LIVE ANIMAL ULTRASOUND MEASUREMENTS OF FAT THICKNESS AND LONGISSIMUS MUSCLE AREA IN RELATION TO GROWTH AND CARCASS PARAMETERS IN FEEDLOT STEERS

By

MICHAEL TODD SMITH

Bachelor of Science

California Polytechnic State University

San Luis Obispo, California

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Thesis approved:

James W. Oltjen
Thesis Advisor

Donald R. Gill

Donald G. Wagner

Norman N. Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

As the beef industry moves toward a value-based marketing system, performance predictability and product uniformity becomes increasingly important. Unfortunately, today's fed cattle do not readily lend themselves to meet these desired goals. Diversity in age, weight, condition, previous nutritional status and breed-type all influence feedlot performance and composition of growth, thus, it is extremely difficult for cattle to be fed, managed and marketed in a uniform manner. A means of accurately assessing composition in livestock would allow for the grouping of animals to reach targeted endpoints and thus, produce a consistent and market desirable product in terms of both quality and cutability. The trend toward marketing livestock within narrow specifications has dramatically increased the need for of methods of ascertaining the composition of both live animals and their carcasses. Determining the composition of animals remains an important research goal in animal agriculture. Unfortunately, accurate determination of carcass parameters and composition of live animals still eludes scientists. Recent technological advancements in the field of human medicine have led to the development of highly accurate imaging techniques. Ultrasound is a promising technology for elucidating compositional differences among animals. While ultrasound is not a new method of discerning compositional differences among animals, the development of "real-time" ultrasound has dramatically improved the resolution of generated images and has sparked renewed interest in its use among animal and meat scientists.

The objectives of this research were: a) to evaluate the precision and accuracy of real-time ultrasonic measurements of fat thickness and longissimus muscle area in live feedlot steers; and b) to assess the ability of ultrasound and visual appraisal to account for and predict performance and carcass parameters in feedlot steers.

CHAPTER II

REVIEW OF LITERATURE

Methods of determining carcass composition

In order to evaluate and compare techniques of predicting live animal and carcass composition it is imperative to understand the numerous variables used by scientists for describing composition or endpoints. No single method of determining composition of animals and their carcasses is applicable to all situations; however, there is a need to standardize compositional endpoints to facilitate the comparison of research results (Hedrick, 1983).

Direct Methods

Whole body chemical composition is often the preferred methodology among animal nutritionists (Garrett and Hinman, 1969) as maximum information regarding chemical constituents in the body and energetic efficiencies are obtained. Initial studies by Moulton et al. (1922) involved the analysis of the total empty body of cattle. Presently, chemical analysis are mainly restricted to the carcass (Miller et al., 1988). As with all direct methods of determining composition, whole body analysis is time consuming and costly. This labor intensive technique does not allow for differentiating between tissue or edible vs inedible carcass parts and has the added disadvantage of drastically decreasing product value.

Complete carcass dissection has been used by many researchers, (Seebeck and Tulloh, 1968; Cianzio et al., 1982) in growth and nutritional studies as a means of understanding composition and distribution of the various tissues in the carcass. Although physical carcass dissection into separable fat, lean and bone is the preferred compositional endpoint of many, (Berg and Butterfield, 1968) cost is prohibitive and error due to dissection technique may occur.

A modification to physical carcass dissection is the determination of fat-free muscle through chemical analysis of the lean tissue. This method accounts for the variation in lipid content within muscle tissue (Kauffman et al., 1976) and, barring economic constraints, is the most comprehensive endpoint of compositional determination (Cross, 1982).

Another endpoint often used in research studies is the determination of saleable product or edible portion using commercial cutting techniques. Boneless retail cuts (Murphey et al., 1960) is but one example of a compositional endpoint that utilizes saleable product as a measure of composition in beef cattle. When compared to physical carcass dissection, Kempster et al. (1980) found results expressing saleable product as a percentage of carcass weight in agreement with carcass lean percentage. As a rule, these methods are relatively easy to employ, do not affect the value of the carcass and offer valuable information to the beef industry in regard to carcass value. Unfortunately, it is difficult to standardize the cutting and trim levels used and it does not account for variation in intramuscular fat (Cross, 1982).

Indirect Methods

Due to the economic restraints posed by direct methods of determining carcass composition, researchers have developed numerous indirect methods for determining reliable carcass composition. The use of indicator cuts or sub-carcass measurements have been used, with varying degrees of accuracy, to predict carcass composition (Orme et al., 1960; Callow, 1962; Williams et al., 1974; Lunt et al., 1985). One of the first part to whole studies, conducted by Hankins and Howe (1946), was based on physical separation of the 9-10-11th rib section into muscle, fat and bone. The authors reported correlation coefficients between proportion of separable lean in the rib section and lean of the carcass of steers and heifer of .92 and .72, respectively. In a more recent study, Miller et al. (1988) reported that of the many live and carcass techniques used to determine composition (real-time ultrasound, deuterium oxide dilution, specific gravity, separable and chemical composition of the 9-10-11th rib section, and carcass measured traits) that composition of the 9-10-11th rib section was the most accurate (R^2=.85) and precise ($s_{y \cdot x}$=2.0%) predictor of proportion of carcass fat in fed steers. The rib section was chosen because of its ease of removal from the carcass; however as noted by the authors, the amount of bone and fat in the rib section is subject to splitting and trimming errors. For this reason, Lunt et al. (1985) utilized rib sections from both carcass sides and found that 92% of the variation in carcass separable fat could be accounted for with 9-10-11th rib fat.

Butterfield (1965) suggested the shin as a predictor of carcass composition, reporting a correlation coefficient (r) between shin muscle group and total side muscle weight of .95. The shin was chosen as it is a relatively cheap part of the carcass that is easily obtained with minimum damage to the carcass. However, Kempster et al. (1977) expressed concern in using indicator cuts to predict carcass lean percentage. These researchers found that smaller and more easily obtainable cuts, particularly the shin and leg, showed considerable bias in predicted composition.

Prediction equations have been developed by a number of researchers (Murphey et al., 1960; Cross et al., 1973 Johnson and Ball, 1989) to predict carcass composition. These equations are based on a number of objectively measured carcass traits and offer an empirical approach to ascertaining compositional differences among carcasses through the relationships between single or multiple carcass entities and composition. Hedrick (1983) suggest prediction equations be revised when changes occur in animal and carcass characteristics due to production and management practices. Determining which carcass traits to measure and the extent of their usefulness in determining carcass composition is often a subject of debate. Because fat is the most variable tissue in the body (Callow, 1948; Berg and Butterfield, 1976), a measure of fat would be beneficial in elucidating live animal or carcass composition. Numerous researchers (Murphey et al., 1960; Crouse et al., 1975; Crouse and Dikeman, 1976;) have reported that twelfth rib fat thickness over the longissimus dorsi muscle to be the single most useful carcass measure for predicting composition.

Area of the longissimus dorsi muscle has been used as an indicator of carcass muscling and composition with varied success. Murphey et al. (1960) and Abraham et al. (1980) reported longissimus muscle area was a useful carcass measurement for determining composition. In contrast, Miller et al. (1988) found this measure of little use in determining carcass chemical composition, but this was due to the wide variation in muscle to bone ratio among their cattle.

However, it is important to note that breeds of cattle differ in the distribution of their carcass fat (Charles and Johnson, 1976; Kempster et al., 1976; Lunt et al., 1985). Likewise, differences exist among breeds in carcass lean content at a give level of fatness and reflect differences in muscle to bone ratios (Berg et al., 1978). Therefore, compositional differences often exist between breeds of cattle at the same level of fatness, and Kempster et al. (1982) argue that in the absence of better predictors, breed type be included as a factor in prediction equations to overcome such bias.

Specific gravity is another indirect method of carcass composition often used in research studies. It is relatively easy to determine and does not devalue the carcass. According to the Archimedean principle, a body immersed in water displaces a volume equal to its own. From this relationship, carcass density can be determined by dividing the weight of the carcass in air by the difference of the weights in air and water. Garrett and Hinman (1969) reported a series of prediction equations to estimate the chemical components and energy content of beef carcasses from carcass density. Correlation coefficients (r) between carcass density and the chemical constituents of the empty body were -.96, .93, .92 and -.95 for percent fat, water and nitrogen, and energy (kcal/gm), respectively. Conversely, in a more recent study, Miller at al. (1988) reported that specific gravity was not useful for predicting percentage carcass fat within a given age class of beef cattle, (yearlings, R^2=.17; fed cattle, R^2=.51). The authors suggest the discrepancy with earlier findings may be a result of newer commercial slaughter techniques that utilize mechanical hide pullers. These researchers suggest that the amount of air entrapped in the fat and muscle of dressed beef has increased since original equations (Garrett and Hinman, 1969) were developed.

Determining Live Animal Composition

Objective Measures

Of the various objective methods used to determine composition in the live animal, many researchers (Anderson et al., 1983; Stouffer et al., 1989) feel that ultrasound techniques offer considerable potential as non-invasive, and relatively accurate methods. Because the use of ultrasound is central to this thesis, a brief review of the history, physics and application of ultrasound is warranted.

According to Kratocwil (1978), ultrasound was developed in response to the *Titanic* tragedy of 1912 and man's need for locating objects such as icebergs at sea. The wartime development of sonar, and the discovery of high frequency pulse-echo ultrasound led to its application for detecting flaws in metallic structures (Firestone, 1946) and eventually to medical diagnostic uses (Wild and Neal, 1951; Howry and Bliss, 1952). Ultrasound is a mechanical wave phenomenon resulting from the transmission of orderly vibrations through a medium at frequencies above the range of human hearing (McDicken, 1976). These longitudinal compression waves are generated from crystalline structures having piezoelectric (pressure-electric) properties. These piezoelectric elements are the basic component of ultrasonic transducers - devices capable of transforming energy from one form to another (Kossoff, 1978). Transducers are the central feature of ultrasound imaging, and in most applications, the same transducer is used to generate and receive sound waves (Fleischer and James, 1980). Other components essential to ultrasonic imaging include: a pulsed voltage generator to excite the crystals, a system to amplify returning sound echoes and an electronic display function.

The velocity with which sound waves are transmitted is dependant upon the density and elasticity of the medium through which they propagate (Sample and Erikson, 1980). The velocity of propagation in various biological materials as well as the acoustical impedance of that material are listed in Table 1. Differences in acoustical impedance at tissue interfaces are of importance in ultrasound imaging as they are responsible for reflecting sound waves back toward the transducer.

All ultrasound imaging is based on measuring scattered or transmitted waves from tissue exposed to an incident ultrasound field (Leeman and Roberts, 1986). Sound waves are reflected at tissue interfaces due to differences in tissue density and acoustical impedance. The magnitude of reflection in biological tissue is listed in Table 2. The amount of energy reflected at soft-tissue interfaces is relatively small, thus allowing the incidence wave to move deeper into the tissue where it may reach another interface. The reflected energy at bone and soft-tissue interface is much greater (65%), and at air and soft-tissue, virtually total reflection occurs (McDicken, 1976). Much of the knowledge of the physics of ultrasound-tissue interactions is imperfectly understood; therefore, the accuracy of ultrasonic imaging depends on the ability to describe wave propagation (Leeman and Roberts, 1986).

Tissue dimensions are delineated by incorporating the physics of wave propagation, velocity of sound in tissue, and the interaction of soundwaves with tissue interfaces. Assuming a constant velocity of wave propagation in soft-tissue, distance is measured by determining the time required for ultrasonic energy to leave the transducer and return. (Fleischer and James, 1980). Most manufacturers of ultrasound equipment use the velocity of 1540 m/s in machine calibration (Christensen, 1988).

Animal researchers have been using ultrasound for many years (Temple et al., 1956; Stouffer et al.,1959). These early studies involved the use of relatively simple A-mode ultrasound equipment that displayed a series of peaks on an oscilloscope. A-mode refers to "amplitude" display and offered limited information as it was one-dimensional in nature (Wells, 1977). Later, A-mode equipment was modified so that the returning signal was displayed as spots varying in brightness. B-mode or "brightness" modulation, was thus developed and two-dimensional images were available (Christensen, 1988). Today, most ultrasound studies are conducted using modern, real-time, high-resolution gray-scale imaging equipment (Leeman and Roberts, 1986).

Ultrasound research in beef cattle has predominantly centered around estimating fat thickness and area of the longissimus muscle in live animals. The anatomical position that is measured on the live animal varies with researcher and geographic location, but the majority have chosen the twelfth-thirteenth rib position due to its ease of location and because it corresponds to most commercial cutting practices. A wide range in correlation coefficients have been reported in the literature for the relationship between measurements of fat thickness and longissimus muscle area determined ultrasonically and on the carcass. Researchers using A and B-mode equipment have reported correlation coefficients ranging from .01 to .93 for fat thickness (McReynolds and Arthaud, 1970; Watkins et al., 1967), and from .22 to .92 for longissimus muscle area (Stouffer et al., 1961; Hedrick et al., 1962). In a recent review article, Houghton (1988) found correlation coefficients between ultrasonic estimates obtained with modern real-time ultrasound equipment ranging from .42 to .92 and .47 to .86 for fat thickness and longissimus muscle area, respectively. These values are difficult to compare and are related to the population size and variation of the dependent variable studied. Berg and Butterfield (1976) and Kempster et al.

(1982) question the importance of correlating ultrasonic measurements with those subsequently taken on the carcass and argue that all ultrasonic studies should attempt to directly estimate carcass composition.

In a study utilizing fifty beef animals varying widely in age, weight and composition, Miller et al. (1988) reported that ultrasonic measurements taken at the shoulder, twelfth rib and rump were useful in accounting for variation in percentage carcass fat across age class (R^2 and $s_{y \cdot x}$ values of .69, 3.45; .72, 3.29; and .72, 3.32 respectively). However, R^2 was influenced by the large variation in fatness which occurred across age, and were generally less accurate when the analysis was conducted within age class. Ultrasonic fat thickness measurements at the twelfth rib and rump, coupled with an ultrasonic fat thickness area measurement were able to account for 71% of the variation in carcass fat proportion among fed steers with a residual standard deviation of 2.9%.

Ultrasonic determination of marbling has received much interest in recent years, with two distinctly different methods currently being employed: quantification of attenuation values obtained with real-time sector scanning and subjective gray scaling of ultrasonic images generated from real-time linear array ultrasound equipment.

Perry et al. (1989) were 80% accurate in distinguishing between USDA Select and Choice carcass quality grades (small degree marbling) using attenuation values obtained with a sector scanner. The technique is based on the principle that as transmitted ultrasound and echoes passes through tissue, they are reduced in intensity (Mountford and Wells, 1972). This reduction, referred to as attenuation, is due to reflection, refraction, scattering and absorption of sound in tissue (Hill, 1978). In this method, attenuation of ultrasound is quantified, with increased values being theoretically associated with corresponding increases in intramuscular fat. Equipment cost and portability, as well as time required to obtain attenuation values, limits the usefulness of this technique (Stouffer, personal communication).

