight (HCWT) increased in each group from a low of 82.9 in G1 to 87.7% in G4, respectively, indicating that as the steers increased in both live and carcass weight the soft tissues of the carcass grew at a more rapid rate than bone, which as a percentage decreased. Carcass skeletal muscle increased in absolute weight in each group, but, as expected the percentage of the carcass skeletal muscle decreased to about 58% which is consistent with data in the literature.

Table 5-5 contains the group means and standard errors of the chemical composition of the hot carcass and the 9-10-11 rib section (RIB) from the left sides of each carcass. Additionally, the percentage of bone in the carcass and the RIB is reported in Table 5-5 by group

TABLE 5-3. GROUP MEANS AND STANDARD ERRORS FOR CARCASS TRAITS

	Group			
Item	1	2	3	4
Hot carcass weight, kg	188.1	247.2	303.7	365.7
SE	3.8	1.84	2.74	3.12
12th rib fat, mm	2.6	4.8	8.7	11.4
SE	.02	.03	.03	.05
Longissimus area, cm^2	60.3	75.2	80.8	86.6
SE	.98	1.93	3.71	3.60
KP, %	2.0	2.5	2.5	3.1
SE	.11	.16	.16	.19
Yield grade	1.7	1.8	2.4	3.0
SE	.12	.16	.13	.18

TABLE 5-4. GROUP MEANS AND STANDARD ERRORS FOR CARCASS TRAITS

	Group			
Item	1	2	3	4
Carcass soft tissues (CST), kg	156.0	209.9	262.9	320.7
SE	3.99	2.43	2.28	2.66
CST % of HCWT,	82.87	84.93	86.51	87.69
SE	.57	.37	.36	.41
Carcass skeletal muscle, kg	124.2	154.5	179.7	211.7
SE	3.68	.46	2.76	2.72
Carcass muscle, %	66.0	62.51	59.19	57.89
SE	.72	.52	1.0	.47
Carcass bone, %	17.1	15.1	13.4	12.3
SE	.47	.44	.18	.32

means. It is interesting to note that the decrease in percentage bone in the RIB is not as dramatic as the decrease in carcass bone as shown in Table 5-4.

Table 5-6 contains the percentage protein (N X 6.25) found in the composite skeletal muscle. Though a slight nonsignificant (P>.10) numerical decrease of protein occurred in successive groups, the average percentage protein for all steers was 21.0%, consistent with present USDA findings of 20.94% (USDA, 1987). Since detailed total physical dissection into skeletal muscle and carcass adipose tissue was conducted on each carcass, it was possible to determine both the total protein content (kg) of the CST as well as the total protein content (kg) of only the skeletal muscle (Tables 5-4 and -5). The ratio of skeketal muscle water to skeletal muscle protein remained constant averaging 3.54. The ratio of skeletal muscle protein (kg) to total carcass protein was determined to be constant averaging .95 across all groups. This relationship has not been reported in the literature. During normal development since the ratio of water to protein in skeletal muscle remains constant as in the present study and the CST water to protein ration remained essentially constant at about 3.62 (Chapter 1), it follows that the relationship of skeletal muscle protein to carcass protein should remain constant. This relationship is important in studies in which the effects of various exogenous anabolic compounds

on carcass composition and skeletal muscle mass are to be measured. In order to measure the effects of such compounds on muscle, either complete physical dissection must be conducted, or typically the RIB is used to predict carcass protein and fat, and then effects on carcass muscle are extrapolated from percentage carcass protein. Carcass muscle can be estimated only if equations accurately predict carcass protein and bone.

Table 5-7 contains the group means, standard errors and statistical comparison (paired t-test) between actual percentage carcass bone, predicted percentage carcass bone from the equation of Hankins and Howe (1946) and predicted carcass bone using equation 1 in Table 5-8 derived from the present study. In G1 and G2 prediction of percentage carcass bone using the Hankins and Howe equation (H/H) did not differ from actual carcass bone ($P>.10$). However, in G3 and G4 predicted percentage carcass bone (H/H) differed ($P<.01$) from actual.

