The use of real-time ultrasound measurements to predict composition and estimate genetic parameters of carcass traits in live beef cattle

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The use of real-time ultrasound measurements to predict composition and estimate genetic parameters of carcass traits in live beef cattle

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GENERAL INTRODUCTION

Results of the National Consumer Retail Study (Savell et al., 1989) have made clear to all segments of the beef industry the need for change. Today's more health and diet conscious consumers are demanding a lean, consistent, high-quality product that is convenient and reasonably priced. If the beef industry is unable to supply such a product, consumers are likely to buy other products. Consequently, if the beef industry is going to maintain or increase market share, a unified effort by all segments is a must. This includes everyone in the production chain from the seedstock producer to the retailer.

Packers and retailers provided the initial response to consumer's demands for a leaner product by trimming excess fat from beef cuts before they reached the retail case. Although this response was a positive one it is a short-term solution to the problem that is inefficient and costly to the entire industry. At the producer level much of the discussion of change centers around the management practices, production systems and genetic selection of beef cattle that have the potential to improve profitability and product acceptance in all segments of the beef industry. Of these, genetic improvement of specific carcass characteristics offers both permanent and cumulative change and is certainly one of the most critical areas to be addressed.

Progress in the genetic evaluation and improvement of carcass traits has certainly not kept pace with other traits of economic importance such as growth and maternal ability. The major holdback has been the lack of good data. Some reasons include: the expense and difficulty of collecting carcass information, maintaining animal identification and contemporary groups and the reliance on progeny testing because of the inability to measure the trait in the breeding animal itself. But, likely the most important reason for the slow adoption of carcass evaluation on a large scale basis is that the current fed cattle pricing structure fails to provide incentive for producing cattle superior in carcass merit.

Real-time ultrasound technology offers a relatively low-cost alternative to expensive and time consuming progeny testing of beef sires for carcass merit. Consequently, this technology has the potential to alleviate some of the above-mentioned obstacles by evaluating carcass composition in the live animal, thus paving the way for a more efficient and cost-effective genetic evaluation system. The concepts of specification beef, instrument grading, and value-based marketing are certain to become a reality; and consequently the industry segments must prepare themselves to respond. Producers and breed associations with knowledge of their genetic base as it relates to carcass merit and with genetic evaluation systems in place are likely to be in a better position to capitalize on premiums associated with genetics capable of producing a superior product.

The objectives of the studies contained in this document were to: 1) Evaluate the relationship between ultrasound and carcass measurements of 12-13th rib fat thickness and longissimus muscle area, 2) Characterize the growth and compositional changes of performance tested yearling bulls via serial measurements, 3) Determine appropriate data collection and adjustment strategies for ultrasonically evaluated carcass traits in potential breeding animals, 4) Estimate genetic parameters for growth and ultrasonically measured carcass traits with serially collected data from yearling bulls, and 5) Generate growth and carcass trait expected progeny differences for the sires of these bulls from ultrasonically collected data.

Explanation of Dissertation Format

This dissertation is presented as a general introduction, a general review of literature, three individual papers, and a concluding general summary. References cited in the general introduction and literature review follow the general summary. All citations of references are in accordance with the CBE Style Manual used by the Journal of Animal Science to which a portion of these papers may be submitted. Each individual paper consists of an abstract, materials and methods, results and discussion, and an implications section.

REVIEW OF LITERATURE

A Changing Industry

Some of the major goals of the beef industry are to become more competitive in the marketplace, to regain and enhance consumer demand and confidence, and profitability (Cross et al., 1992). During the past several years the beef industry has made great progress toward accomplishing these goals (Cross et al., 1986; Savell et al., 1987, 1989, 1991). By transition from a commodity to a consumer-driven industry, consumer demands for a leaner product have been realized through a reduction of fat in the meat case by over 27% (Savell et al., 1991). Retailers reducing average fat trim from 13 mm to 4 mm was perhaps the most significant response the beef industry has ever made to consumer demand.

Following these dramatic reductions in fat at the retail level, the entire beef industry prepared to respond to the anticipated retailer demand for a trimmer primal cut. Packers knew they must reduce excess fat either through buying trimmer cattle or through trimming before the boxed product was marketed. Some segments of the packing industry began to experiment with new carcass specification programs, and others sought alternative methods of removing excess fat from the carcass. Feeders began the search for the types of cattle that could achieve the desired level of marbling without producing excess trimmable fat. Cow-calf producers began the search for the genetics necessary to respond to those expected economic signals (Cross et al., 1992).

Since the National Consumer Retail Study (Savell et al., 1989), the entire beef industry has waited for the expected economic signals to crystalize in the marketing system so that it could respond. To almost everyone's surprise, nothing happened. These signals have yet to emerge in the marketplace (Cross et al., 1992). Retailers continue to trim beef cuts to ≤ 4 mm fat with many trimming virtually all subcutaneous and intermuscular fat from beef cuts sold through their retail case. Packers are selling boxed product with varying amounts of trimmable fat, although recently certain packing companies are offering a very closely trimmed boxed product to retailers. At the same time, packers continue to use fat to enhance dressing percentage and feeders continue to sell fed cattle on the average. The industry realized that the marketing system was not functioning correctly and that until it became functional there could be no value-based marketing system, because a value-based marketing system is one that sends clear and accurate economic signals from the consumer backward through the marketing chain (Cross et al., 1992).