Brethour (1989) reported similar accuracy (81%) in identifying steers with or without adequate intramuscular fat to reach the USDA Choice quality grade. These results were obtained using ultrasonic images generated from real-time linear array scans of live cattle. The recorded ultrasound images were visually analyzed and subjectively scored according to the amount of "speckle" present in the gray-scale image.

The Instrument Grading Subcommittee of the National Cattlemen's Association has proposed a multi-phased research project for the development of an accurate and repeatable means of determining carcass value (Anon. 1990). Research has been conducted with ultrasound to estimate fat thickness and longissimus muscle area of ensanguined cattle prior to hide removal (Recio et al., 1986). These researchers reported correlation coefficients lower than those generally obtained in live cattle (r=.76 and .50 for carcass adjusted fat thickness and ribeye area, respectively). Savell et al. (1989) investigated the use of ultrasound to yield grade carcass prior to hide removal. Ultrasonic fat thickness measurements were obtained prior to hide removal and applied to the following equation: ultrasound yield grade = .03 + (1.18 X ultrasound fat, cm) + (.27 X estimated kidney, pelvic and heart fat, %) + (.002 X hot carcass weight, kg). Results similar to actual USDA yield grades were found, with the exception of USDA yield grade 1 and 4 carcasss where estimates were off by greater than one full yield grade. Presently there is little known about the effect of rigor mortis on the velocity of sound in tissue (Miles et al., 1972), and as noted by McDicken (1976), the condition of the tissue being studied, living or dead, affects its mechanical properties and thus the velocity of sound. Therefore, the choice of a suitable calibration velocity presents a problem when scanning carcasses and is yet to be determined.

Sources of error

The accuracy and precision with which live animal ultrasonic measurements can be made of carcass parameters are subject to error due to technological limitations, technician technique, conformational changes which occur when the live animal is moved from a standing to the hanging carcass position and interpretational error on the part of the technician.

Equipment currently being utilized in animal research was developed specifically for human medicine and poses limitations in regard to imaging capabilities in livestock (Cross, 1989). The length of the transducers utilized in ultrasonic imaging is one such limitation, as it requires the operator to overlap two images in order to produce one complete image of the longissimus muscle (Moore et al., 1985) This limitation may have been rectified with the recent development of a longer transducer (Stouffer, personal communication). Tissue dimensions, as presented on the display screen, are derived using the average velocity of sound in soft tissue. Sound velocity differs among the primary tissues types (Table 1); therefore, when accurate measures are needed, the precise value of velocity in the tissue of interest becomes important (McDicken, 1976).

Scanning position must be accurately located on the animal if accurate results are to be obtained from corresponding carcass measurements. The position of the last rib is easily located on the live animal; thus, ultrasonic measurements of longissimus muscle area and fat thickness are generally obtained between the 12th and 13th ribs (Stouffer et al., 1959). The amount of pressure applied with the transducer during the scanning procedure can cause tissue distortion and affect the accuracy of fat thickness measurements as subcutaneous tissue is easily compressed (Heckmatt et al., 1988). These authors also noted that the angle of transducer placement relative to the tissue structure being scanned affects apparent tissue depth. One common cause of poor results is inadequate acoustical contact between the transducer and the skin surface to eliminate air gaps (Sample and Erikson, 1980). Air has a reflection coefficient approaching 100%, and as little as .1 mm of air is required to attenuate a 5 MHz ultrasound beam by half (McDicken, 1976).

Another source of error, inherent to all methods of estimating carcass measures, is the relative changes of tissue structure which occur during processing (i.e. hanging, splitting and quartering) and *rigor mortis*. In a study conducted by Miles et al. (1972), the position of live animal ultrasonic measurements were determined by palpation and marked by injecting vegetable dye through the hide prior to its removal. Corresponding measurements were also obtained directly from the carcass after normal chilling procedures. The position of the soft tissue relative to the skeleton moved cranially in the extreme thoracic regions and in a caudal manner in the lumbar region. The authors note that besides movement of surface tissue due to gravitational forces, the vertebral column was also distorted, thereby complicating the interpretation of accuracy with regard to *in vivo* measurements. Temple et al. (1965) reported that locations scanned on the live animal shifted in relation to the skeleton as much as 5 cm when the carcass was hung on a rail.

Brackelberg et al. (1967) note that carcass fat thickness may be altered when carcasses are scribed during processing, allowing the fat and muscle to rotate away from the spinous processes of the thoracic vertebrae. These results were substantiated by Ramsey et al. (1965). They reported that scribing tended to increase fat thickness and change longissimus muscle configuration, making interpretation of ultrasonic images more difficult.

Additional error can be attributed to the manner in which carcasses are quartered between the 12th and 13th ribs. In a study to assess the variation in measured longissimus muscle area between ribs, Stouffer et al. (1961) made five slices through the frozen 12th-13th rib section of fifteen carcass and found ultrasonic muslce area more closely associated with the middle slices than to those on or next to either rib. Error due to this processing step can be expected when carcass measurements are obtained in commercial meat processing facilities as ribbing is generally done in a manner to maximize economic return, i.e. closer to the twelfth rib.

Determining tissue dimensions from ultrasonic imagery is not entirely objective in nature, and in its present form, the accuracy associated with this technology is dependent upon subjective interpretational error of the ultrasonically generated images (Miles et al., 1972).

Repeatability studies (Stouffer et al., 1961; Wallace et al., 1977; Bailey et al., 1988) have shown that there is more variation between interpretation of the same ultrasonic image than image obtainment, suggesting that improvements in accuracy may be achieved by automating image analysis (McLaren et al., 1989), effectively removing subjective human interpretation. Miller et al. (1988) noted that ultrasonic twelfth rib fat measurements and corresponding carcass measurements were not always close, pointing to the difficulty of making accurate live measurements.

Studies suggested that low correlations between ultrasonic and carcass measured fat thickness area are in part due to misinterpretation of the lateral boundary of the longissimus muscle (Stouffer and Wellington, 1960). Hedrick et al. (1962) noted that subjective determination of the medial and lateral ends of the longissimus muscle was often necessary. Discerning boundaries of the longissimus dorsi muscle is a problem with real-time ultrasound as well and can be explained by refraction of the sound waves at the curved ends of the longissimus muscle as well as increased attenuation of sound in deep tissue (Cross, 1989).

To remove the subjectivity involved with ultrasonic measurements of carcass traits, Miles et al. (1983, 1987) suggest using the speed of ultrasound transmission as a means of determining composition. In this procedure, two transducers are used: one to transmit, and the other to receive sound. The transducers, are placed facing one another and by measuring the distance and time required for the sound wave to travel between them, the velocity of sound in a given tissue or medium is quantified. The velocity of sound in individual tissue components (muscle, fat and hide) from cattle, sheep and swine was found to differ very little between species (Miles and Fursey, 1974). However, there were differences in velocity between the tissue components themselves: 1.43 to 1.44 km/s and 1.59 to 1.61 km/s for fat and muscle, respectively. A major advantage of this technique is that differences in intermuscular (seam) fat, the fat depot that makes up the greatest proportion of total carcass fat, is accounted for.

Another imaging technique currently attracting considerable interest by the medical field is nuclear magnetic resonance (NMR), also referred to as magnetic resonance imaging. An excellent description of the physical and biological principles of NMR is presented by Bushong (1988). In addition to providing information for assessing composition (lean/fat ratio), NMR could be beneficial in relating the chemical composition of tissue being examined (Worthington, 1984).

Other ultrasound uses

Mackay (1984) suggested that insitu ultrasonic measurements of the elastic properties of the eye lens might be useful as an index of age in animal studies. Perhaps ultrasonic age determination could replace the subjective carcass maturity assessments currently used in determining quality differences attributable to the age of an animal.

Initial measurements on feeder cattle

Due to its non-invasive nature, ultrasound is a useful tool for monitoring dimensional changes (i.e., fat thickness and longissimus dorsi area) that occur in an animal during any stage of development. McLaren et al. (1989) ultrasonically measured fat thickness and loin eye area at the last rib of market hogs every two weeks . Their research showed that ultrasound was a useful tool in monitoring composition of the growing pig. Using real-time ultrasonic measurements of fat thickness obtained on day 0, 58, 86 and 107 of a 111 day feeding period, Brethour (1988) developed the following exponential growth model to predict carcass fat in feedlot steers: $Y = A*2.7183^{k*t}$, where Y is predicted carcass fat (mm), A is ultrasonic measured fat (mm), k is the rate coefficient and t is time (d). The steers in this study were categorized on the basis of color and conformation to one of three breed-type groups: British, British by European crosses, and predominantly European breeding. Significant differences ($p<.01$) in rate constants were evident for the three breed types. Average errors of prediction were 2.95, 2.35 and 1.86 mm for ultrasonic measurements taken 111, 54 and 26 days prior to slaughter. The author concluded that accurate and precise prediction of carcass cutability grade could be determined several months prior to slaughter using ultrasound.

Houghton (1988) reported on a Kansas study that utilized ultrasonic fat thickness and linear hip height measurements to sort 706 head of incoming feedlot steers. Steers were sorted into six pens and slaughtered when a 15% sample from each pen ultrasonically scanned 1 cm fat thickness or reached a weight of 590 kg. A 21 d difference was noted in time on feed required for pens to reach this criteria, with small framed heavy conditioned steers requiring 83 d and large framed steers 104 d. Similar quality and yield grade were observed among pens, leading the author to suggest that sorting feeder cattle in this manner would allow determination of appropriate d required for a pen of cattle to reach acceptable and consistent quality and yield grades. In a more recent study, Houghton et al. (1990) utilized 997 yearling steers from two different origins to compare feedlot performance and carcass trait uniformity with visual and ultrasonic sorting methods. No significant differences ($p>.05$) in uniformity were found between sorting techniques. Differences observed between the two studies is likely a reflection of genetic and environmental effects as steers used in the first trial were of one breed and raised in the same environment prior to the feedlot study.

Table 1. Density, velocity and acoustical impedance of various biological materials.

Material	Density[a] g/ml	Velocity[b] m/s	Acoustical impedance[b] $gm \cdot cm^{-2} s^{-1}$
Air		331	$.0001 \times 10^5$
Water	1.00	1430	1.5×10^5
Blood	1.06	1570	1.6×10^5
Fat	0.92	1450	1.4×10^5
Muscle	1.07	1585	1.7×10^5
Bone	1.4-1.8	4080	8.0×10^5
Kidney	1.04	1561	1.6×10^5
Soft tissue (average)		1540	1.6×10^5

[a]Adapted from Wells (1977).
[b]Adapted from Goldberg et al. (1975).

Table 2. Magnitude of reflection at various interfaces[a].

Interface	Reflection, %
Blood-fat	7.9
Muscle-fat	10.0
Muscle-bone	64.6
Air-any soft tissue	99.9

[a]Adapted from Goldberg et al. (1975).

CHAPTER III

EVALUATION OF ULTRASOUND FOR PREDICTION OF CARCASS FAT THICKNESS AND LONGISSIMUS MUSCLE AREA IN FEEDLOT STEERS

Abstract

Four hundred fifty-two yearling steers from two experiments were ultrasonically measured for subcutaneous fat thickness and longissimus muscle area between the twelfth and thirteenth ribs using real-time linear array ultrasound equipment. Ultrasonic predictions were compared to corresponding carcass measurements to determine ultrasound accuracy. In Experiment 1, 74% of the ultrasonic estimates of fat thickness were within 2.54 mm of carcass values (r=.81) and muscle area was predicted within 6.45 cm^2 for 47% of the carcasses (r=.43). Although similar correlation coefficients between ultrasonic and carcass fat thickness were obtained in Experiment 2 (r=.82), estimates were more biased with only 62% of ultrasound estimates within 2.54 mm of carcass measurements. Improvement in longissimus muscle area estimates was noted in Experiment 2, with 54% of ultrasonic estimates within 6.45 cm^2 of carcass values (r=.63). The extremes for each trait proved most

difficult to predict; fat thickness was underestimated on fatter cattle, muscle area was underpredicted on heavier muscled steers. Ultrasonic measurements of fat thickness are precise and accurate in determining carcass fat thickness, but muscle area estimates are inconsistent and warrant further investigation.

Introduction

Live animal estimation of carcass parameters and the ultimate determination of composition of livestock remains an important research goal in animal agriculture. Methods for obtaining carcass estimates are as varied in scope and complexity as the results they produce. They range from relatively inexpensive and readily obtainable linear measurements (Daley, 1981) to complex, and often costly, imaging techniques currently employed in the field of human medicine (Groeneveld et al., 1984). Ultrasound is an imaging technology which holds great promise for elucidating compositional differences in animals (Kempster et al., 1982; Berg and Butterfield, 1976). Ultrasound imaging involves transmitting high frequency sound waves through the hide of the live animal. These sound waves are reflected at varying rates due to differences in density among the primary tissue types (bone, muscle, fat). Estimates of fat thickness and muscle area of the live animal are then determined from the cross-sectional images that are produced. The ability to use ultrasound to precisely and accurately estimate carcass parameters in live animals is important because it would enable the beef industry to move away from the current practice of pricing cattle on pen averages to a value-based marketing system. Additionally, serial ultrasound measurements could replace the need for costly serial slaughter designs frequently employed in growth studies. Research has shown that individuals interpret the same ultrasonic image differently, and that there are differences in their accuracy between scanned anatomical locations, thus making the technique highly technician dependent (Miles et al., 1972). However, as a technician becomes more experienced, accuracy improves (Moody et al., 1965). In a review article, Houghton (1988) found correlation coefficients between live animal ultrasonic and carcass measurements of fat thickness and longissimus muscle area from .42 to .92 and .47 to .86, respectively. Therefore, the objective of this study was to evaluate ultrasonic measurements of fat thickness and longissimus muscle area taken prior to slaughter for prediction of carcass fat thickness and longissimus muscle area.

Materials and Methods

The 315 yearling steers of various breed types used in Experiment 1 were part of a feeding trial conducted to determine the effect of virginiamycin, a feed-grade antibiotic, on performance and carcass characteristics of feedlot steers. Because steers differed in initial body weights, they were slaughtered in two groups to achieve similar final weights. The first group was fed a high concentrate diet for a total of 135 d, while the second group was fed 149 d. Five d prior to slaughter, steers were restrained in a hydraulic squeeze chute and scanned using an Aloka 210DX[1] real-time diagnostic ultrasound unit equipped with a 3 MHz linear array transducer. Light mineral oil was used as an acoustical couplant. Scanning site, as determined by physical palpation, was located between the twelfth and thirteenth ribs on the left side of the animal. Ultrasound images were obtained using the double frame display capabilities of the equipment, and a transducer guide was utilized to minimize error that may occur due to animal backline curvature and the overlapping step. First, an image of the medial portion of the muscle was recorded on video tape, then the transducer was moved ventrally and the lateral portion was recorded. The resulting ultrasound images were later viewed on a 30 cm display monitor to determine both carcass fat thickness (UFT) and longissimus muscle area (ULMA) estimates. Carcass fat thickness, measured three-fourths the length of the longissimus muscle from the chine bone end (FT), and longissimus muscle area were measured at the 12th and 13th rib interface 24 h postmortem. Carcass longissimus muscle area was determined using a standard dot grid (LMA), 10 dots per 6.45 cm^2, for

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[1]Distributed by Corometrics Medical Systems, Inc., Wallingford, CT

both groups. In addition, acetate tracings (TLMA) of the longissimus muscle were obtained from carcasses of steers fed 135 days. An electronic digitizing board was used to determine the area of these tracings. Research has shown that area of longissimus muscle measures differ using these two methods; however, these differences were generally smaller than those noted between carcass sides (Henderson et al., 1966). Longissimus muscle area was also predicted as a function of shrunk final body weight (WLMA) using the assumption that a steer of average muscling will produce .156 cm^2 of longissimus muscle per kg of body weight (Boggs and Merkle, 1990). Means and standard deviations for parameters of interest in this study are presented in Table 1.