Table 5-8 contains equation 1 to predict percentage carcass bone using the percentage bone in the RIB as the independent variable. Percentage bone of the RIB accounted for 76% of the variation in carcass bone across all groups and more accurately ($P>.10$) predicted percentage carcass bone in G3 and G4 (Table 5-7) than equations derived by Hankins and Howe (1946). Also included in Table 5-8 are equations 2 and 3 which estimate percentage carcass protein

TABLE 5-5. GROUP MEANS AND STANDARD ERRORS FOR CARCASS AND 9-10-11 RIB COMPOSITION

	Group			
Item	1	2	3	4
Carcass H_2O, %	63.93	59.53	54.8	52.64
SE	.53	.77	.93	.68
Carcass EEL, %	16.87	23.18	29.28	32.01
SE	.40	.96	1.16	.77
Carcass protein, %	18.11	16.46	15.11	14.51
SE	.30	.18	.25	.19
9-10-11 rib H_2O, %	66.96	61.27	53.24	50.6
SE	.58	.88	.36	.96
9-10-11 rib EEL, %	15.19	20.98	31.15	34.75
SE	.39	.94	.38	1.4
9-10-11 protein, %	17.47	17.14	14.94	14.17
SE	.26	.10	.25	.36
9-10-11 bone, %	19.63^{a}	17.69^{b}	17.23^{bc}	15.79^{c}
SE	.49	.46	.88	.40

^{abcd} Values within a row with different superscripts differ ($P < .05$).

TABLE 5-6. GROUP MEANS FOR PERCENTAGE PROTEIN IN SKELETAL MUSCLE AND PERCENTAGE OF SKELETAL MUSCLE PROTEIN IN TOTAL CARCASS PROTEIN

	Group			
Item	1	2	3	4
Skeletal muscle, protein, %	21.4	21.2	20.8	20.9
SE	.12	.10	.24	.16
Skeletal muscle H_2O/protein ratio	3.54	3.55	3.55	3.52
SE	.03	.04	.03	.06
Carcass skeletal muscle protein of total carcass protein, %	95.0	95.0	94.3	95.2
SE	.14	.12	.29	.13

from the protein content of the RIB as discussed in Chapter 4.

Table 5-9 contains the flow chart and list of required information to predict skeletal muscle using the RIB. Carcass soft tissues can be determined by subtracting the predicted carcass bone (kg) from hot carcass weight as in step 1. The quantity of carcass protein in CST is then predicted in step 2 using an equation which accurately predicts carcass protein from the RIB. Ninety five percent of the protein associated with skeletal muscle protein is determined in step 3. Weight of skeletal muscle can be predicted in step 4 by dividing skeletal muscle protein by .21.

Table 5-10 contains an example using data from the present study to estimate CST using the method outlined in Table 5-9. Table 5-11 contains actual and predicted carcass protein reported in Chapter 4. Multiplying the predicted CST by the estimated percentage protein in the carcass and then by .95 as indicated in Table 5-9, the weight of skeletal muscle protein was determined. G1 carcass protein was estimated using the Hankins and Howe equation since it was more accurate in predicting percentage carcass protein in this group. G2, G3 and G4 carcass protein was estimated by equation 3 (Table 5-8),

TABLE 5-7. GROUP MEANS AND STANDARD ERRORS FOR ACTUAL CARCASS BONE AND PREDICTED BONE FROM 9-10-11 RIB[a]

Item	Group 1	2	3	4
Carcass bone, %	17.1[b]	15.1[b]	13.4[b]	12.3[b]
SE	.47	.44	.18	.32
Hankins/Howe carcass bone, %	16.7[b]	15.6[b]	15.3[c]	14.5[c]
SE	.28	.26	.23	.23
Eqn #1 carcass bone, %	16.2[b]	14.5[b]	14.1[b]	12.8[b]
SE	.43	.40	.35	.35

[a] Calculated from Hankins and Howe (1946).
[b] Values within a column with different superscripts differ ($P < .01$).