Since beef carcass grading began in 1927, its application has been primarily subjective, particularly with respect to USDA quality grades. The USDA beef carcass yield grades can be determined somewhat objectively, but Cross et al. (1980) reported that in actual application, error was greater for yield grades than for quality grades. Certainly, one of the keys to the eventual implementation of a value-based system is a more objective evaluation of the carcass for yield and quality. The meat industry has had an interest in instrument grading for the past 15 years

(Cross et al., 1989), but most efforts during this time period have not been very well concentrated or organized.

The following is an abbreviated history of instrument grading efforts as presented by Cross et al. (1989, 1992).

The United States Department of Agriculture (USDA), in cooperation with the National Aeronautics and Space Administration (NASA) and the Jet Propulsion Laboratory, began a project in 1978 to develop an instrument for objective evaluation of beef carcass quality and yield grade traits. NASA identified two technologies that could potentially accomplish the USDA's goals of instrument grading: ultrasound and video image analysis (VIA).

The VIA instrument was tested at USDA's Meat Animal Research Center in cooperation with Kansas State University in the early 1980s. The VIA system was based on a camera/computer system that assessed the chilled, ribbed surface of the muscle and fat areas at the 12/13th rib interface. The system was designed to measure subcutaneous fat depth, the total number and area of marbling pieces, and lean color. The system had a potential of measuring 600 carcasses per hour on a moving chain system. The results of the tests were quite promising, especially in yield prediction (Cross et al., 1983).

In early 1984, the USDA invited 12 industry representatives (beef, pork, and lamb) together to discuss the status of instrument grading. The industry representatives were unanimous in expressing the need for an objective grading system. The group felt that the instrument should be able to function on unribbed, unchilled carcasses. This was a major deviation from previous efforts on chilled ribbed carcasses. A second meeting of industry representatives in mid-1984 was called to discuss state-of-the-art technology that could be used to assess value objectively. Five types of instrumentation were discussed: 1) nuclear magnetic response (NMR), 2) near infrared reflectance, 3) real-time ultrasound, 4) video imaging, and 5) CAT-scan. The group effectively eliminated video imaging from future consideration by the USDA because of the requirement for unribbed, unchilled carcasses. Expensive methods such as NMR and CAT-Scan were eliminated because the research has not progressed far enough to make a good assessment and because it could not determine marbling (as perceived by this group). The group felt that, because of recent advances in ultrasound for use in the medical community, this approach offered the best chance of success. It was then decided that further research needed to be conducted to make certain that ultrasound had the potential to measure traits that predict yield [fat thickness (FAT) and longissimus muscle area (LMA)] and marbling. Early research at Cornell and Texas A&M Universities provided very promising results concerning FAT and LMA, while results on marbling were poor. These preliminary results indicated strong potential for ultrasound. Consequently, several research and industry groups became involved in researching and implementing ultrasound technology. Activities included use of ultrasound both as a tool for instrument grading of carcasses and as a way of evaluating live breeding and market animals for carcass traits; the latter of which can be used for the development of Expected Progeny Differences (EPDs) of carcass traits.

Application of Ultrasound Imaging to Beef Cattle

Ultrasound was initially applied to the livestock industry to determine density boundaries without tissue destruction (Wild, 1950). These boundaries occurred at the subcutaneous fat to muscle interface and in the womb of pregnant animals. The resulting applications were fat depth measurement and pregnancy testing (Lake, 1991). Wild and Neal (1951) demonstrated that the interface between muscle and fat could be determined in live cattle. In another early study done with cattle, Temple (1956) reported that ultrasound provided a reliable indication of fat thickness. While estimation of live animal composition using ultrasound has been available for many years, Lake (1991) reported that the technology and quality of equipment has improved dramatically in the past decade. This has resulted in real-time, linear-array scanners designed for medical applications which could easily image subcutaneous fat and provide sufficient detail about interfacial layers in the muscles to allow the size of muscles, such as the longissimus muscle, to be determined with reasonable accuracy. Lake (1991) stated that these applications have involved a certain amount of operator skill in interpreting the reflections, especially when imaging systems were not used. A recent summary of ultrasound literature (Ferguson, 1991) indicated a volume of reports which have shown that ultrasound measurements taken by experienced operators were highly correlated with corresponding carcass measurements and were useful predictors of retail meat yield.

Modern ultrasound technology permits the rapid, relatively inexpensive, noninvasive evaluation of the internal structure of animals and research interests include its use as a predictor of composition in breeding stock. An understanding of the basic principles of ultrasound and its interaction with body parts is required for a general understanding of ultrasound technology's use in live animal evaluation.