The 137 yearling steers of various breed types used in Experiment 2 were obtained from a trial conducted to determine the effect of anabolic implants, both estrogenic and androgenic, on performance and carcass characteristics of feedlot steers fed a high concentrate diet. Steers were slaughtered in two groups to facilitate ease of data collection. Steers in the first group were fed 119 d and those in the second group 126 d. Five d prior to slaughter, steers were scanned with the same equipment as in Experiment 1, although technique differed slightly. Images used to determine fat thickness were obtained from the same location as in Experiment 1 using the single frame mode as it offered greater resolution. Location of fat thickness measure (three-fourths the length of the longissimus muscle) was estimated by the technician as only a portion of the longissimus muscle was displayed on the monitor at any given time. Fat thickness (UFT) was determined at the time of scanning by utilizing the machines internal electronic calipers. An additional image was obtained for each animal using the split-screen mode, as in Experiment 1, and recorded for later viewing to determine carcass longissimus muscle area estimates. Recorded ultrasound images were interpreted independently by two technicians for the determination of longissimus muscle area values. Utilizing a large display monitor, each technician interpreted the recorded images, tracing the configuration of the longissimus muscle on clear plastic sheeting. Area was determined from these tracings using an electronic digitizing board. Technician A (ULMA1) was responsible for the generation and recording of ultrasonic images and had more experience in scanning livestock than technician B (ULMA2). Technician A had similar responsibilities in Experiment 1; however, technician B made tracings for determination of ULMA in Experiment 1. In addition to ultrasonic measurements, longissimus muscle area was also predicted as a function of shrunk final body weight (WLMA) as in Experiment 1.

One d prior to shipping steers to the slaughter facility, a trained livestock evaluator subjectively estimated carcass fat thickness (SFT) and longissimus muscle

(SLMA) for each animal. Off-test weights for each steer were made available to the evaluator at the time subjective estimates were made. Carcass fat thickness (FT), adjusted fat thickness (ABF) based on subjective assessment of unusual fat deposits in other carcass locales (USDA, 1989) and longissimus muscle area (LMA) were measured at the 12th and 13th rib interface 24 h postmortem. Means and standard deviations for parameters of interest in Experiment 2 are presented in Table 1.

For both experiments, residuals (predicted minus observed values, Table 2) were initially analyzed in a model which included breed-type and observed carcass values and their interaction. Because neither breed or breed-related interactions were significant ($p>.05$), final models presented here include only effects of carcass values.

Results and Discussion

Experiment One

Simple correlations (r) between predicted (UFT, ULMA, WLMA) and observed carcass values (FT, LMA, TLMA) are presented in Table 3. Ultrasonic estimates of fat thickness were strongly correlated with carcass values ($r=.81$) and appear to be precise predictors of carcass fat thickness. The relationship between ultrasonic and carcass longissimus area, however, was moderate to low depending upon method of determining carcass values ($r=.43$, LMA; $r=.20$, TLMA).

Improper placement of the transducer by the technician, poor image resolution of deep tissues (Cross, 1989) or inaccurate interpretation of the image produced (Miles et al., 1972) may explain these low values. Changes in muscle configuration during processing, onset of rigor mortis and differences in muscle configuration that exist between the standing animal and the hanging carcass may affect longissimus muscle areas and thus precision of ultrasonic estimates (Temple et al., 1965). Interestingly, longissimus muscle areas predicted from final weight were more strongly related to carcass values (r=.53, LMA; r=.47, TLMA) than ultrasonic estimates.

Accuracy of ultrasound estimates may also be determined by assessing the relative frequency in which estimates are within an absolute range of carcass parameters. In this study, ultrasonic fat thickness estimates were within 2.54 mm of carcass measured fat thickness for 74% of the animals (Table 4). Henderson-Perry et al. (1989) reported that 93% of their ultrasound estimates were within 3 mm of carcass fat thickness. The 227 steers used in their trial had a mean carcass fat thickness of 10.6 mm or 23% less than mean fat thickness of the carcasses in this experiment (13.8 mm). This could explain their higher reported accuracy. Steers with carcass fat thickness less than 12.7 mm were estimated within 2.54 mm for 82% of the steers compared to 67% for those with carcass fat thickness greater than 12.7 mm. Similar discrepancies in accuracy have been observed by others (Houghton and Stouffer, personal communication). Ultrasonic longissimus muscle area estimates (ULMA) were within 6.45 cm^2 of LMA and TLMA for 47% and 55% of the animals, respectively. Estimates of longissimus area based on final weight of the animal (WLMA) were within 6.45 cm^2 of LMA and TLMA for 45% and 37% of the animals, respectively (Table 5).

To illustrate the accuracy of ultrasonic measurements, residuals (ultrasonic minus carcass values) were plotted against carcass fat thickness and longissimus muscle area. As shown in Figure 1, there is a tendency to underpredict fat thickness of fatter cattle. This is likely due to ultrasonic misinterpretation of connective tissue layers that normally develop within fat to provide support and rigidity as an animal increases in fatness (Dolezal, personal communication). Longissimus muscle area is generally overpredicted for carcasses with areas of less than 71 cm^2 and is underpredicted for carcasses with areas over 84 cm^2 (Figure 2).

Experiment Two

Simple correlations (r) between ultrasonic (UFT), subjective (SFT) and carcass (FT, AFT) fat thickness are presented in Table 6. Ultrasonic fat thickness measurements were strongly correlated with actual values (r=.82, FT; r=.81, AFT), while subjective estimates (SFT) were less closely associated with carcass values (r=.56, FT; r=.60, AFT). When visually estimating fat thickness the evaluator used indicators of overall fat cover; therefore, one would expect greater correlation coefficients between subjective and adjusted fat thickness.

Table 6 also contains simple correlations (r) between predicted (ULMA1, ULMA2, SLMA, WLMA) and carcass longissimus muscle area (LMA). Ultrasonic longissimus area measurements were moderately correlated with carcass values and did not differ between technicians (r=.63). Apparently there were interpretational differences of ultrasonic images, as the relationship between technicians' estimates was not perfect (r=.71). Subjective estimates of longissimus area (SLMA) were also moderately correlated with carcass values (r=.61) and indicate that the evaluator was able to identify differences in muscularity between animals. Longissimus muscle area predicted from final weight showed the weakest relationship (r=.48) with carcass values observed in this study.

Again, a more useful measure of the predictive capacity of a given technique is the relative frequency with which estimates are within a given range of actual carcass parameter values. Ultrasonic estimates of carcass fat thickness were within 2.54 mm for 62% of the steers and within 5.08 mm for 95% of the steers (Table 7). Faulkner et al. (1990) reported 72% of all cattle ultrasonically measured for fat thickness (n=27) were within 2 mm of carcass fat thickness. While their ultrasonic technique was similar to that in Experiment 2, results are not comparable with this study as hides were removed with a knife in their study and not a hide puller.

Carcasses with less than 12.7 mm fat thickness were estimated within 2.54 mm for 76% of the animals compared to 51% for those with carcass fat thickness greater than 12.7 mm. The same general trend was noted for subjective estimates of carcass adjusted fat thickness, with 55 and 82% of all steers estimated within 2.54 and 5.08 mm of carcass values, respectively. The evaluator was more accurate in assessing adjusted carcass fat thickness with thinner steers (<12.7 mm) as evident by a greater proportion of those cattle estimated within 2.54 mm of carcass values (63% vs 49%).

Of the methods used to estimate carcass longissimus muscle area (Table 8), predicting area as a function of final weight (WLMA) identified the greatest proportion of steers within 6.45 cm^2 of carcass values (61%). Ultrasonic estimates of longissimus muscle area by technician A were of similar accuracy (58% within 6.45 cm^2) as weight estimates and better than those of technician B (51%). Subjective visual estimates (SLMA) were within 6.45 cm^2 of carcass values for only 42% of the steers even though the correlation coefficient was similar to that of ultrasonic measurements (.61 vs .63). This points to the fallacy of utilizing correlation coefficients (measures of precision) as indicators of accuracy.

Ultrasonic estimates were least accurate in determining longissimus muscle area for steers with areas greater than 96 cm^2, with 35 and 30% of those estimates within 6.45 cm^2 for technician A and B, respectively. In contrast, the live evaluator (SLMA) was most accurate within this range, correctly estimating carcass longissimus area for 50% of the steers within 6.45 cm^2. Predicting longissimus muscle area as a function of weight (WLMA) was most accurate for steers with carcass longissimus muscle areas of less than 77 cm^2 and least accurate for those in excess of 96 cm^2.

To illustrate the accuracy of subjective and ultrasonic estimates, residuals (ultrasonic or subjective minus carcass values) were plotted against carcass fat thickness and longissimus muscle area. As shown in Figure 3, ultrasound estimates tended to overpredict fat thickness on steers with less than 10 mm carcass fat thickness and underpredict fat thickness for steers with greater than 15 mm carcass measured fat thickness. A similar trend is noted with subjective visual estimates (Figure 4) as all carcasses with greater than 20 mm adjusted fat thickness were underestimated. Ultrasonic estimates of longissimus muscle area generally were underpredicted for heavier muscled steers (Figures 5 and 6), with both technicians underpredicting all animals with carcass longissimus muscle areas greater than 103 cm^2. The residuals associated with subjective estimates of longissimus muscle area (Figure 7) tended to be more variable; however, longissimus muscle area was generally overpredicted for steers with less than 80 cm^2 carcass longissimus muscle area. When using weight to predict carcass longissimus muscle area, systematic error is evident (Figure 8). As carcass longissimus muscle area increased, errors of prediction increased. These results suggest that the steers used in this study were heavier muscled than the general cattle population if one assumes that an average muscled steer will produce .156 cm^2 of longissimus muscle per kg of body weight (Boggs and Merkle, 1990).

It is interesting to note that, regardless of the method used to predict fat thickness and longissimus muscle area, bias increased with fatter and heavier muscled animals. Comparison of the two experiments reveals that precision of ultrasonic fat thickness measurements was essentially unchanged (r=.81, Exp. 1; r=.82, Exp. 2). However, there was a reduction in the accuracy of estimates (74 vs 62% within 2.54 mm of carcass fat thickness for Exp. 1 and Exp. 2, respectively). Reduction in accuracy may be in part due to the manner in which ultrasonic estimates were obtained. In Experiment 1, fat thickness estimates were obtained from recorded images of complete longissimus muscle and associated fat cover sites, thus allowing a more objective determination of measurement location. In contrast, fat thickness estimates in Experiment 2 were more subjective in nature as only a portion of the longissimus muscle could be scanned at any given time and thus, location of fat thickness measure was not as precise as in Experiment 1.

An increase in both precision (r=.43 vs r=.63) and accuracy (47 vs 54% of estimates within 6.45 cm^2 of carcass longissimus muscle area) of ultrasonic longissimus muscle area estimates was evident over the two experiments for technician B, suggesting accuracy improves with experience. However, both mean and standard deviation of longissimus muscle area were greater in Experiment 2, thus results may reflect differences in the two populations studied.

It is generally agreed that accurate live animal estimates of fat thickness are obtained with ultrasound (Stouffer et al., 1989; Henderson-Perry et al., 1989; Perry et al., 1989; Faulkner et al., 1990). Also, fat thickness over the longissimus muscle at the 12th rib has been shown to be the most accurate indicator of carcass composition (Murphey et al., 1960; Crouse et al., 1975). Therefore, ultrasound offers tremendous potential as a means of estimating cutability among fed cattle.

Technological advances in the field of ultrasonics are needed to improve accuracy of fat thickness and longissimus area estimates. Research has been initiated to design a multi-frequency transducer that will optimize the frequency utilized during the scanning process, thereby increasing image resolution and allowing more accurate determination of tissue interfaces of interest (Cross, 1989). Additional efforts are being made to automate the interpretation of ultrasonic images using artificial intelligence techniques (Cross, 1989). Recently, a new transducer has become available that has a longer active surface area, thus eliminating the need to use the split-screen mode with current ultrasound equipment to generate a complete image of the longissimus muscle. The transducer provides increased resolution and should offer increased accuracy (Stouffer, personal communication).

Implications

Results of this study demonstrate that ultrasonic measurements made prior to slaughter are useful for estimating carcass fat thickness, yet imprecise in predicting longissimus muscle area. In fact, predicting longissimus muscle area as a function of live weight proved nearly as or more accurate than ultrasound estimates. I question the use of ultrasound for identifying differences in longissimus muscle area in steers prior to slaughter and suggest caution in making breeding or management decisions from longissimus muscle estimates generated from this technology until additional progress in made in equipment and expertise.

Table 1. Description of steers used in Experiment 1 and Experiment 2.

	Experiment 1 (n=315)				Experiment 2 (n=137)			
Parameter	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum
Final weight[a], kg	502.2	36.2	412.9	601.5	528.9	37.4	500.0	612.9
Carcass weight, kg	331.2	25.2	269.5	391.1	344.0	25.8	276.8	404.3
Fat thickness (FT), mm	13.8	4.5	3.1	29.5	13.7	4.8	3.1	30.5
AFT[b], mm					14.4	4.5	5.1	29.5
UFT, mm	13.1	3.7	4.3	31.0	13.0	3.8	5.1	27.4
SFT, mm					13.2	3.6	5.1	25.4
Longissimus muscle area[c] (LMA), cm^2	78.4	8.0	58.7	103.9	86.4	9.6	68.4	121.3
TLMA[d], cm^2	81.4	8.3	57.8	110.5				
ULMA1[e], cm^2					83.6	8.4	61.3	106.3
ULMA2, cm^2	75.8	10.5	39.8	107.6	83.2	8.3	61.8	105.1
SLMA[f], cm^2					91.9	9.7	71.0	121.9
WLMA[g], cm^2	71.4	5.3	58.7	85.5	82.7	5.9	70.4	95.9

[a]Final weight is body weight shrunk 4%.
[b]AFT, UFT and SFT are adjusted, ultrasound and subjective FT, respectively.
[c]Measured using a standard dot grid with ten dots per 6.45 cm^2.
[d]Longissimus muscle area digitized from acetate tracings, n=199.
[e]ULMA1 and ULMA2 are ultrasound LMA for technicians A and B, respectively.
[f]SLMA is subjective LMA.
[g]WLMA is .156 x final weight (Boggs and Merkle, 1990).