TABLE 5-8. REGRESSION EQUATIONS TO PREDICT PERCENTAGE CARCASS BONE AND CARCASS PROTEIN

Equation number	Independent variables	Intercept	Regression coefficient	R^2	RSD
1	% bone of RIB	-.9493	.8733	.76	1.39
2	% protein of RIB[a]	2.361	.85923	.76	.73
3	% protein of RIB[b]	5.8824	.6147	.82	.40

a calculated from all groups (G1 - G4).
b calculated from G2 - G4 only and used in calculations.

developed in the present study (Chapter 4).

Table 5-12 contains the means and standard errors for estimated quantity of skeletal muscle and percentage of skeletal muscle from the carcasses in each group, using the method described in this study.

TABLE 5-9. FLOW CHART OF INFORMATION AND SEQUENCE TO PREDICT CARCASS SKELETAL MUSCLE

Information needed:

* Hot carcass weight
* 9-10-11 rib composition
* Percentage bone in 9-10-11 rib
* Percentage protein in skeletal muscle
* Equations to predict % carcass bone and % carcass protein from RIB

Step 1	HCWT
	- HCWT * %CB (from RIB)
	Predicted carcass soft tissue (CST)
Step 2	X % CP (from RIB)
	Weight of carcass protein
Step 3	X .95%
	Weight of skeletal muscle protein
Step 4	- .21%
	Weight of skeletal muscle in hot carcass

TABLE 5-10. GROUP MEANS AND STANDARD ERRORS FOR ACTUAL AND PREDICTED CARCASS SOFT TISSUES[b]

Item	Group 1	2	3	4
Actual CST tissue, kg	156.0[b]	209.9[b]	262.9[b]	320.7[b]
SE	3.99	2.43	2.28	2.66
Predicted CST, kg	157.6[b]	211.4[b]	260.9[b]	318.8[b]
SE	2.69	2.17	2.69	3.92

[b] Means in the same column with a different superscript differ ($P < .01$).

TABLE 5-11. GROUP MEANS AND STANDARD ERRORS FOR ACTUAL CARCASS PROTEIN AND ESTIMATED CARCASS PROTEIN FROM 9-10-11 RIB

Trait	Group 1	2	3	4
Actual CP, %	18.1[b]	16.5[b]	15.1[b]	14.5[b]
SE	.30	.18	.25	.19
RIB CP, %	17.5[bc]	17.3[c]	15.9[c]	15.4[c]
SE	.17	.10	.16	.23
Eqn 2 CP, %	17.4[c]	17.0[bc]	15.2[b]	14.5[b]
SE	.22	.13	.22	.31

[b,c] Means in the same column with a different superscript differ ($P < .01$).

TABLE 5-12. GROUP MEANS AND STANDARD ERRORS FOR ACTUAL AND PREDICTED WEIGHT OF CARCASS SKELETAL MUSCLE AND PERCENTAGE SKELETAL MUSCLE

Trait	Group 1	2	3	4
Carcass skeletal muscle, kg	124.2[b]	154.5[b]	179.7[b]	211.7[b]
SE	3.68	.46	2.76	2.72
Predicted skeletal muscle, kg	124.7[bc]	157.0[b]	177.8[b]	210.6[b]
SE	1.4	1.38	2.56	5.36
Actual skeletal muscle, %	66.0[b]	62.5[b]	59.2[b]	57.9[b]
SE	.72	.52	1.0	.47
Predicted skeletal muscle, %	66.3[bc]	63.5[b]	58.5[b]	57.5[b]
SE	.43	.39	.79	1.0

[b] Means in the same column with a different superscript differ ($P < .01$).