Properties of Ultrasound

Sound is a mechanical wave of compressions and refractions within a medium. A sound wave can be compared to a longitudinal wave having length, frequency and velocity. The wave-length is the distance of two similar points on a given wave. Frequency is the number of cycles or wavelengths occurring in a given time period (usually one second). Velocity is derived from the computation of frequency and wavelength. Frequency is described in cycles per second or hertz (Hz). Audible sound varies from 20 to 2000 Hz. Diagnostic ultrasound uses frequencies in the range of 2 to 10 MHz, which is well beyond the range of audible sound. If one knows the velocity and frequency, the wavelength can be calculated. Because the velocity of sound in a given tissue is constant, changing the frequency will change the wavelength. This will, in turn, affect the resolution and quality of an ultrasound image (Rantanen and Ewing, 1981; Herring and Bjornton, 1985).

Diagnostic ultrasound is produced by transducers housing crystals with piezoelectric (pressure-electric) properties. When piezoelectric crystals are deformed by pressure, electricity is produced. Conversely, when an electrical current is applied to them, the crystals will deform. This is the process by which ultrasound is generated and received by the transducer. When reflected, the sound returns to the transducer and a slight deformation of the crystal is produced. This generates an electric current. This current is displayed on an oscilloscope as an image of the tissue interfaces (Rantanen and Ewing, 1981; Houghton and Turlington, 1992).

As the sound beam passes through body tissue, a portion of the beam is reflected back to the transducer. Reflection occurs at tissue interfaces of differing acoustic impedance. The amplitude of the returning echo is determined by the absolute difference in acoustic impedance of one tissue compared to another. The closer the acoustic impedance of one tissue to a second tissue, the smaller the returning echo (Herring and Bjornton, 1985; Lake, 1991).

Each echo returns to the transducer, where it is changed into an electrical pulse and is displayed on a cathode-ray tube screen. The ultrasound scanner calculates the time it takes for a pulse to be emitted and the echo to be returned, which allows it to compute the exact distance of the acoustic interface from the transducer. Sound beams travel at approximately 1540 m/s in soft tissue (Lake, 1991). Therefore, the only variable that contributes to the difference in acoustic impedance of one soft tissue to another is its density. When two tissues of different density are in contact with one another, this creates an acoustic interface or a reflecting surface (Herring and Bjornton, 1985; Lake, 1991).

Sound travels through bone at approximately 3100 m/s. The density of bone is considerable compared with that of soft tissue. Therefore, a very high impedance mismatch occurs at the soft tissue-to-bone interface (Herring and Bjornton, 1985). The absolute value of acoustic impedance of any tissue is relatively unimportant, but it is the magnitude of the difference in acoustic impedance at tissue interfaces that determines the amount of reflection of the beam (Rantanen and Ewing, 1981).

Energy is removed from the sound beam as it passes through soft tissues. This energy removal is referred to as attenuation and is caused by two forces. The first process is absorption, which is the conversion of ordered motion of ultrasound into the disordered motion of heat. The amount of absorption increases with the frequency of the sound beam. The second process is scattering of the sound beam by small tissue interfaces, which results in energy loss from the sound beam. The intensity of the scattered sound escalates with increasing frequency. Because factors causing absorption and scattering of the beam are frequency dependent, a sound of lower frequency will penetrate further into soft tissue than a higher frequency sound (Rantanen and Ewing, 1981; Lake, 1991; Ferguson, 1991). For this reason, a 3-MHz transducer is more appropriate to use for deeper locations in the body (i.e., muscle area) where as a 5-MHz transducer is conducive for analyzing tissues close to the body surface (i.e., fat thickness) (Houghton and Turlington, 1992).

There are three basic display formats or modes. The first, called amplitude mode (A-mode), ultrasonic imaging is a one-dimensional display of returning echo amplitude and distance. This mode consists of vertical peaks along a horizontal axis. The height of the peak corresponds to the amplitude of the echo and the distance between the peaks represents the distance between the interfaces of differing acoustic impedance (Rantanen and Ewing, 1981; Herring and Bjornton, 1985).

Brightness mode (B-mode) ultrasonic imaging is another display format that consists of a two-dimensional display of dots. The transducer is placed on the surface of the body and a cross-sectional image of the anatomy is depicted. The vertical position of the dot on the screen is determined by the time it takes for an echo to return to the transducer, which indicates the depth of the tissue interface. The horizontal location of the dot on the screen is determined by the position of the crystal in the transducer head. The brightness of the dots is proportional to the amplitude of the returning echoes, which is again determined by the magnitude of the differences in acoustic impedance at the tissue interface.

Real-time ultrasonic imaging is a form of B-mode used to record movement of structures. In real-time imaging, echoes are recorded continuously on a nonstorage cathode-ray display screen. Encoders spatially orient the returning echoes on the display screen to depict tissue interfaces. With real-time units these encoders are contained in a moveable head to allow rapid transducer movement from one area to another (Rantanen and Ewing, 1981; Herring and Bjornton, 1985).