Table 2. Fat thickness and longissimus muscle area residuals (ultrasonic and visual estimates minus carcass values) for Experiment 1 and Experiment 2.

	Experiment 1 (n=315)				Experiment 2 (n=137)			
Parameter	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum
Fat thickness, (FT), mm								
RUFT[a], mm	-0.7	2.6	-10.4	5.3	-0.8	2.8	-8.1	6.1
RSFT[b], mm					-1.3	3.7	-13.0	9.7
Longissimus muscle area,[c] (LMA) cm^2								
RULMA1[d], cm^2					-2.8	7.8	-23.1	15.6
RULMA2, cm^2	-2.6	10.1	-31.1	34.0	-3.2	7.8	-27.0	15.9
RUTLMA[e], cm^2	-1.0	10.2	-28.6	31.2				
RSLMA[f], cm^2					5.5	8.5	-20.0	24.5
RWLMA[g], cm^2	-7.0	6.9	-27.8	10.1	-3.7	8.5	-28.2	17.8
RWTLMA[h], cm^2	-8.4	7.4	-30.2	7.6				

[a] Ultrasonic fat thickness minus FT.
[b] Subjective fat thickness minus adjusted carcass fat thickness.
[c] Measured using a standard dot grid with ten dots per 6.45 cm^2.
[d] RULMA1 and RULMA2 are ultrasonic muscle area minus LMA for technician A and B, respectively.
[e] Ultrasonic muscle area minus muscle area determined from acetate tracings, n=199.
[f] Subjective estimates of longissimus muscle area minus LMA.
[g] RWLMA is .156xfinal weight minus LMA.
[h] RWTLMA is .156xfinal weight minus longissimus area determined from acetate tracings.

Table 3. Correlations of various estimates of fat thickness and longissimus muscle area in Experiment 1.

Item[a]	UFT	LMA	TLMA	ULMA	WLMA
FT	.81[b]	-.17	-.15	.09	.21
UFT		-.07	-.05	.13	.23
LMA			.89	.43	.53
TLMA				.20	.47
ULMA					.42

[a]For description of symbols see Table 1.
[b]If r>.11 then p<.05; if r>.15 then p<.01.

Table 4. Cumulative frequency distribution (%) of carcass fat thickness measurement error in Experiment 1.

Range of absolute residual, mm	All data	Fat thickness, mm	
		<12.7	>12.7
RUFT[a]			
0-2.54	74	82	67
0-5.08	92	97	88
0-7.62	99	100	98
0-10.16	100	100	99

[a]Ultrasonic fat thickness minus carcass fat thickness.

Table 5. Cumulative frequency distribution (%) of carcass longissimus muscle area measurement error in Experiment 1.

Range of absolute residual, cm^2	Comparison[a]			
	RULMA	RUTLMA	RWLMA	RWTLMA
0- 6.45	47	55	45	37
0-12.90	79	81	81	76
0-19.35	94	94	96	92

[a]For description of symbols see Table 2.

Table 6. Correlations of various estimates of fat thickness and longissimus muscle area in Experiment 2.

Item[a]	AFT	UFT	SFT	LMA	ULMA1	ULMA2	SLMA	WLMA
FT	.96[b]	.82	.56	-.29	.04	-.02	-.04	.05
AFT		.81	.60	-.35	.00	-.05	-.12	.04
UFT			.52	-.25	.01	-.13	-.01	.07
SFT				-.23	.00	-.09	-.06	.18
LMA					.63	.63	.61	.48
ULMA1						.71	.37	.22
ULMA2							.33	.32
SLMA								.63

[a]For description of symbols see Table 1.
[b]If $r>.17$ then $p<.05$; if $r>.23$ then $p<.01$.

Table 7. Cumulative frequency distribution (%) of carcass fat thickness measurement error in Experiment 2 for ultrasonic and subjective estimates.

Range of absolute residual, mm	All data	Fat thickness, mm <12.7	Fat thickness, mm >12.7
RUFT[a]			
0-2.54	62	76	51
0-5.08	95	95	95
0-7.62	99	100	99
RSFT[b]			
0-2.54	55	63	49
0-5.08	82	92	75
0-7.62	93	98	89

[a]Ultrasonic fat thickness minus carcass fat thickness.
[b]Subjective fat thickness minus adjusted carcass fat thickness.

Table 8. Cumulative frequency distribution (%) of carcass longissimus muscle area measurement error in Experiment 2.

Range of absolute residual, cm^2	All data	Longissimus muscle area, cm^2 <77	77-96	>96
RULMA1[a]				
0- 6.45	58	62	61	35
0-12.90	85	86	88	75
0-19.35	99	100	99	95
RULMA2				
0- 6.45	51	57	54	30
0-12.90	88	90	93	60
0-19.35	99	100	100	90
RSLMA				
0- 6.45	42	29	43	50
0-12.90	80	81	81	75
0-19.35	96	86	99	96
RWLMA				
0- 6.45	61	76	68	10
0-12.90	86	90	96	35
0-19.35	94	100	100	60

[a]For description of symbols see Table 2.

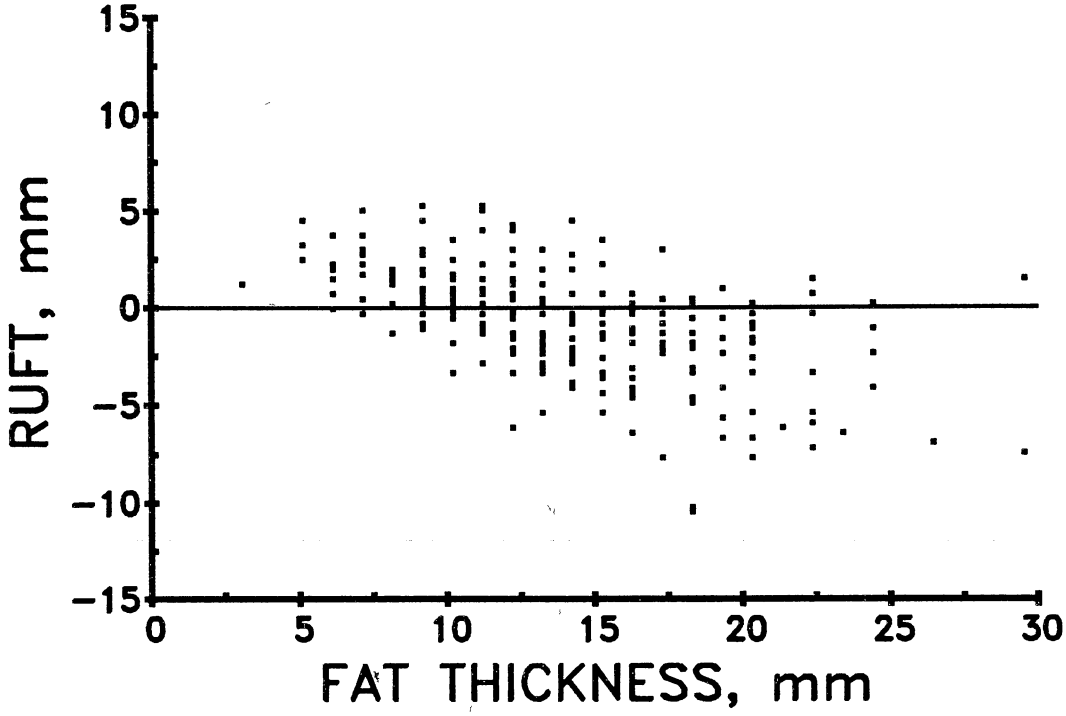

Figure 1. The relationship of residual (ultrasound minus carcass) fat thickness (RUFT) and carcass fat thickness of feedlot steers in Experiment 1.

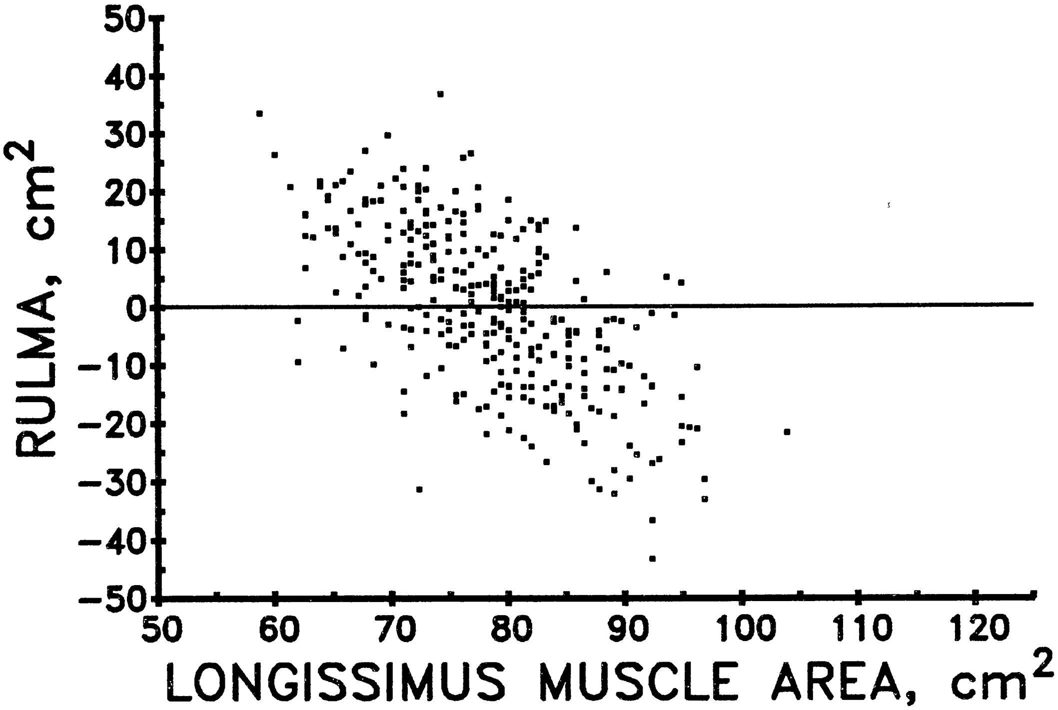

Figure 2. The relationship of residual (ultrasound minus carcass) longissimus muscle area (RULMA) and carcass longissimus muscle area of feedlot steers in Experiment 1.

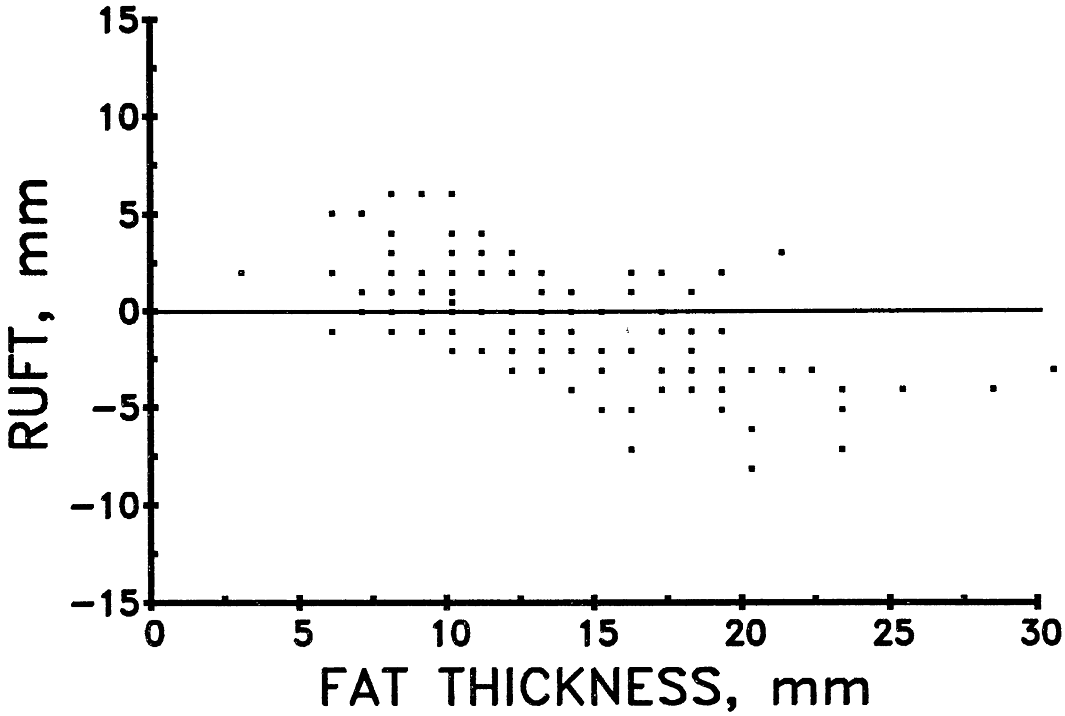

Figure 3. The relationship of residual (ultrasound minus carcass) fat thickness (RUFT) and carcass fat thickness of feedlot steers in Experiment 2.

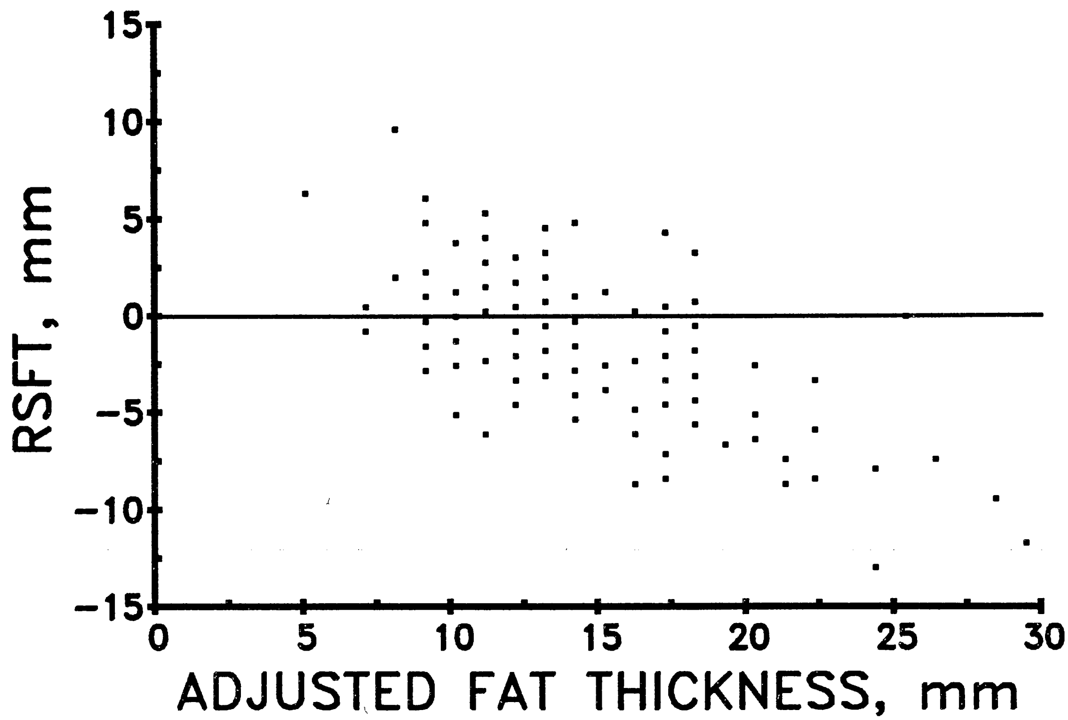

Figure 4. The relationship of residual (subjective minus carcass) fat thickness (RSFT) and carcass adjusted fat thickness of feedlot steers in Experiment 2.