[c] Calculated using equations of Hankins and Howe (1946) to predict %CP.

SUMMARY

While the composition data from the 9-10-11 rib section are time consuming to obtain, many studies require more detailed information than 12th rib fat thickness, longissimus area and yield grade. The RIB certainly is more cost effective than performing a total physical dissection of individual beef carcasses and in most cases the relatively minor expense or loss in carcass value be justified. Since the RIB has been a widely accepted method of estimating carcass composition, reliable information may be obtained using prediction equations which accurately estimate carcass composition. Skeletal muscle may also be obtained using the relationships described in the present study. This technique should be studied and tested by researchers on other steer carcasses to identify refinements that could increase the predictive ability of the procedure, save labor and increase carcass salvage value when compared with physical separation of half carcasses.

OVERALL SUMMARY AND CONCLUSIONS

The objectives of the studies in this dissertation were to investigate in continental European crossbred steers developmental changes in: 1) empty body and carcass composition; 2) relationships between empty body and carcass water, protein and fat; 3) amount of skeletal muscle protein as a percentage of total empty body protein; 4) usefulness of deuterium oxide dilution in predicting empty body composition and skeletal muscle; 5) the relationship between creatinine excretion and lean body mass, empty body protein and skeletal muscle protein; 6) accuracy of present indirect methods to predict carcass composition and 7) develop new equations, if necessary, to estimate skeletal muscle, carcass composition and empty body composition.

Twenty genetically similar continental European crossbred steers were selected from approximately 357 calves. Calves were randomly allotted to one of four slaughter weight groups. Groups 1 and 2, typical of feeder cattle in today's beef production system were slaughtered at 300 and 390 kg, respectively. Groups 3 and 4 representing cattle during the typical finishing phase were slaughtered at 480 and 570 kg. Each steer was slaughtered when its slaughter weight was reached after creatinine

excretion and deuterium oxide water space had been measured. At slaughter, complete physical dissection and chemical analysis were conducted on all empty body and carcass components. The left side of each carcass was chilled, specific gravity determined and the 9-10-11 rib section removed and chemical analysis completed.

When compared to studies conducted during the past 50 years, continental European crossbred steers in the present study had the genetic capacity to grow to heavier live weights and contain less fat at similar weights when compared to previously reported studies. In the finishing phase, group 3 steers contained an average of 29.3% carcass fat and 2 of 5 graded USDA choice. Group 4 steers contained an average of 32% carcass fat and 5 of 5 graded USDA choice. This suggests that it may be necessary for carcasses to contain between 29 and 32% carcass fat in order to routinely grade USDA choice.

The composition of gain of the steers in this study showed that even though improvements in carcass fat (decrease) and carcass muscle (increase) have occurred using exotic breeds, the production of fat by continental European crossbred steers was excessive. Further research studies need to be conducted to improve the efficiency of protein deposition and to reduce fat accumulation in the empty body and carcass of cattle.

Skeletal muscle accounted for 42.3% of the live weight

in group 1 steers and declined to between 38 and 39% of live weight in groups 3 and 4. Carcass skeletal muscle was 66% of the carcass weight in group 1, and as expected, decreased to about 58% of carcass weight in group 4 steers. Carcass bone as a percentage of carcass weight decreased from 17.1 to 12.3% in groups 1 to 4, respectively. The muscle to bone ratio of the carcasses in the present study increased from 3.88 to 4.7 in group 1 to 4, respectively.

Interestingly, dissection and chemical analysis of the skeletal muscle from the empty body and carcass showed that the protein content of the skeletal muscle as a percentage of empty body protein and carcass protein remained constant at 52% of total empty body protein and 95% of carcass soft tissue protein. These relationships have not previously been reported in the literature and can be useful in predicting empty body skeletal muscle and carcass muscle by indirect methods.

The empty body water:protein ratio, empty body water:lean body mass, carcass moisture:protein and skeletal muscle moisture:protein ratios were relative constants across slaughter groups. These results were unexpected based on data from Haecker (1920).