The third display format is that of motion mode ultrasound (M-mode) and is a one-dimensional format displaying dots. With M-mode, the transducer is held in place over moving organs. This form of ultrasonics is used primarily in echo cardiographic studies (Rantanen and Ewing, 1981; Herring and Bjornton, 1985; Lake, 1991; Houghton and Turlington, 1992).

Accuracy of Ultrasound

Ultrasound technology was introduced early in the 1950s as a means for estimating compositional differences among livestock (Wild, 1950). Technological advances during the 1970s and 1980s have dramatically improved ultrasound equipment (Houghton and Turlington, 1992). Ultrasound units that produce real-time images are now the most commonly accepted ultrasonic instruments for use in beef cattle. Most of the currently used instruments were originally developed for use in the medical field and only in the past few years has any of this equipment been developed or designed specifically for use in the livestock industry. There have been several brands and models of real-time ultrasound equipment used to evaluate carcass traits in livestock. Previous to 1991, the Technicare 210 DX, G. E. Datascan and Equisonics machines were the most widely used (Houghton and Turlington, 1992). Since that time the Aloka 500V was developed for use in livestock and appears to be the instrument of choice.

The accuracy of ultrasound measurements of carcass traits, specifically subcutaneous fat thickness (FAT) and the area of the longissimus muscle (LMA), measured between the 12th and 13th ribs has been examined by many over the past 20 years and reports indicate a great deal of variability in results. These findings came from several different machines and from operators with a wide range of experience. Consequently, this review will only cover the recent evaluations of accuracy. A summary, adapted from Houghton and Turlington (1992), of the accuracy work done since 1988 is presented in Table 1. Correlation coefficients are used to evaluate the relationship between ultrasound and carcass measurements of FAT and LMA. Table 1 also relates the researcher and the equipment used in the study. Correlations between ultrasonic and carcass measurements of FAT range from .75 to .96 with an average of .86 among this group. The correlation between ultrasonic and carcass measurements of LMA range from .20 to .90 with an average of .73. This demonstrates rather clearly that, in general, ultrasound measurements provide a very accurate assessment of FAT and while the results are generally lower and more variable, LMA is evaluated fairly well in most cases. Later in this review, several of these studies will be examined more closely for other ways of assessing accuracy.

Much of the accuracy data reported to date have been in the form of correlation coefficients (r). Although correlation coefficients are useful, it is important to understand the limitations associated with this method of reporting ultrasound accuracy. These limitations include: 1) the fact that population variation influences correlation coefficients (i.e., a larger than normal variation can produce higher correlation coefficients, whereas a uniform population will usually result in lower correlation coefficients); 2) correlation coefficients do not reflect bias (i.e., an ultrasonic technique that consistently under- or over-estimates measurements); and 3) correlation coefficients may not be easily understood by some producer groups (Houghton and Turlington, 1992).

Table 1. A summary of ultrasound accuracy in measuring fat cover and longissimus muscle area

Investigator and year	Instrument	Correlation (r) with carcass measurement at 12th-13th rib	
		FAT	LMA
Stouffer and Cross, 1985	Technicare 210DX	.78	.87
Smith et al., 1988	Technicare 210DX	.81	.20-.43
Turner, 1988	Technicare 210DX	.81-.94	.71-.94
Faulkner et al., 1989	Technicare 210DX	.89	
Yale, 1989	Technicare 210DX	.80-.83	.74-.82
Stouffer et al., 1989	Technicare 210DX	.86	.76
Perry et al., 1989	G.E. Datason	.86	.76
Houghton et al., 1989	Technicare 210DX	.87	.78
Brethour, 1990	Technicaare 210DX	.87	
Duello et al., 1990	Aloka 633	.87	.75
Henderson-Perry et al., 1990	Equisonics	.85	.71
Perry et al., 1990	G.E. Datason	.96	.90
Smith et al., 1990	Technicare 210DX	.82	.63
Moylan et al., 1991	Aloka 500V	.87	.76
Perkins et al., 1992	Technicare 210DX	.75	.60
Perkins et al., 1992B	Aloka 500V	.86-.87	.76-.82
Waldner et al., 1992	Technicare 210DX	.86	.73
Brethour, 1992	Technicare 210DX	.92	
Robinson, 1992	Technicare 210DX and Aloka 500V	.90	.87

With these limitations in mind, alternate methods of reporting accuracy data should be considered. One method is to report data in the form of a frequency distribution (i.e., what percent of the measurements are within a predetermined range of the carcass measurement) (Houghton and Turlington, 1992). This method can also be applied as a measure of repeatability of multiple scans or between scanners. Another method of evaluating accuracy is by the standard error of prediction (SEP) between the two measurements (Robinson et al., 1992). Standard errors of prediction have an advantage over the mean absolute differences because of their general acceptance as a measure of variability and, by squaring differences, a few large errors are properly considered more serious than a greater number of smaller discrepancies (Robinson et al., 1992). Regardless of the method used to report accuracy, there is thought to be considerable variation between species, technicians and instrumentation in the ability of ultrasound to predict carcass measurements.