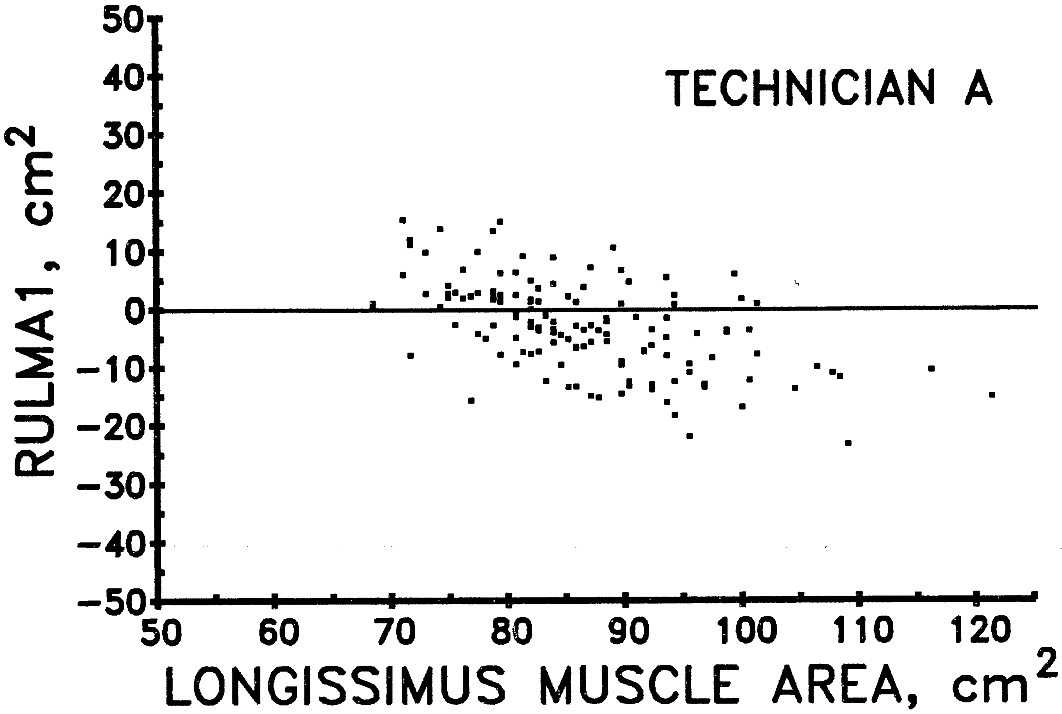

Figure 5. The relationship of residual (ultrasound minus carcass) longissimus muscle area (RULMA1) and carcass longissimus muscle area of feedlot steers for technician A in Experiment 2.

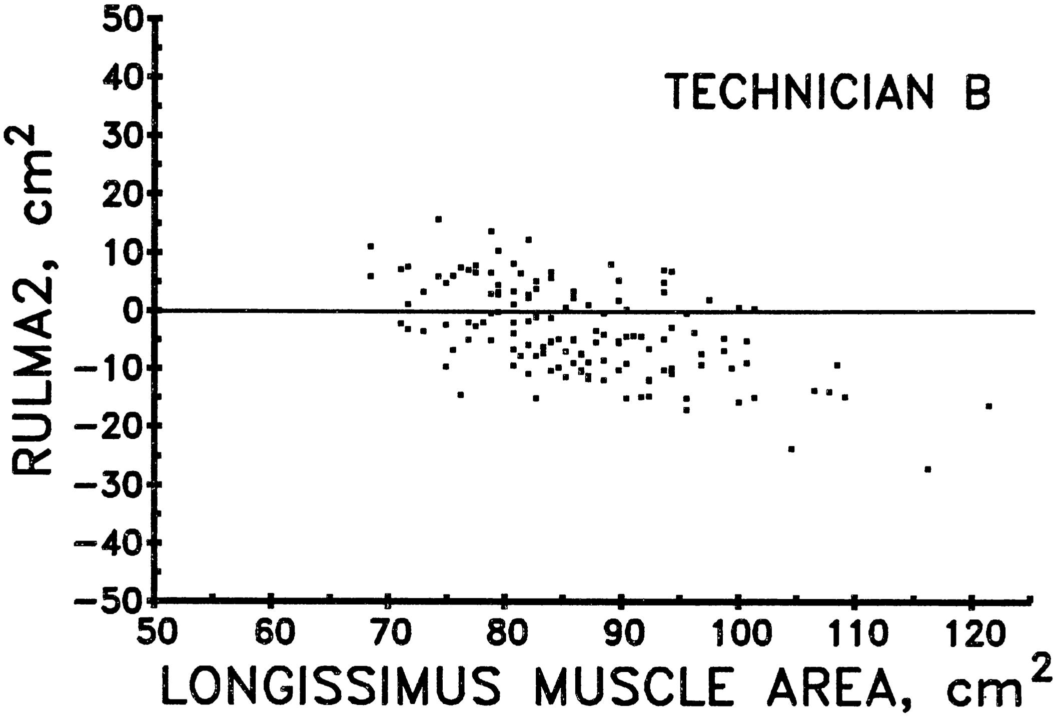

Figure 6. The relationship of residual (ultrasound minus carcass) longissimus muscle area (RULMA2) and carcass longissimus muscle area of feedlot steers for technician B in Experiment 2.

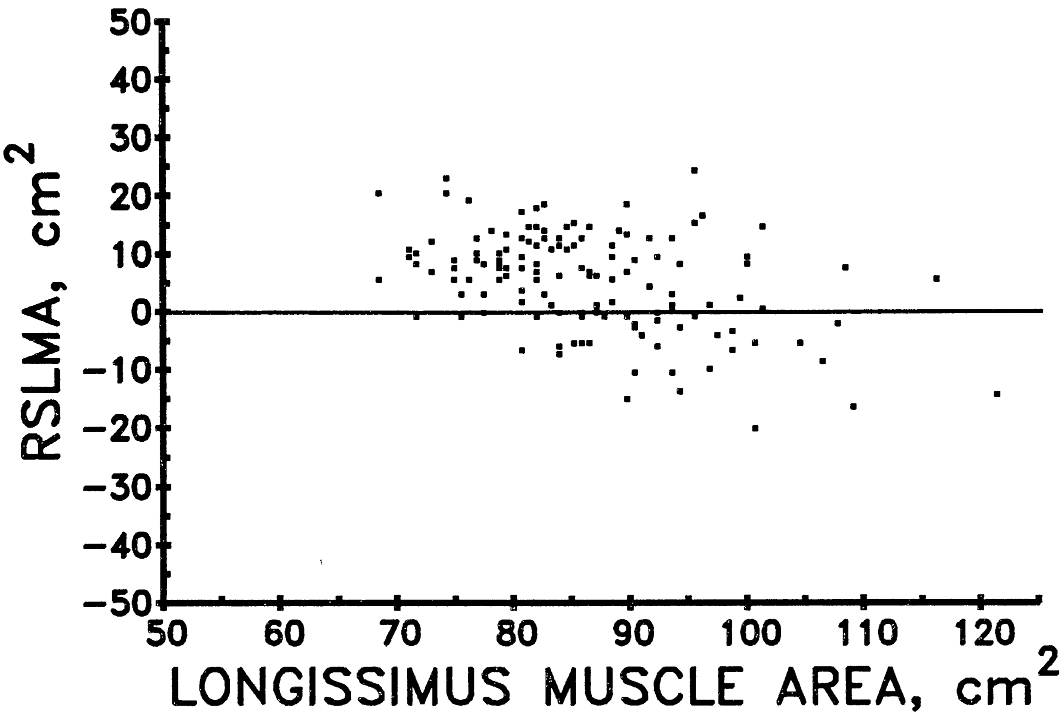

Figure 7. The relationship of residual (subjective minus carcass) longissimus muscle area (RSLMA) and carcass longissimus muscle area of feedlot steers in Experiment 2.

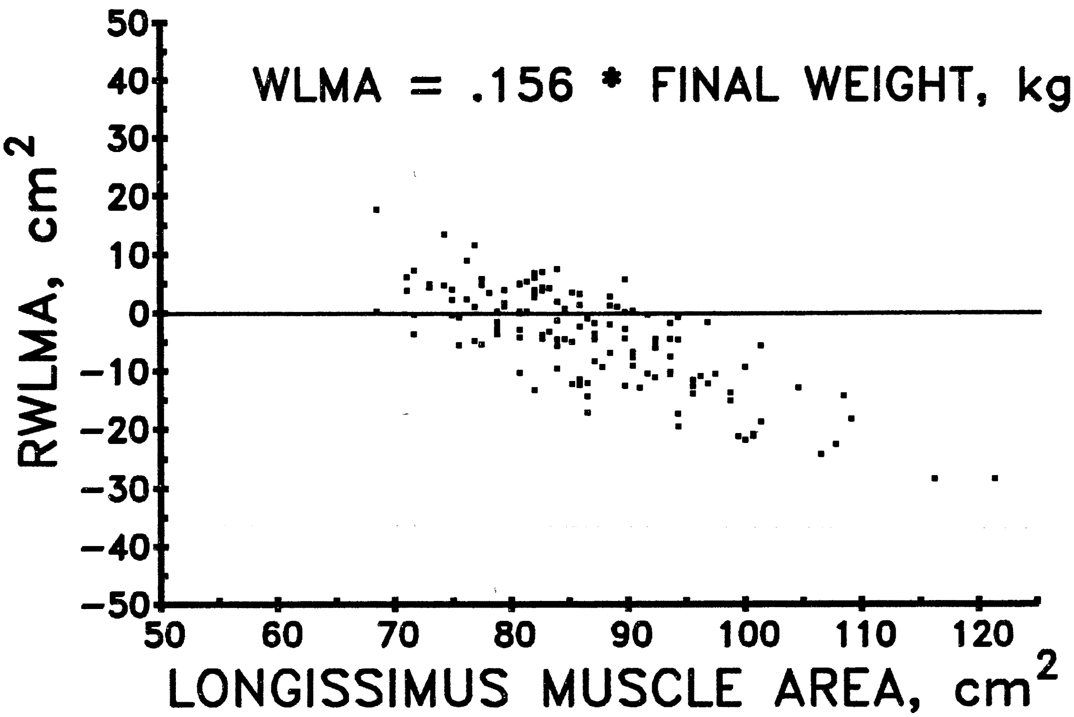

Figure 8. The relationship of residual (WLMA minus carcass) longissimus muscle area (RWLMA) and carcass longissimus muscle area of feedlot steers in Experiment 2.

CHAPTER IV

ULTRASOUND AND VISUAL APPRAISAL AS METHODS TO ACCOUNT FOR VARIATION IN GROWTH AND CARCASS PARAMETERS IN FEEDLOT STEERS

Abstract

Yearling steers of various breed types and initial weights (258 to 372 kg) were used to determine the effectiveness of initial ultrasound measurements and live animal evaluation in explaining variation in feedlot performance over 135 and 149 d feeding periods. Experienced evaluators subjectively scored each steer for condition, capacity, muscle, frame and quality. Fat thickness and longissimus muscle area were determined from ultrasonic images obtained at the initiation of the feeding trial. Initial weight, breed type, ultrasound and visual appraisal were used to estimate average daily gain, fat thickness, longissimus muscle area, marbling and yield grade. In general, observed variation in rate of gain and carcass marbling were difficult to explain by the initial measurements used in this study. Greater success was obtained in predicting quantitative carcass parameters, with initial weight, breed and ultrasonic variables best

describing fat thickness and yield grade (R^2 of .51 and .60, respectively). Regression analysis was conducted on growth patterns of fat thickness and longissimus muscle area as measured with ultrasound. Significant breed-type effects were evident for fat thickness, but not for longissimus muscle area. Linear models described growth curves of fat thickness with greater accuracy than exponential or allometric equations. These result suggest that ultrasonic measurements of initial fat thickness and longissimus muscle area are useful to explain variation in carcass fat thickness and cutability. Also, ultrasound can be used to monitor changes in fat deposition and determine optimal slaughter time.

Introduction

As the beef industry moves toward the production of cattle to meet target specifications, more accurate prediction of feedlot cattle performance and carcass merit is needed. Accurate estimates of these characteristics would allow producers to sort cattle into groups which can be fed to simultaneously reach a relatively homogeneous slaughter endpoint, ultimately improving feedlot profitability and industry efficiency. Sorting based on subjective evaluation has met with limited success (Strasia et al., 1989); however, recent studies suggest that sorting incoming feedlot cattle by hip height and ultrasonic fat thickness measurements permits the grouping of cattle for uniform feeding and marketing and reduces time on feed (Houghton, 1988). In this Kansas study, steers were of similar breed and origin. By industry standards, uniformity of incoming feedlot steers is the exception rather than the rule. Therefore, the objective of this study was to determine if variation in ultrasonic measurements of fat thickness and longissimus muscle area could be used to account for and predict differences in rate of gain and carcass parameters of typical feedlot steers. Additionally, serial ultrasonic measurements were used to develop growth curves of fat thickness and longissimus muscle area for feedlot steers.