Empty body soft tissues (muscle, fat and connective tissues, other than bone and cartilage) increased most dramtically in absolute weight and as a percentage of empty body weight as expected. Suprisingly, the major tissues of

the empty body (other than muscle, fat and bone) hide, blood and gastrointestinal tract components as a percentage of empty body weight remained relatively constant across groups. The remaining tissues, typically known to be early maturing, (respiratory system, reproductive/urinary system, central nervous system and cardiovascular system) decreased as a percentage of empty body weight.

Use of present prediction equations which utilize deuterium oxide space to estimate empty body composition overpredicted empty body water in most cases. Since present prediction equations utilize the relationships between empty body water, protein, mineral and fat to estimate composition, empty body protein predicted from empty body water was also overestimated and fat underestimated. Although physical dissection of the empty body of steers in the present study showed many of the relationships between water, protein and ash to indeed be constant, there appeared to be a developmental change probably related to water flux among tissues, in the ability of present equations to predict empty body composition. Equations using deuterium oxide space to predict empty body composition were developed in the present study. If deuterium oxide is to be considered for future use in studies investigating changes in composition, these equations need to be validated. The data from this study suggest using either the one pool method of deuterium

oxide dilution or urea dilution to estimate total body water and ultimately empty body water. The two pool method which attempts to account for gastrointestinal water appeared to introduce variation in predictng body water such that this method did not accurately predict empty body water and thus inaccurately predicted empty body protein, fat and mineral which was calculated from empty body water.

Daily creatinine excretion increased as live weight, fat-free muscle mass, empty body protein and muscle mass as measured by dissection increased. Equations predicting lean body mass, empty body protein and skeletal muscle protein using daily creatinine excretion and live weight as independent variables were developed and all had a R^2 greater than .95.

Equations using composition of the 9-10-11 rib section developed by Hankins and Howe (1946) for steers overpredicted carcass moisture and protein and underpredicted carcass fat in steers weighing more than 390 kg. Predicted carcass fat using equations developed by Miller et al. (1988) did not differ statistically from actual carcass fat. In steers weighing 480 kg or more, carcass protein was accurately predicted by an equation developed by Crouse and Dikeman (1974). The increase in live and carcass weight related to use of continental European genetics appears to suggest that the equations of Hankins and Howe (1946) were not accurate and need

modification. Equations by Miller et al. (1988) and Crouse and Dikeman (1974) may be more accurate and useful in larger framed leaner cattle. Prediction equations developed using both the Miller et al., (1988), Crouse and Dikeman (1974) data and the present data set will need further validation in order to gain wide acceptance.

Using specific gravity of carcasses dressed in the traditional manner using a cradle, may be useful for predicting carcass composition when labor and money are restricted. Removal of kidney and pelvic fat improved the ability and reduced the variation of specific gravity in estimating carcass composition.

Carcass muscle can be predicted using the composition of the 9-10-11 rib section and relationships between skeletal muscle protein and carcass soft tissue protein. Accurate estimation of carcass bone and carcass soft tissues is essential in order to predict carcass muscle.

APPENDIX

APPENDIX TABLE 1. EMPTY BODY AND CARCASS ORGANS, TISSUE WEIGHTS AND COMPOSITION COMBINED TO DETERMINE EMPTY BODY AND CARCASS COMPOSITION

Empty Body Components:

- Hide - (HD)
- Blood - (BD)
- Central nervous system - (CNS; brain and spinal column)
- Gastrointestinal tract - (includes esophagus, reticulum rumen, omasum, abomasum, small intestine, large intestine, spleen, pancreas and lymph glands) - (GIT)
- Mysenteric adipose tissue - (MYAT, surrounding intestines)
- Omental adipose tissue - (OMAT, surrounding stomachs)
- Liver - (LV)
- Respiratory tract - (REST; lungs, trachea, larnyx)
- Reproductive and urinary tract - (URIN)
- Vascular system - heart, arteries, veins, etc. - (VAS)
- Total bone - (TBON)
- Empty body skeletal muscle - (EBMUS)
- All other EB tissues - includes soft tissues from skull, lower leg - (OEBT)