It has been hypothesized that some of the differences between ultrasound and carcass measures of FAT and LMA are due to changes tissues undergo during the chilling process (Mersman, 1982; Houghton and Turlington, 1992). Lauprecht et al. (1957) investigated the effects of chilling position on subcutaneous fat thickness but found few differences. In contrast, Turlington (1990) concluded that carcass position does influence carcass measurements, thereby influencing the perceived accuracy of ultrasound. In this study, pigs were scanned one day pre-slaughter. After slaughter, one-half of each carcass was either hung on the rail in a traditional manner or was placed in a standing position by use of a specially made rack. Results of this study indicate no significant ($P > .05$) differences for backfat measurements between the live animal and standing carcass but indicate significant ($P < .05$) differences between the live animal and hanging carcass. In all cases, backfat taken from hanging carcasses exceeded those of the live animal or standing carcass. Significant differences were also found for longissimus muscle area between the live animal, standing carcass, and hanging carcass. In this case the live animal measurement was intermediate to the standing and hanging carcass. Although similar data do not exist for cattle, it is reasonable to assume that carcass position also influences carcass measurements.

Other possible reasons for the increased variation of the measurement explained by Stouffer (1988), who suggests that 1) dirt, hide thickness and hair; 2) degree of fatness, 3) ability to match the medial and lateral halves of the LMA when using split screen technique, and 4) parallel interfaces to ultrasonic sound waves (i.e., medial and lateral boundaries of the LMA) may contribute to some of the discrepancies between ultrasound and carcass measurements.

When comparing ultrasound measurements of FAT and LMA to carcass measurements one must remember that carcass measurements are not without error. Especially when these measurements are taken by many different people and in most cases in commercial packing facilities at chain speed. In a study where carcasses ($n = 94$) were measured by two experienced carcass evaluators, Rouse et al. (1992) obtained correlations of .97 and .94 between the two evaluators for FAT and LMA, respectively. In an

Australian study, two people independently measured each side of a carcass twice (Robinson et al., 1992). Fat depths were measured with calipers and LMAs were traced and later digitized twice. Digitizing error proved to be negligible. There was an overall difference between carcass LMA tracers of 1.3 cm^2 (±.20), presumably due to the tendency of carcass evaluators to deviate either to the inside or outside of the muscle boundary (Robinson et al., 1992). Consequently, there are evaluator differences in carcass measurements and although they are perhaps the best we can do, they are not without error.

Robinson et al. (1992) presented several different accuracy and repeatability measures from ultrasound accreditation clinics. The average correlation between ultrasound and carcass measurements for FAT and LMA were .90 and .87, respectively, while the SEP between live and carcass measurements were .9 mm for FAT and 5.04 cm^2 for LMA. The SEP between repeated measures by the same technician (.62 mm for FAT, and 3.98 cm^2 for longissimus muscle area) indicate a very high degree of repeatability.

It is also a condition of accreditation that applicants undergo an annual accreditation test. At the time of publishing, Robinson et al. (1992) reported all retests were successful and results suggest that experience improved repeatability and accuracy of measurements. The only equipment differences noted were that scanners using an Aloka 500V system with a 17 cm transducer versus those technicians who were using equipment with a split screen feature to measure LMA had reduced variation between scan and carcass LMA by approximately 25%, although fat scans were approximately 25% less accurate.

Robinson et al. (1992) also noted that average correlations were highest between scan data and the mean of the right and left hand side of the carcass rather than the particular side that was scanned. This suggests that rather than biological differences, much of the variation between right and left hand sides of the carcass is, in fact, due to handling and dressing procedures. Also correlations between right and left fat scan measurements were higher than their carcass equivalents, again suggesting that extra variation had been introduced by handling and dressing procedures. Scanned rib fat depths were reasonably close to carcass measurements, but there was a tendency for scan measurements to overestimate carcass values for animals with little fat and to underestimate values for fatter animals. It is suggested that because the 12/13th rib site is located in a concave area of the hanging carcass, rib fat layers may bunch here and be thicker than on the standing animal. These effects may be greater on fatter animals as may any expansion or separation of fat layers during or after hide removal. Results similar to these were reported by Brethour (1992) and Savell et al. (1989) who took ultrasound measurements of hanging cattle before hide removal. Robinson et al. (1992) concluded that with experienced, well-trained technicians, fat depths can be measured on live animals almost as accurately as on the carcass, and the best technicians measure LMA only marginally less accurately.

Smith et al. (1992) reported on two experiments to evaluate accuracy of ultrasound measurements. In the first, involving 315 yearling steers of various breed types, 74 percent of the ultrasonic estimates of FAT were within 2.54 mm of carcass values (r = .81) and LMA was predicted within 6.45 cm^2 for 47 percent of all carcasses (r = .43). Steers with carcass fat thickness < 12.7 mm were estimated within 2.54 mm for 82% of the steers, compared with 67 percent for those with carcass fat thickness > 12.7 mm. There was a tendency to underpredict fat thickness of fatter cattle. Similarly, LMA was generally overpredicted for carcasses with LMAs < 71 cm^2 and was underpredicted for carcasses with areas > 84 cm^2. This experiment also compared measuring carcass LMA using a standard dot grid versus an acetate tracing, which was later evaluated on an electronic digitizing board. The relationship between these two measurement procedures (r = .89) again suggests the imperfections of carcass measurements.