Materials and Methods

The 96 yearling steers used in this experiment were part of a feeding trial conducted to determine the effects of virginiamycin, a feed-grade antibiotic, on performance and carcass characteristics of feedlot steers. Steers were of various breed type and crosses thereof. A total of 320 steers were used in the feeding trial. Upon arrival at the feedlot, cattle were individually weighed, then divided into 10 equal blocks of similar weight. Within each weight block, steers were randomly assigned to one of four treatments (four pens of eight steers). A trained evaluator subjectively classified the steers into three breed-type categories (Table 1) and breed type was equalized across treatment. Three of the ten weight blocks were used in this study with mean initial weights of 272, 331 and 358 kg. Initial fat thickness and longissimus muscle area were determined for each steer between the twelfth and thirteenth rib using real-time ultrasound[1]. After steers were allocated to pens, two trained evaluators visually appraised each animal for the following parameters: frame, muscle, condition, body capacity and quality. Scores for all parameters were on a scale from one to nine; the mean for the two evaluators' scores was used for analysis. Frame scores represented an estimate of hip height in relation to age. Muscle score was an estimate of thickness and muscle volume (1=very light, 9=very heavy), condition was an assessment of fatness (1=very thin, 9=very fat), and capacity was a subjective evaluation of potential feed consumption. Quality scores were based on phenotypic assessment of conformation and general thriftiness and were estimates of feedlot performance and carcass merit. Ultrasound measurements were inadvertently missed on one steer initially and a second steer was removed during the feeding period due to injury; therefore, performance and carcass measurements were available for 94 head. Initial weights were those obtained off the truck upon arrival and were not shrunk. Steers were weighed full every 28 d after initiation of the feeding trial. Final live weights were taken at the end of the feeding trial, 5 d prior to

[1]Aloka 210DX real-time diagnostic unit equipped with a 3 MHz transducer.

slaughter, in compliance with FDA mandated drug-withdrawal regulations. Body weight was calculated by multiplying intermediate and final weights by .96. Carcass adjusted final weight was calculated by dividing hot carcass weight by .63; these final weights were used to calculate average daily gain. Additional ultrasonic measurements were obtained every 28 and 56 d after initiation of the feeding trial for fat thickness and longissimus muscle area, respectively, as well as 5 d prior to slaughter for all steers. All animals were slaughtered at a commercial packing plant, and approximately 24 h postmortem, complete USDA yield and quality data were recorded.

Regression analysis was conducted to determine the amount of variation in gain and carcass traits that could be explained using initial measures. Because the cattle were fed for differing lengths of time, analysis was conducted by slaughter group. Steers in the two heavier weight blocks were fed a total of 135 d (KILL 1) and those in the lightest weight block (272 kg initial weight) were fed for 149 d (KILL 2). Step-wise linear regression (SAS, 1987) was conducted to determine the amount of variation accounted for in the following parameters by initial measures: average daily gain (ADG), fat thickness (FT), longissimus muscle area (LMA), yield grade (YG) and marbling (MARB). Included in the models were all combinations of the following sets of variables: initial weight and the class variable breed (WB), subjective scores (S) and ultrasonic measurements of fat thickness and longissimus muscle area (U). Due to limited degrees of freedom, variables and only their two-way interactions were included. The probability at which independent variables were entered and removed from the model was set at 15%.

Growth patterns of fat thickness and longissimus muscle area as measured ultrasonically were analyzed in models containing linear, quadratic and cubic regression coefficients for time or shrunk live weight. In these fat thickness models, initial ultrasonic fat thickness and its interaction with time or weight terms were included only as independent variables. Similarly, in longissimus muscle area models, initial ultrasonic longissimus muscle area and its interaction with time or weight terms were only included as independent variables. Preliminary analysis showed a significant breed-type effect for fat thickness; therefore, that analysis was conducted within breed-type. The models adopted were those including all terms of a given order up to and including those significant ($p<.10$) of highest order. Analysis of ultrasonic measures over time were also conducted using the exponential function of time (Ae^{kt}), where A is estimated initial ultrasonic measure, k is rate constant and t is days on feed. In addition, the allometric function of weight ($A \cdot BW^{b}$) was fit to ultrasonic measures, where A and b are model parameters (Huxley, 1924).

Results and Discussion

The proportion of variation explained by each set of variables for the parameters of interest in this study are presented in Table 2. Observed variation in rate of gain was difficult to explain and varied across slaughter group. As a set of independent variables, subjective measures (S) explained the most variation in average daily gain among steers in slaughter group one (R^2=.26); however, they offered no contribution ($p>.15$) for gain prediction in slaughter group two. When ultrasonic measures were used with initial weight and breed (WBU), they explained more variation in gain (36%) than WBS (19%) in Kill 1, but similar amounts in Kill 2 (20 and 22%, respectively). When all variables were used in combination (WBSU) 44 and 29% of the variation in average daily gain could be explained in Kill 1 and Kill 2 steers, respectively.

Models explained a greater proportion of the variation in carcass parameters than in feedlot performance. Among steers in Kill 1, initial ultrasound measurements (U) predicted about half the variation in carcass fat thickness (R^2=.51). No other model or combinations thereof improved the fit beyond that obtained using ultrasonic measurements of fat thickness and longissimus area. Similar relationships were observed with numerical yield grade (R^2=.43) and reflect the magnitude with which fat thickness influences calculated yield grade values. Using all available information (WBUS), 64% of the variation in yield grade was accounted for in Kill 1 steers. Results for Kill 2 showed slightly better predictions for models including subjective scores for fat thickness and yield grade. Caution is warranted when making inferences in regard to results obtained from Kill 2 steers due to limited observations (n=31) in that data set.

Among steers in Kill 1, WB, S and U explained 20, 26 and 28% of the variation in longissimus muscle area, respectively, and their combination (WBUS) improved the fit (R^2=.41). There was relatively little improvement in R^2 when S was added to WBU, indicating that subjective measures were of limited value when initial weight, breed and ultrasound measurements were known. In contrast, subjective scores improved the fit among Kill 2 steers when used in combination with WB (R^2=.62).

Of all carcass traits, marbling was the most difficult to predict by initial measurements. Among steers in Kill 1, subjective scores proved the most useful as independent sources of information, but accounted for little variation (R^2=.15); the combination of WB and S explained the greatest proportion (36%) of variation in marbling. Ultrasonic measures did not improve the fit when added to WBS, indicating that ultrasonic fat thickness and longissimus muscle area measurements are of limited value for marbling and quality grade prediction when breed, initial weight and subjective scores are known. Models accounted for less than 25% of the variation in marbling for Kill 2 steers.

These results indicate that initial ultrasonic measurements of fat thickness and longissimus area are useful in accounting for variation in carcass fat thickness. Subjective scores, initial weight and breed-type appear to be useful in some instances to account for variation in longissimus muscle area. Coupling ultrasound measures with initial weight and breed-type to predict yield grade could be of benefit to the cattle feeder in identifying individuals or groups of cattle that need to be managed differently to avoid problems in carcass cutability.

To test this assertion, parameters for relationships of interest were estimated using significant variables from the step-wise regression analysis. Relationships were developed only for Kill 1 steers due to the limitation posed by insufficient observations in Kill 2. Figure 1 illustrates predicted average daily gain, by breed-type, for steers with mean initial weights of 331 and 358 kg. These equations, developed from initial weight and ultrasonic fat thickness measurements, explained 29, 82 and 33% of the variation in gain for BRIT, CONT and BRAH steers, respectively. Initial fat thickness had little effect on predicted rate of gain for lighter BRIT steers. However, among heavier BRIT steers, increased gains were associated with greater initial fat thickness. The same pattern is noted with heavier, thinner CONT steers, suggesting that either animals that grew well prior to entering the feedlot retain an advantage in rate of gain over thinner steers of similar initial weight, or that thinner steers of comparable initial weights never fully compensate from previous nutritional deficiencies. Accurate inference is difficult because the opposite was observed for predicted gain of lighter weight CONT steers, with less initial fat associated with faster gain. This indicates compensatory gain potential for thinner cattle. This is further supported by the fact that, regardless of initial weight, BRAH steers with less initial fat thickness had higher gains than fatter cattle.

Carcass fat thickness for Kill 1 steers was predicted best by initial ultrasonic fat thickness and longissimus muscle area measurements (Figure 2). Steers with greater initial fat thickness produced carcasses with correspondingly more external fat. In addition, steers that scanned larger longissimus muscle areas at the initiation of the feeding period had an increased slope of predicted carcass fat thickness compared to those with less muscle area. This is likely a reflection of the stage of maturity an animal goes on feed rather than a function of absolute dimension, with cattle of larger longissimus muscle area at a greater proportion of their mature size. Therefore, more of their energy intake would be deposited as fat rather than for lean tissue growth. For an average muscled steer, predicted fat thickness increased 1.83 mm per mm increase in initial fat thickness.

Predicted carcass yield grade for BRIT steers varying in initial weight, fat thickness and longissimus muscle area is illustrated in Figure 3. Initial fat thickness had little effect on yield grade for lighter steers with small longissimus muscle areas; however, among steers with larger longissimus muscle areas of comparable initial weight, numerical yield grade increased rapidly with increased initial fat thickness. Again, larger longissimus muscle area may reflect differences in maturity within this group of steers. Among the heavier steers, smaller longissimus muscle area is associated with higher numerical yield grades; however, predicted cutability decreased with increased initial fat thickness, regardless of initial longissimus muscle size. Figure 4 shows the effect initial weight and ultrasound measurements on yield grade for CONT steers. Increased initial fat thickness was associated with higher predicted yield grades for both light and heavy steers scanning smaller initial longissimus muscle areas. In contrast, a decrease in predicted yield grade is noted with increased initial fat thickness for steers scanning larger longissimus muscle areas than the mean. Yield grade appears to be influenced more by initial muscle area for CONT steers of greater fat thickness. But, because the range of initial fat thickness measurements among CONT steers was not large, differences in previous nutritional status can greatly influence the interpretation of these findings.

Figure 5 illustrates the relationship between subjective condition scores and marbling for steers of British breed-type. Although there is an apparent relationship between marbling and condition score, only 18% of the variation was accounted for by this independent variable. Subjective estimates were not significant ($p>.30$) for predicting marbling in CONT and BRAH steers.

The growth pattern of fat thickness was estimated by regression equations for serial ultrasound measures of fat thickness (Table 3). Linear models were of highest order of significance for British (BRIT) and Brahman (BRAH) steers when ultrasonic fat thickness measurements were regressed on time. The best fit was obtained among BRIT steers (R^2=.79), and the worst among BRAH steers (R^2=.67), suggesting greater variation in subcutaneous fat thickness deposition over time among steers of Brahman breeding. Models including cubic terms were significant for CONT steers and accounted for 72% of the variation in observed ultrasonic fat thickness measurements. For fat thickness described by the exponential function of time, models resulted in smaller R^2 values and greater standard errors than the linear models. Brethour (1988) also noted breed-type differences in fat thickness growth rate; however, he found exponential models more effective in reducing residual variance than linear models.

Using linear models, growth curves for fat thickness were generated for each breed-type (Figure 6). Initial ultrasonic fat thickness values used in the equations were plus or minus one SD from breed-type means. Steers with greater initial fat thickness had more measurable fat at all times. British steers had greater fat thickness than BRAH steers, and for steers with one SD initial fat thickness above the mean, BRAH were fatter than CONT over all times. Continental steers with initial fat thickness greater than the mean exhibited little fat deposition during the first 28 d of the feeding period; those with less initial fat deposited little from day 28 to day 84. However, their rate of deposition increased later.

Only first order terms and their interactions were significant ($p<.10$) when serial ultrasonic fat thickness measures were regressed on body weight for steers of BRIT and CONT breed-type. Initial body weight was not included in the linear model for steers of BRAH breeding ($p>.10$); therefore, fat deposition was related only to body weight for BRAH steers. Other than for BRIT steers, models developed from initial fat thickness and body weight were less precise in accounting for variation in serial ultrasound fat measurements than from those using initial fat thickness and time. Additionally, when the allometric equation (Huxley, 1924) was used to describe ultrasonic fat thickness and body weight relationships, results similar to those obtained using the exponential function of time were noted as R^2 were less than those from linear models. The growth pattern of fat thickness as a function of body weight is presented in Figure 7. At comparable weights, BRIT steers with greater initial fat thickness deposited more fat as a function of body weight. CONT breed-type steers with small initial fat thickness had relatively little subcutaneous fat deposition suggesting that these cattle were of larger mature size or of slower maturity breeding.

Longissimus muscle growth was also analyzed to develop best fit equations (Table 4). In a preliminary analysis of the data breed-type effects were not significant; therefore, ultrasonic longissimus area data were pooled across breed-type. Only first order terms and their interactions were significant ($p<.10$) when serial ultrasonic longissimus muscle area measures were regressed on time, but quadratic terms were significant when body weight was the independent variable. As noted for fat thickness, the exponential and allometric models generated for longissimus muscle area growth resulted in greater standard errors of prediction than the linear models.

Figure 8 illustrates the growth of longissimus muscle area over time. The rate of longissimus muscle area growth is greater for those steers with smaller initial muscle areas and the areas of each group converge over time. When ultrasonic longissimus muscle area is regressed on body weight (Figure 9) a similar phenomenon is noted, suggesting the tendency for initial environmental effects on longissimus muscle area to disappear as maturity increases and muscles approach mature size. In a similar study, Matissino et al. (1984) found significant breed differences among cattle. They reported R^2 ranging from .63 to .79 for the linear fit of ultrasonic longissimus muscle measurements in relation to live weight. In general, the growth patterns of subcutaneous fat thickness and longissimus muscle area reported in this experiment are in agreement with growth studies (Berg and Butterfield, 1976) and suggest that ultrasound could be of benefit in monitoring the composition of growth in live animals.

Implications

Results of this study demonstrate that ultrasonic measurements of fat thickness and longissimus muscle area made at the beginning of a feeding period are of limited use for explaining variation in rate of gain and carcass marbling score for cattle fed similar times. Greater success is obtained when these measurements are used to predict fat thickness and carcass yield grade. Significant breed-type differences in subcutaneous fat deposition exist. Linear models accounted for much of the variation in serial ultrasound measurements, suggesting that ultrasound could be used to monitor composition of growth in research studies. Because ultrasonic measurements of fat thickness are beneficial in accounting for variation in carcass fat thickness, models of fat deposition may prove useful in sorting cattle into different lengths of feeding period groups to target carcass specifications for cutability.

Further research is warranted to develop criterion for sorting feedlot cattle using ultrasound measurements and visual indicators to maximize the economic benefits associated with this process.

Table 1. Mean and standard deviation of initial measurements and carcass traits of steers by slaughter group and breed-type[a].

	Kill 1 (n=63)			Kill 2 (n=31)		
Parameter	BRIT(n=29)	CONT(n=19)	BRAH(n=15)	BRIT(n=9)	CONT(n=4)	BRAH(n=18)
Initial weight, kg	346(16.3)	346(15.3)	340(14.4)	272(7.1)	272(6.0)	275(5.0)
Initial fat thickness, mm	5.0(1.5)	4.4(1.2)	4.9(1.8)	3.5(1.2)	4.1(1.2)	3.9(1.4)
Initial longissimus muscle area, cm^2	43.8(4.6)	45.1(5.7)	43.9(4.4)	41.1(2.5)	40.4(4.3)	39.0(2.9)
Frame	3.8(.93)	5.0(.75)	4.3(1.0)	3.8(.97)	5.0(.82)	4.8(.73)
Muscle	4.1(.58)	4.1(1.0)	3.7(.62)	4.1(.60)	3.8(.50)	3.8(.88)
Capacity	5.8(.56)	5.5(.84)	5.4(.99)	5.3(1.0)	5.3(1.7)	4.9(.90)
Condition	5.4(.68)	4.6(.83)	5.4(.91)	5.6(1.1)	5.5(1.0)	5.3(.59)
Quality	3.7(.76)	3.8(.90)	3.3(.62)	3.6(.53)	3.8(.96)	3.3(.83)
ADG, kg/d	1.6(.21)	1.7(.19)	1.5(.22)	1.4(.15)	1.4(.16)	1.3(.14)
Carcass fat thickness, mm	15.5(4.3)	12.4(4.1)	14.8(6.3)	11.6(3.0)	15.5(4.8)	12.1(4.9)
Carcass longissimus muslce area, cm^2	81.9(8.6)	87.5(6.8)	78.0(4.9)	77.1(5.3)	72.1(9.3)	71.6(6.5)
Yield grade	3.4(.77)	2.8(.63)	3.6(.82)	2.9(.44)	3.5(.65)	3.1(.69)
Marbling score[b]	444(83.5)	369(49.8)	425(98.4)	458(54.3)	425(26.5)	442(69.4)

[a]BRIT is British and British X British, CONT is Continental and Continental crossbred and BRAH is Brahman crossbred steers. Breed-type determined by color and conformation.
[b]Marbling score of 400=Sm^{00} (Choice -).