Carcass Components:

- Total carcass bone only -CARBON
- Total carcass bone includes heavy connective tissue and ligaments- (CBON)
- Carcass skeletal muscle - (CMUS)
- Kidney - (KID)
- Perirenal adipose tissue - (KP; kidney and pelvic channel fat)
- Subcutaneous adipose tissue - (ScAT)
- Intermuscular adipose tissue (seamfat) - (IMAT)
- Intramuscular (intrafasicular) adipose tissue (marbling) - (IFAT)
- Other carcass adipose tissue - thoracic cavity (heart fat, rib overflow fat, vertebral column fat (TCAT)
- All other carcass tissues - (ACT)

APPENDIX TABLE 2. CARCASS TISSUES, INDIVIDUAL MUSCLES AND BONES AND ABBREVIATIONS, COLLECTED AND SUBSAMPLED AT SLAUGHTER

Item	Abbreviation
Adipose tissues:	
Subcutaneous adipose tissue (AT)	ScAT
Perirenal and pelvic AT	KP
Intermuscular AT	IMAT
Intramuscular AT	IFAT
Other AT (including rib overflow, heart and vertebral column fat)	TCAT
Muscles:	
Biceps brachii	BB
Biceps femoris	BF
Gastrocnemius	GA
Gluteus medius	GM
Gluteus profundus	GP
Infraspinatus	IF
Intercostal muscles	INM
Latissimus dorsi	LAT
Longissimus dorsi	LD
Quadriceps	QD
Psoas major	PM
Pectoralis profundus	PP
Rectus abdominus	RA
Rectus femoris	RF
Rhomboideus	RH
Subscapularis	SB
Spinalis dorsi	SD
Semimembranosus and adductor	SM
Supraspinatus	SS
Semitendinosus	ST
Serratus ventralis	SV
Trapezius	TP
Triceps brachii	TB
Vastus lateralis	VL
Vastus medialis	VM

APPENDIX TABLE 3. CARCASS TISSUES, INDIVIDUAL MUSCLES AND BONES AND ABBREVIATIONS, COLLECTED AND SUBSAMPLED AT SLAUGHTER

Item	Abbreviation
Bones:	
Total carcass bone	TCB
Humerus	HMB
Radius/ulna	RUB
Femur	FMB
Tibia/fibula	TFB
Vertebral column	VCB
3rd costa	3RB
10th costa	10RB
Rib cage (including sternum and costa cartilage)	RCB
Other carcass soft tissues:	
Includes tendons, ligaments, glands	OCST

APPENDIX TABLE 4. ABBREVIATIONS OF TERMS USED IN CALCULATIONS

EEIM	--	EEL of IMAT (intermuscular fat)
EEIMIF	--	Ether extractable lipid in the intermuscular and intramuscular AT
EMIF	--	EEL of IFAT from the skeletal muscle
FFM	--	Fat-free muscle
FFMEE	--	Skeletal muscle including IFAT and the M, P from IMAT
FFMIF	--	Fat-free muscle and marbling adipose tissue (includes M and P of IFAT)
M	--	Moisture
P	--	Protein
MPIM	--	Moisture and protein associated with IMAT
TM	--	Muscle tissue without IFAT
TIFAT	--	Total weight of marbling adipose tissue
T%IFAT	--	Percentage of total MAAT
TMM	--	Total of skeletal muscle and IFAT