The second study reported by Smith et al. (1992) compared both ultrasound measurements and visual appraisal to carcass measurements as well as comparing the accuracy of two technicians. Although similar correlation coefficients between UFAT and CFAT were obtained (r = .82), estimates were more biased; only 62 percent of the ultrasound estimates were within 2.54 mm of carcass measurements compared to 74 percent in experiment one. Again, ultrasonic estimates of LMA were only moderately correlated (r = .63) with carcass measurements and did not differ between technicians. The relationship between carcass measurement and subjective evaluation of fat cover in the live animal was far less accurate (r = .56

vs. $r = .82$) than the relationship between carcass and ultrasound measurements. Visual evaluation of LMA in the live animal on the other hand was quite comparable in accuracy to ultrasound ($r = .61$ vs. $r = .63$). Moylan et al. (1991) experienced similar results for visual evaluation versus ultrasound measurement of FAT ($r = .45$ vs. $r = .87$) and LMA ($r = .72$ vs. $r = .76$). The frequency of scan measurements that were within 2.54 mm for fat cover were similar to those in experiment one and the frequency of ultrasound LMAs within 6.45cm^2 of the carcass improved slightly. Smith et al. (1992) concluded that fat thickness can be accurately evaluated with ultrasound and, although the LMA accuracy did improve from experiment one to experiment two, it is still questionable.

Waldner et al. (1992) evaluated 60 Brangus bulls using two real-time ultrasound machines and four technicians to estimate FAT and LMA every four months from 4 to 24 months of age. Ten bulls were slaughtered every 4 months to determine actual FAT, LMA, YG, and 9-10-11th rib chemical composition. They concluded that scanned mean fat was accurate ($P < .05$) at 16 months of age and not different ($P < .09$) from the actual mean FAT (95% of the time error in estimation was $\leq .33$ cm). Scanned LMA was accurate ($P < .05$) at 12 months of age (95% of the time the error in estimation was ≤ 20.0 cm^2). Partial correlation coefficients (removing the effects of birth and slaughter months) among live animal and carcass measurements were .86 and .73 for FAT and LMA, respectively. Similar to the findings of others (Smith et al., 1992; Robinson et al, 1992), this study showed that as cattle became fatter they were increasingly underestimated, and contrary to the above mentioned studies the bulls with smaller LMA (< 70 cm^2) were underestimated and those with larger LMAs (> 85 cm^2) were overestimated.

Although all operators had some experience with this equipment they were thought to have varying degrees of skill (Waldner et al., 1992). This work suggests that the level of operator skill did not improve the accuracy of FAT or LMA estimates. Thus, it is suggested that persons with little experience in using real-time ultrasound instruments can easily be trained to collect images of FAT and LMA in live cattle with accuracy equal to experienced operators. On the other hand, this work would agree with (although not as conclusively) Lopes et al. (1987) and McLaren et al. (1991) using similar equipment, and that interpretation of the scanned images was found to be more important than the skill of the operator obtaining the images. There was no difference (P > .05) between the two instruments for both actual and absolute differences in FAT or in absolute differences in LMA.

Waldner et al. (1992) also reported that ultrasound FAT was similar to actual fat with correlation coefficients for yield grade (Y6) and percentages of moisture, lipid and protein of .61, -.57, .61, and -.55, respectively. Faulkner et al. (1990) and Miller et al. (1986) reported correlations between carcass and ultrasound FAT with percentage carcass fat to be .83 to .81 and .69 to .56, respectively. Waldner et al. (1992) also showed that carcass and ultrasound LMA were not significantly correlated (P > .05) with 9-10-11th rib composition or YG. Fortunately, this study indicates that the most accurate time to evaluate carcass merit in bulls and the time that these estimates (both carcass and ultrasound) are most predictive of actual YG and chemical composition is the time in the bull's life cycle that it is most practical for scanning (approximately 12 months of age). Waldner et al. (1992) cautions breeders about using individual animal ultrasound measurements for selection but suggests that they are useful in evaluating groups of bulls (i.e., sire groups) to make genetic change.

Brethour (1992) examined the repeatability of ultrasound FAT measurements on 217 cattle and the association of ultrasound and carcass backfat measurements on 580 animals. The correlation (repeatability) between consecutive ultrasound measurements, by the same technician, was .975. The average difference between two ultrasound measures on the same animal was .72 mm and error size was directly related ($P < .001$) to the amount of FAT. Ultrasound FAT measures averaged 8 percent ($P < .001$) less than carcass measures. The average absolute difference between these two measures was 1.57 mm. Discrepancies were ($P < .001$) larger when FAT was thicker. Cattle with FAT measuring < 10 mm averaged 1.43 mm absolute difference whereas those with FAT > 10 mm averaged 1.89 mm absolute difference. The variance of the discrepancies was partitioned into three components: ultrasound measurement error (14%), drift related to intercept and slope (15%), and residual (71%). The residual component may have represented errors in carcass measurement.