Table 2. Proportion of variation (R^2) in gain and carcass parameters explained using initial measurements of weight and breed-type (WB); subjective scores for frame, muscle, condition, capacity and quality (S); and ultrasonic fat thickness and longissimus muscle area (U) in models analyzed both independently and in combination with one another using step-wise regression.

	ADG		FT[a]		LMA		YG		MARB	
Model	Kill 1	Kill 2	Kill 1	Kill 2	Kill 1	Kill 2	Kill 1	Kill 2	Kill 1	Kill 2
WB	.08	.23	.11	.18	.20	.09	.13	.07	.14	.00
S	.26	.00	.21	.24	.26	.13	.27	.27	.15	.13
U	.00	.07	.51	.13	.28	.08	.43	.10	.12	.10
WBS	.19	.22	.21	.34	.35	.62	.32	.51	.36	.13
WBU	.36	.20	.51	.33	.38	.35	.60	.39	.22	.10
SU	.29	.08	.50	.26	.33	.35	.46	.34	.19	.24
WBSU	.44	.29	.50	.45	.41	.71	.64	.67	.36	.24

[a]FT is fat thickness, LMA is longissimus muscle area, YG is USDA numerical yield grade and MARB is marbling ($400=Sm^{00}$).

Table 3. Models used in growth pattern analysis of ultrasonically measured fat thickness (mm) over time (T) and as a function of body weight (BW).

	Breed-Type[a]			
Model	All	BRIT	CONT	BRAH
Time				
Linear				
intercept	.42	.22	-.18	.57
FT0[b]	.853	.926	1.018	.793
T	.0422	.0415	.3141	.0413
T^2			-.005904	
T^3			.00003100	
$FT0 \cdot T$	.00505	.00577	-.05651	.00491
$FT0 \cdot T^2$			.0012720	
$FT0 \cdot T^3$			-.000006550	
R^2	.72	.79	.72	.67
$s_{y \cdot x}$	2.19	1.95	1.99	2.49
Exponential				
A	4.453	4.710	4.317	4.265
k	.008075	.008153	.008093	.007982
R^2	.51	.52	.62	.46
$s_{y \cdot x}$	2.91	2.95	2.27	3.16
Body weight				
Linear				
intercept	-21.48	-3.74	-48.06	-6.14
FT0	4.318	-.687	10.418	
BW	.10261	.01758	.23164	.03392
BW^2	-.00009677		-.00024267	
$FT0 \cdot BW$	-.019006	.003653	-.048077	
$FT0 \cdot BW^2$	.000024580		.000056125	
R^2	.65	.77	.53	.50
$s_{y \cdot x}$	2.47	2.05	2.55	3.04
Allometric				
A	.0001716	.0000585	.0005620	.0001163
b	1.7583	1.9365	1.5477	1.8320
R^2	.50	.63	.42	.48
$s_{y \cdot x}$	2.93	2.61	2.79	3.08

[a]See Table 1 for description of breed-type.
[b]FT0 is initial ultrasonic fat thickness.

Table 4. Models used in growth pattern analysis of ultrasonically measured longissimus muscle area (cm^2) over time (T) and as a function of body weight (BW).

Model	Coefficients		
Time			
Linear		Exponential	
intercept	3.945	A	44.670
LMA0[a]	.9617	k	.003155
T	.3723		
LMA0*T	-.004785		
R^2	.79		.67
$s_{y \cdot x}$	4.84		6.02
Body weight			
Linear		Allometric	
intercept	-94.18	A	.6597
LMA0	1.7811	b	.7294
BW	.51600		
BW^2	-.00043062		
LMA0*BW	-.0060505		
$LMA0*BW^2$	.0000055903		
R^2	.82		.77
$s_{y \cdot x}$	4.52		5.0

[a]LMA0 is initial ultrasonic longissimus muscle area.

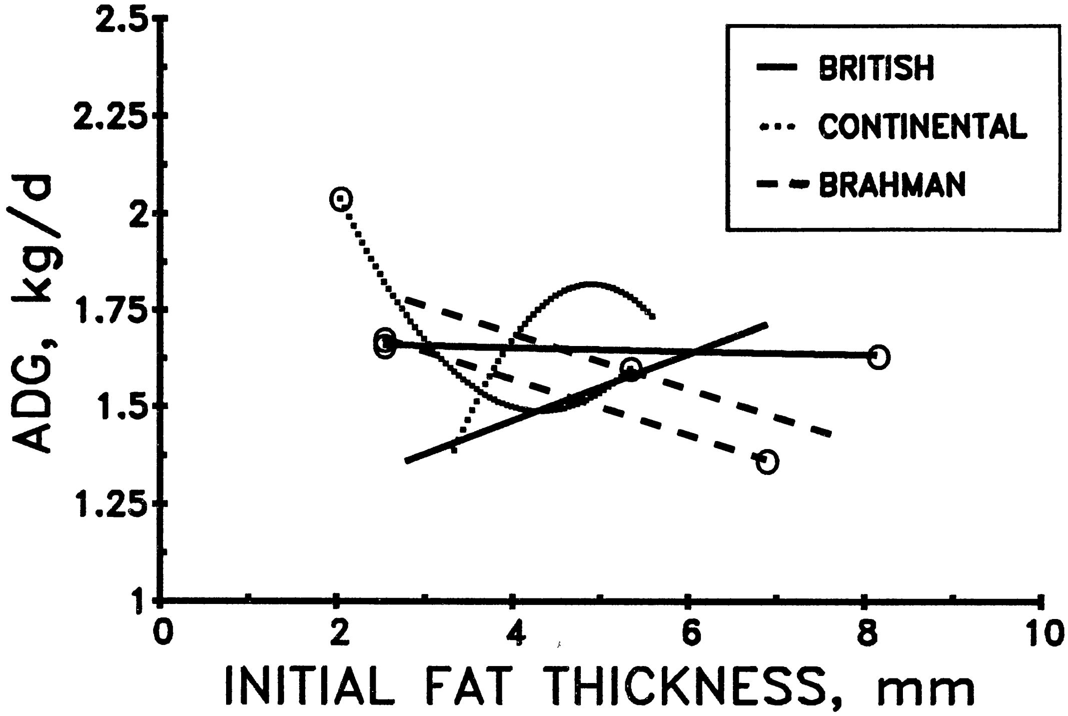

Figure 1. Predicted average daily gain (ADG) versus initial ultrasonic fat thickness for British, Continental and Brahman steers with mean initial weights of 331 and 358 kg. Lines ending with open circles represent steers with mean initial weights of 331 kg.

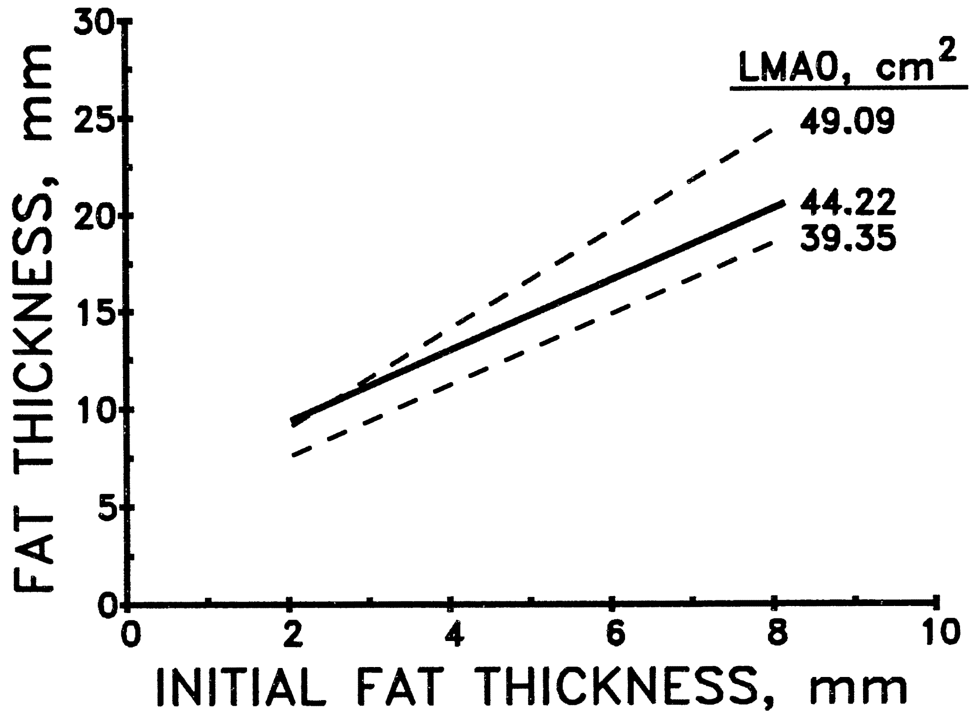

Figure 2. Predicted carcass fat thickness versus initial ultrasonic fat thickness for steers varying in initial longissimus muscle area (LMA0).

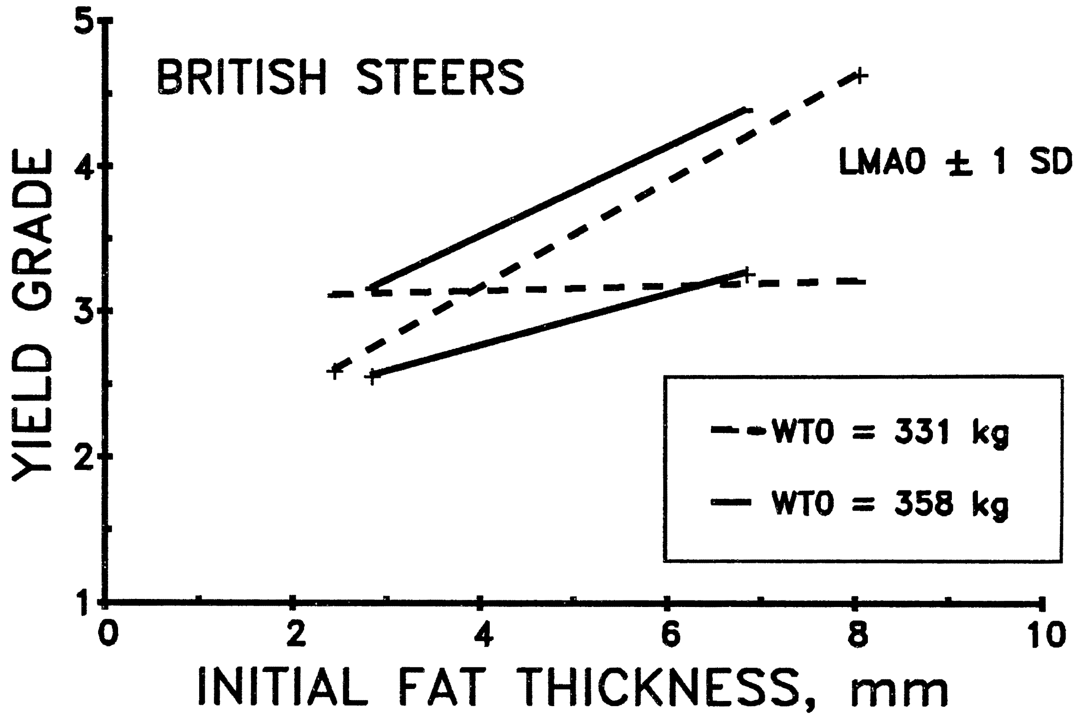

Figure 3. Predicted carcass yield grade versus initial ultrasonic fat thickness for British steers with mean initial weights of 331 and 358 kg and initial longissimus muscle areas (LMA0) of plus (+) or minus (-) one SD from mean LMA0.

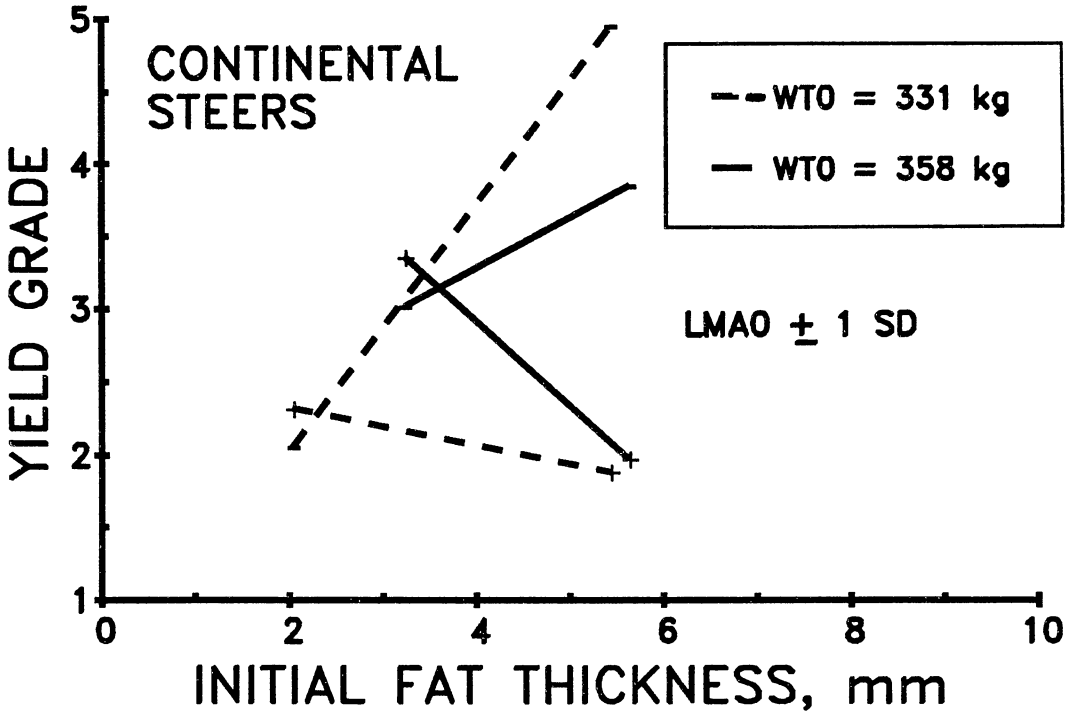

Figure 4. Predicted carcass yield grade versus initial ultrasonic fat thickness for Continental steers with mean initial weights of 331 and 358 kg and initial longissimus muscle areas (LMA0) of plus (+) or minus (-) one SD from mean LMA0.