TABLE 5. FLOW DIAGRAM FOR CALCULATION OF SKELETAL MUSCLE, INTERMUSCULAR AND INTRAMUSCULAR ADIPOSE TISSUE

	Soft tissue (SOTi)	
minus	SQAT, tendons, ligaments	
	SOTi 1	--- Muscle, intermuscular and intramuscular adipose tissue (includes all moisture, lipid and protein associated with tissues)
minus	EEIMIF	--- EEIM and EEIF (ether extractable lipid from IMAT and IFAT)
	FFM	--- Fat free muscle (includes moisture and protein associated with IMAT and IFAT as well as skeletal muscle moisture and protein)
	FFM / (1 - % EEL in composite muscle sample)	
	FFMEE	--- FFM + EEL associated with IFAT
minus	FFM	
	EEIF	--- EEL associated with IFAT
	EEIMIF	--- EEL in the intermuscular and
minus	EEIF	intramuscular AT
	EEIM	--- EEL associated with IMAT
	EEIM / % EEL of IMAT	(determined by AOAC)
equals		
	Total weight of IMAT	(Intermuscular AT)

TABLE 5. (Continued) FLOW DIAGRAM FOR CALCULATION OF SKELETAL MUSCLE, INTERMUSCULAR AND INTRAMUSCULAR ADIPOSE TISSUE

Total weight of IMAT (Intermuscular AT)

	IMAT	
minus	EEIM	
	MPIM	--- Moisture and protein associated with IMAT
	FFM	
minus	MPIM	
	FFMIF	--- Muscle (M & P) and IFAT M & P
plus	EEIF	--- EEL associated with IFAT
	Total muscle and marbling tissue	(TMM), normally considered skeletal actual muscle as dissected from the carcass
	TMM	
x	T%IFAT	--- % EEL of composite muscle / % EEL of IFAT
	TIFAT	--- Total intramuscular adipose tissue (IFAT)
	TMM	
minus	TIFAT	
	Total Muscle tissue	
		- (muscle free of IFAT, M,F & P) (myofibrillar protein, moisture and connective tissue associated with muscle)

APPENDIX TABLE 6. GROUP MEANS FOR SKELETAL MUSCLE COMPOSITION AS A PERCENTAGE OF EMPTY BODY COMPOSITION

	Group			
Item	1	2	3	4
Skeletal muscle H_2O % of EBH_2O	57.4	56.9	56.8	58.7
Skeletal muscle EEL % of EBF	5.1	5.5	7.5	7.0
Skeletal muscle protein % of EBP	52.1	51.4	51.4	52.9

APPENDIX TABLE 7. GROUP MEANS FOR EMPTY BODY SOFT TISSUE AS A PERCENTAGE OF EMPTY BODY COMPOSITION

	Group			
Item	1	2	3	4
EB soft tissue H_2O % of EBH_2O	9.4	10.0	10.4	9.9
EB soft tissue EEL % of EBF	64.0	68.3	68.0	70.0
EB soft tissue protein % of EBP	8.2	7.1	7.5	6.7

APPENDIX TABLE 8. GROUP MEANS FOR TOTAL BONE COMPOSITION AS A PERCENTAGE OF EMPTY BODY COMPOSITION

	Group			
Item	1	2	3	4
Bone H_2O, % of EBH_2O	7.5	6.4	6.1	5.7
Bone EEL, % of EBF	13.2	9.2	6.6	6.0
Bone protein % of EBP	13.8	13.3	12.8	12.4

APPENDIX TABLE 9. GROUP MEANS FOR GASTROINTESTINAL TRACT COMPOSITION AS A PERCENTAGE OF EMPTY BODY COMPOSITION

	Group			
Item	1	2	3	4
GI tract H_2O, % of EBH_2O	9.1	9.0	8.8	8.4
GI tract EEL, % of EBF	16.7	16.1	17.2	16.2
GI tract protein, % of EBP	5.2	5.1	5.0	4.8