Brethour (1992) also reported that in a subsequent trial with 175 cattle, average differences between ultrasound and carcass FAT were reduced to 1.19 mm. The slope and intercept virtually mimicked that of the first set of cattle. He contends that ultrasound measures can be more precise (minutely exact) and accurate (close to the true value) than carcass measures for assessing absolute FAT thickness in cattle.

Perkins et al. (1992) evaluated two technicians scanning market steers (n = 495) and heifers (n = 151) over a five-month period. The overall correlations between ultrasonic and carcass measurement of FAT and LMA were .75 and .60, respectively. Similar results were reported for the two technicians. Correlations for FAT were .78 and .72 whereas correlations for LMA were .54 and .64 for technicians 1 and 2. This study also examined both the difference (DIFF) and the absolute value of the difference (|DIFF|) between ultrasound and carcass measurements of FAT and LMA. Analysis of variance of these measures of accuracy suggest that neither sex nor technician were significant (P > .01) sources of variation for FAT or LMA. Expressed as a percentage of the carcass measure these |DIFF| can be interpreted as proportional error rates of 20.6 percent for FAT and 9.4 percent for LMA, respectively. Because of the emphasis in most research studies on correlations as measures of precision, the automatic conclusion has been reached that ultrasonic FAT measurements are more accurate than those of LMA. In this respect, that conclusion is incorrect. The DIFF variables provide some indication of the direction of mean bias of ultrasonic measures in relation to carcass measures. Analysis of these values indicated that underprediction occurred more often than overprediction for both carcass traits. This study also found that the fatter cattle (FAT > 1.27 cm) and the heavier muscled cattle (LMA > 83.4 cm^2) were the most inaccurately measured with ultrasound.

Perkins et al. (1992) also reported accuracy results over a five-month period to examine operator skill. Although there was a gradual increase in correlations for backfat, magnitudes of correlation coefficients paralleled those of coefficients of variation of the actual carcass measures. Collectively their results indicate little to no change in accuracy as the level of technician experience increased with time. But, similar to Waldner et al. (1992), these technicians had some experience at the initiation of the project. Wallace and Stouffer (1974) found that significant differences existed between four operators of ultrasound equipment in interpretation of captured images. McLaren et al. (1991) also revealed significant variability among operators for operator-interpreted scans of LMA. Perkins et al. (1992b) suggests equal importance of ultrasonic image retrieval and technician interpretation when estimating UFAT and ULMA. The work of McLaran et al. (1991) involved operators of various degrees of experience while the work of Perkins et al. (1992b) and Waldner et al. (1992) involved technicians with more previous training and experience.

In a study designed to evaluate technician effects Perkins et al. (1992b) ultrasonically evaluated 36 steers of four breed-types just before slaughter and collection of carcass data. Repeated measures of FAT and LMA were taken by two technicians on two consecutive days with an Aloka 500V ultrasound unit equipped with a 17 cm transducer. Ultrasound and carcass measures of FAT and LMA were different ($P < .01$) among breed types but were not different ($P > .10$) between experienced technicians or for technician x breed type interactions. Pooled simple correlation coefficients were .87 and .88 between ultrasound and carcass measurements of FAT and .76 and .82 between ultrasound and carcass measurements of LMA for technicians 1 and 2, respectively. Repeatabilities estimated by interclass correlation methods were .91±.03 and .81±.06 for images repeated over two days and .95±.02 and .83±.05 for images repeated by two technicians for FAT and LMA, respectively. Repeatability estimates of LMA interpretation from video tape were .86±.05 within technician and .76±.07 between technicians. These results indicate equal importance of ultrasonic image retrieval and interpretation by experienced evaluators when estimating FAT and LMA in slaughter cattle.

With the exception of Waldner et al. (1992) the majority of the above reviewed literature examined the relationship between ultrasonic and carcass measurements of market steers and heifers. The use of ultrasound technology in measuring carcass traits of potential breeding animals is one of the key factors to the development of carcass Expected Progeny Differences (EPD). Consequently, a high degree of accuracy is required for these EPD to be valid. As described previously, Waldner et al. (1992) reported that at 12 and 16 months of age, ultrasound provided an accurate measure of FAT and LMA. Duello et al. (1990) reported correlations averaging .82 and .85 between live and carcass measures of FAT in three frame sizes of steers and bulls, respectively. This same study reported correlations between live and carcass estimates of LMA were higher (.79) in bulls than steers (.63). These results indicate that the correlation between ultrasonic live animal and carcass estimates of fat thickness are equally as high in bulls as in steers when fed to achieve relatively high levels of fat thickness. At low levels of fat thickness (more common to potential breeding bulls), correlations between live and carcass estimates of FAT may be slightly lower (Cundiff et al., 1991). Perhaps errors of measurement, either live or carcass, account for a relatively greater proportion of the variation in cattle with relatively low levels of fatness and tend to reduce correlations. The accuracy of ultrasonic LMA is equally as high or higher in bulls as compared to steers.