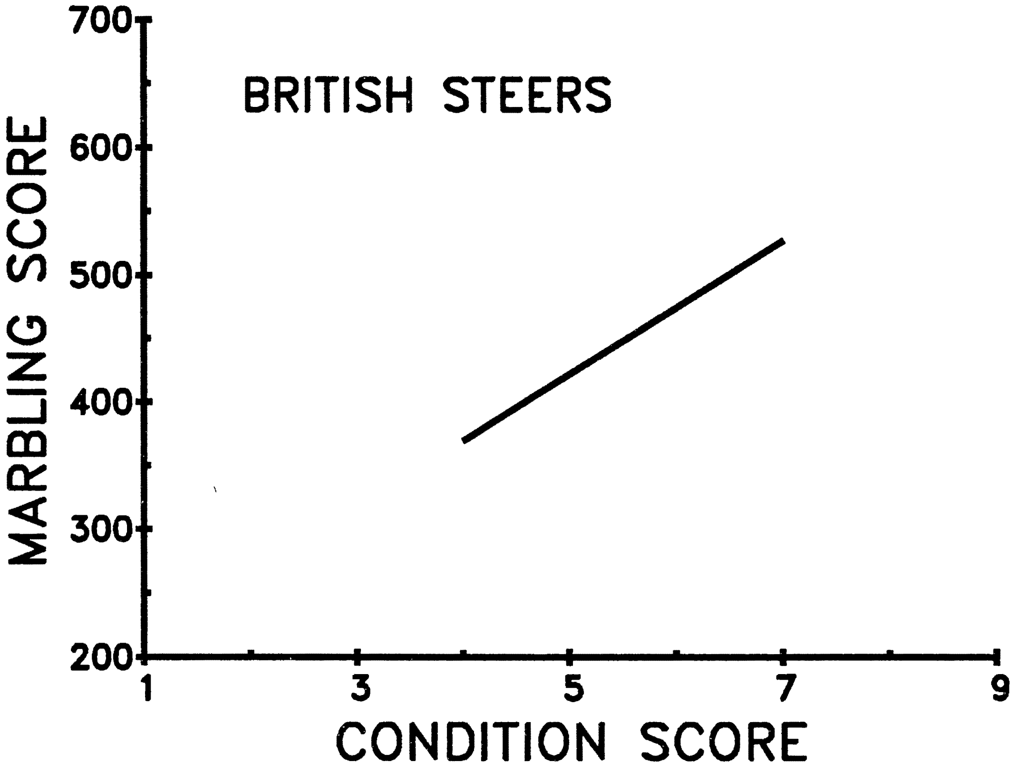

Figure 5. Predicted marbling score (400=Sm^{00}) versus condition score for British steers.

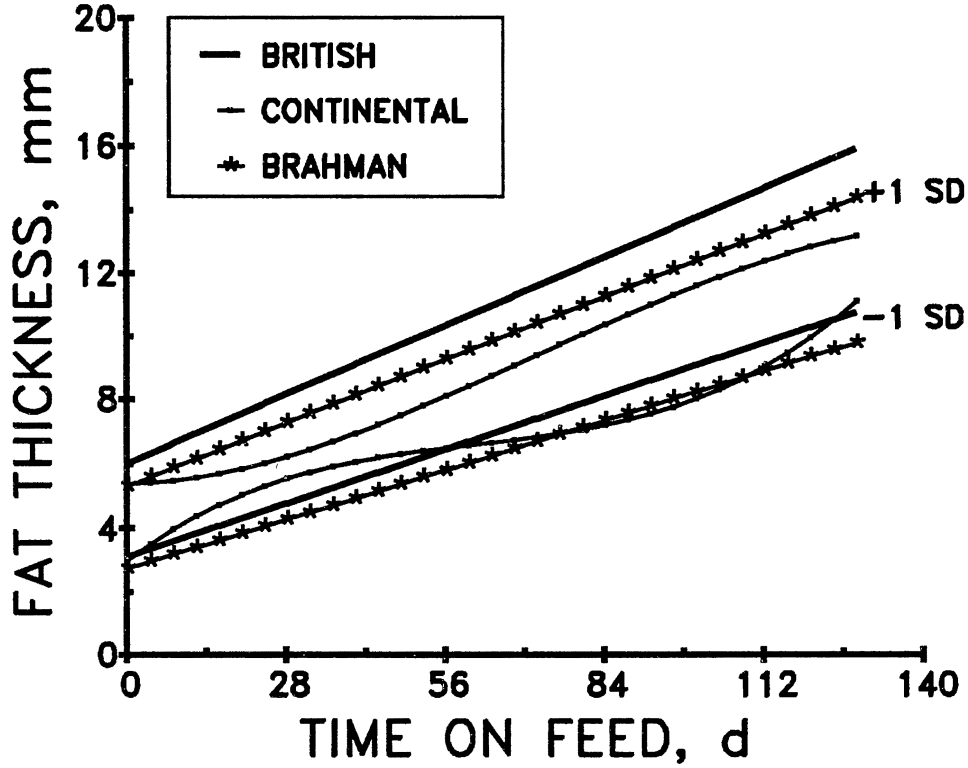

Figure 6. The growth of ultrasonic fat thickness for British, Continental and Brahman steers with initial fat thickness of plus or minus one SD from breed-type fat thickness means.

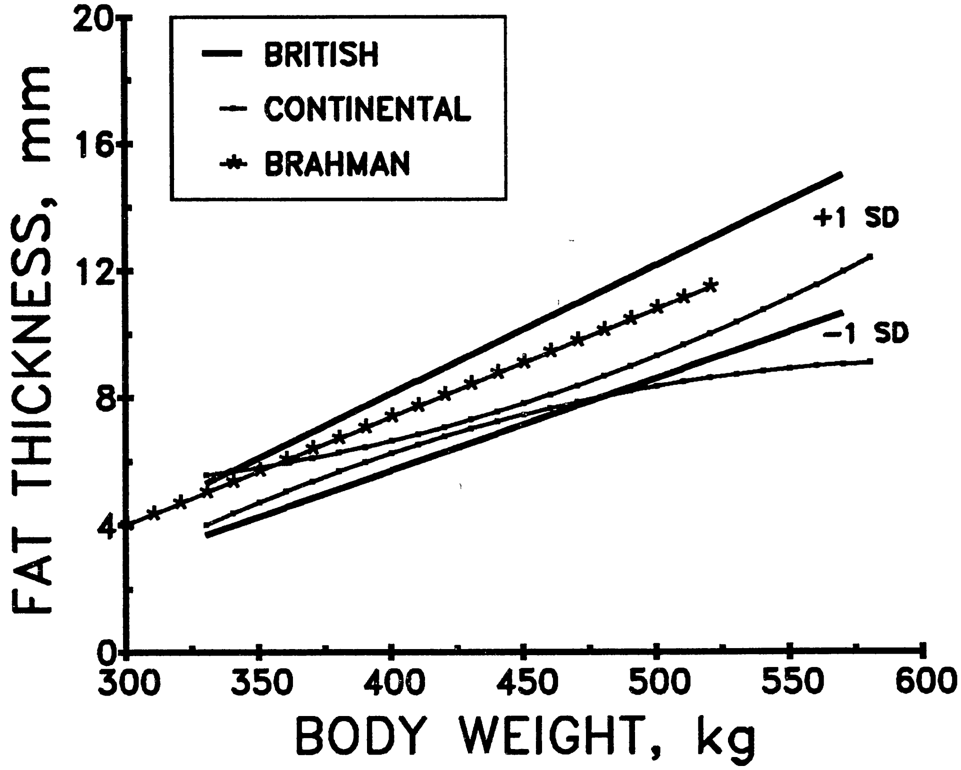

Figure 7. The relationship between ultrasonic fat thickness and body weight for British, Continental and Brahman steers with initial fat thickness of plus or minus one SD from breed-type means.

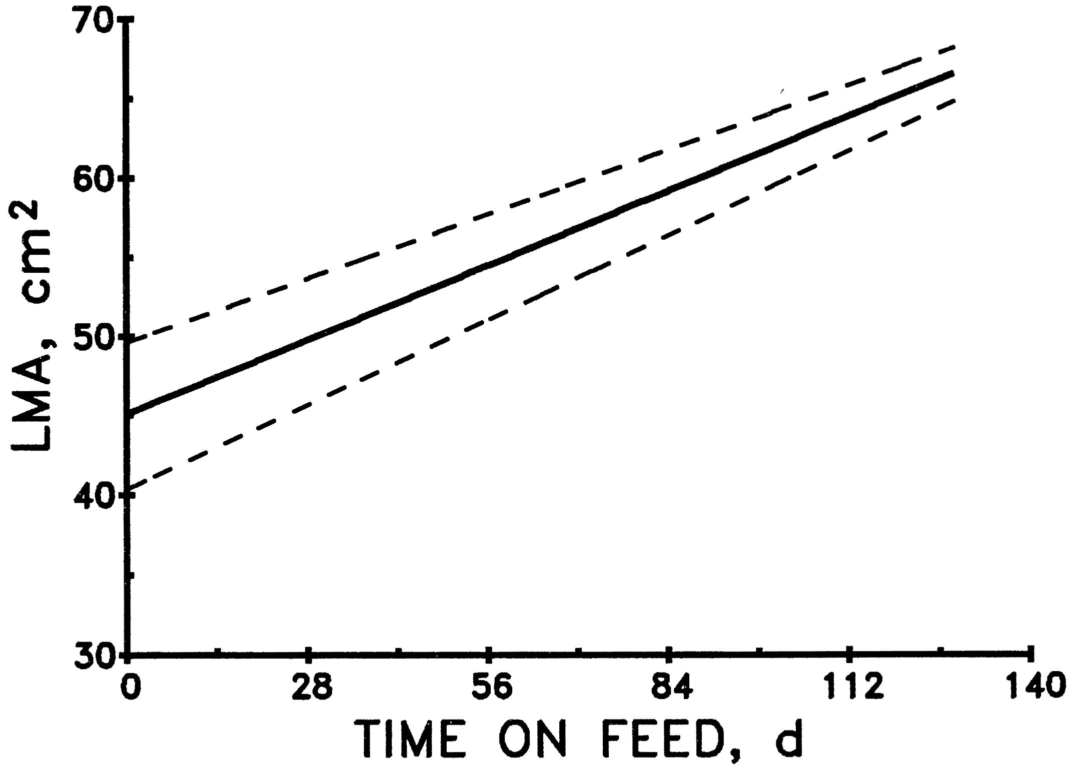

Figure 8. The growth of ultrasonic longissimus muscle area for steers varying in initial longissimus muscle area (LMA0). Dotted lines represent one SD from mean LMA0.

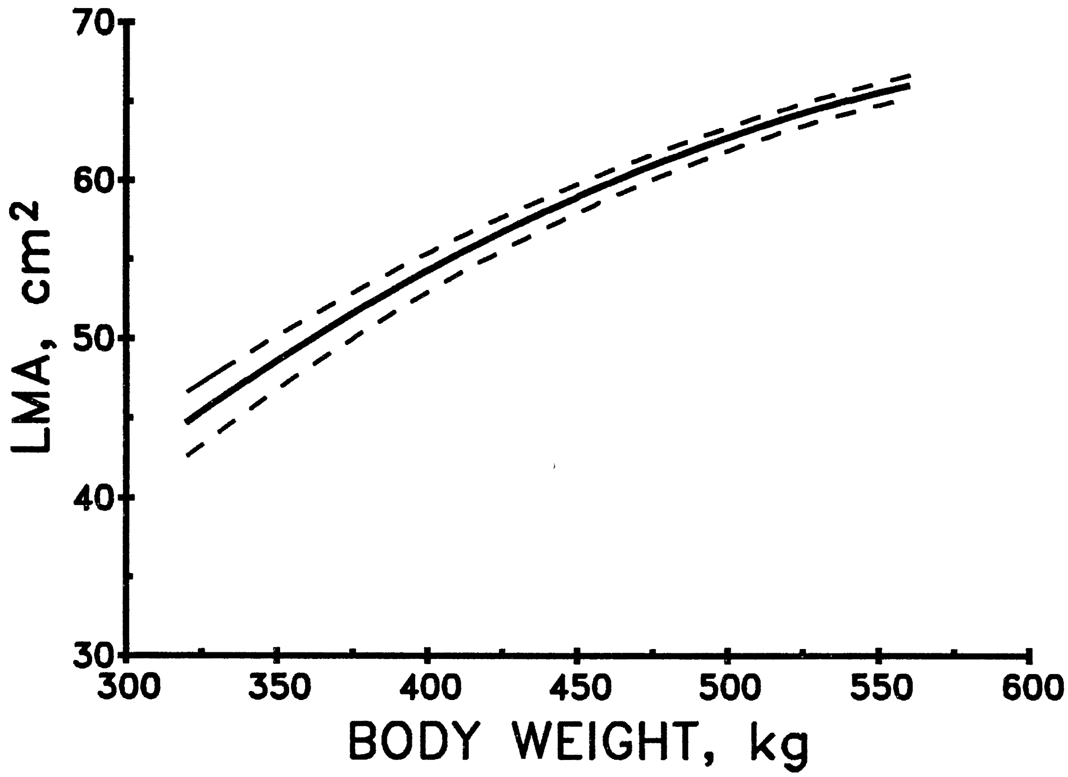

Figure 9. The relationship between ultrasonic longissimus muscle area and body weight for steers varying in initial longissimus muscle area (LMA0). Dotted lines represent one SD from mean LMA0.

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VITA

Michael Todd Smith

Candidate for the Degree of

Master of Science

Thesis: LIVE ANIMAL ULTRASOUND MEASUREMENTS OF FAT THICKNESS AND LONGISSIMUS MUSCLE AREA IN RELATION TO GROWTH AND CARCASS PARAMETERS IN FEEDLOT STEERS.

Major Field: Animal Science

Biographical:

Personal Data: Born in Medford, Oregon, April 29, 1961, the son of R. Dale and Patricia I. Smith.

Education: Graduated from Crater High School, Central Point, Oregon, May 1979; received Bachelor of Science in Animal Science from California Polytechnic State University, San Luis Obispo, California, December 1986; completed the requirements for the Master of Science degree in Animal Science at Oklahoma State University, May 1990.

Professional Experience: Raised on a commercial/purebred cattle ranch in southwestern Oregon; employed by Charley Livestock Co., White City; Morton Milling Co., Medford; Grange Cooperative, Central Point; Cal Poly Animal Science Dept., San Luis Obispo; Oklahoma State University Animal Science Dept., Graduate Research and Teaching Assistant.

Professional Organizations: Alpha Gamma Rho (National Agricultural Fraternity), American Society of Animal Science, Animal Science Graduate Student Association.