APPENDIX TABLE 10. GROUP MEANS FOR HIDE COMPOSITION AS A PERCENTAGE OF EMPTY BODY COMPOSITION

	Group			
Item	1	2	3	4
Hide H2O, % of EBH_2O	8.4	9.4	9.4	9.8
Hide EEL, % of EBF	.4	.4	.4	.4
Hide protein, % of EBP	14.6	16.6	16.8	17.2

APPENDIX TABLE 11. GROUP MEANS FOR BLOOD COMPOSITION AS A PERCENTAGE OF EMPTY BODY COMPOSITION

	Group			
Item	1	2	3	4
Blood H_2O, % of EBH_2O	5.7	5.5	6.0	5.6
Blood EEL, % of EBF	.04	.06	.06	.03
Blood protein, % of EBP	7.6	7.7	7.8	6.8

APPENDIX TABLE 12. EQUATIONS PREDICTING EMPTY BODY COMPOSITION USING DEUTERIUM OXIDE DILUTION

2 Pool (Byers, 1979)

EB water = 1.038 x Pool A - 17.92

EB protein = .3017 x EB water

EB mineral = .0689 x EB water

Gastrointestinal tract weight (GIT) = .832 x Pool B - 3.1

EB fat = live weight - (GIT weight + EB water/.7296)

1 Pool (Loy, 1983)

(Robelin, 1982)

D_2O at time zero ($[D_2O]t_0$) in whole body at time of injection of dose = Y intercept of regression of log $[D_2O]$ vs time.

D_2O space = Dose (mg)/ $[D_2O]t_0$ (ppm)

Total body water (kg) = (.968)(D_2O space)

(Simpendorfer, 1973)

EB weight,kg (EBWT) = (.949)(shrunk live wt.) - 11.987

Gastrointestinal tract fill,kg (GITF) = shrunk live wt - EBWT

Water in gastrointestinal tract contents, kg ($GITCH_2O$) =

(GITF)(.847)

Empty body water,kg (EBH_2O) = TBH_2O - $GITH_2O$

(Garrett and Hinman, 1969)

% EB fat = 94.32 - (1.266)(%EBH_2O)

% EB protein = (100 - %EBfat - %EBH_2O)(.831)

% EB ash = (100 - %EBfat - %EBH_2O)(.186)

APPENDIX TABLE 13. EQUATIONS PREDICTING CARCASS COMPOSITION USING THE 9-10-11 RIB SECTION

Hankins and Howe (1946) (steer equations)		
% Carcass moisture:	16.83 + .75 x RIB % H2O	R = .92 SE = 1.9
% Carcass fat :	3.49 + .74 x RIB % EEL	R = .91 SE = 2.52
% Carcass protein:	6.19 + .65 x RIB % Protein	R = .83 SE = .79
Crouse/Dikeman (1974)		
% Carcass moisture:	17.64 + .71 x RIB % H2O	R^2 =.77 RSD = 1.78
% Carcass fat:	4.03 + .76 x RIB % EEL	R^2 =.88 RSD = 1.17
% Carcass protein:	4.03 + .76 * RIB % Protein	R^2 =.90 RSD = .43
Miller et al. (1988)		
Fed - cattle % carcass fat:	8.1 + .7 x RIB % EEL	R^2 =.66 RSD = 2.2
All cattle % carcass fat:	9.4 + .64 x RIB % EEL	R^2 =.85 RSD = 2.28

APPENDIX TABLE 14. EQUATIONS PREDICTING CARCASS COMPOSITION USING THE CARCASS SPECIFIC GRAVITY

Garrett and Hinman (1969)	
% Carcass moisture:	375.2 x SG - 343.8
% Carcass fat :	587.86 - 530.45 x SG
% Carcass protein:	(20.0 x SG - 18.57) x 6.25

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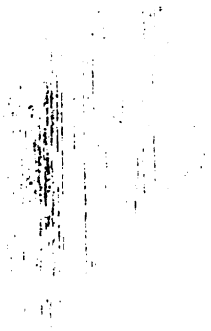

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