It appears quite clear that with a highly skilled technician ultrasound has the potential to accurately and repeatably evaluate FAT and LMA in both live market and breeding animals. But how these measures (carcass and ultrasound) actually predict true composition will be the key to making genetic improvement in the end product. Koch et al. (1982) reported from an evaluation of 2453 crossbred steers that CFAT is highly correlated with carcass percent fat trim and carcass percent retail product ($r = .77$ and $r = -.74$, respectively). Carcass LMA on the other hand was much more moderately correlated with percent fat trim (-.20) and percent retail product (.27). In a similar manner, Wallace et al. (1977) reported the correlation of ultrasound fat thickness with percent retail product (-.72) to be virtually the same as the correlation of carcass fat thickness with percent retail product (-.73). This study also reported that the correlation of both ultrasound and carcass LMA with percent retail product to be similar and very close to zero. Other studies (Alliston, 1982; Jansen et al., 1985; Bailey et al., 1986) indicate that the correlations of both UFAT and CFAT with percentage carcass lean are likely lower in bulls than in steers. They also suggest that in bulls ultrasonic fat estimates predict percent lean or percent fat in the carcass about as accurately as estimates of carcass fat thickness. As bulls are fed to heavier weights and higher average levels of fatness, the correlations improve between ultrasonic or carcass estimates of FAT and percent lean or percent retail products in the carcass (Cundiff et al., 1991).

Collectively, these results indicate that ultrasound has the potential to accurately assess carcass measurements of FAT and LMA. More importantly, although neither is perfect, ultrasound and carcass measurements of FAT and LMA yield similar degrees of accuracy in predicting actual carcass composition. However, there is still room for improvement, research in instrumentation, technique, and alternative sites of measurement are possible areas that could enhance the usefulness of ultrasound technology in assessing body composition.

Genetic Parameter Estimates

Parameter estimates are a very important part of any genetic evaluation because they describe the population being evaluated. The best linear unbiased prediction (BLUP) methodology developed by Henderson (1963, 1973, 1974) has been widely used for animal evaluation. The assumptions and properties of BLUP require that the unknown (co)variance components be substituted with the most accurate estimates available for the population and the traits being studied (Woodward et al., 1992).

Carcass measured traits

Before a genetic evaluation can become a reality, good estimates of heritabilities and genetic and environmental relationships between important traits must be obtained. There is a great deal of this information available on growth and carcass measurements in the literature and only a limited amount for ultrasound measurements of carcass traits. Table 2 presents a summary of heritability (h^2) estimates of carcass measured traits adapted from Koch et al. (1982) and Benyshek et al. (1988). The h^2 estimates are generally in the moderate to high range indicating that carcass traits should respond to selection (Bertrand et al. 1989). Most of these studies were conducted with British breeds and every breed interested in generating carcass genetic values must first have reliable estimates of these parameters.

Phenotype and genetic correlations between some growth and carcass measured traits are presented in Table 3 and Table 4, respectively (Benyshek et al., 1988; Bertrand et al., 1989). In general, Table 3 shows the phenotypic relationships among carcass characteristics to be small. This table also shows small phenotypic relationships between carcass traits and live animal growth traits. The magnitude of these relationships is at least part of the reason today's live animal specifications fall short when trying to predict carcass merit. Table 4 indicates some carcass trait genetic relationships which, if accounted for in selection programs, could be beneficial to economic beef production. For example, the negative relationship between fat thickness and longissimus muscle area is beneficial. Table 4 also suggests that the

Table 2. Heritability estimates from several literature sources

	Literature source cited[a]										
	1	2	3	4	5	6	7	8	9[b]	10[c]	Avg
Carcass wt.	.57	.39	.56			.68	.54	.43		.19	.48
Retail product											
Weight			.64[d]		.38[d]	.38	.55[d]	.58			.51
Percentage		.40	.28[d]		.66[d]		.49[d]	.63			.49
Fat trim wt.			.46	.50	.39	.94		.47			.55
Fat trim %								.57			.57
Bone wt.			.38			.56		.57			.50
Bone %								.53			.53
Kidney fat wt.				.72				.77			.75
Kidney fat %								.83			.83
Fat thickness	.24	.43	.50	.43	.57	.68	.50	.41	.31(.27)	.46	.43
Longissimus muscle area	.26[e]	.73[e]	.41	.40	.25	.28	.45	.56	.32(.26)	.47	.40
Marbling	.17[e]	.62[e]	.31	.73	.31	.34	.56	.40	.29(.40)	.38	.41
Warner-Bratzler Shear								.31			.31

[a]Source (1) Shelley et al. (1963); (2) Cundiff et al. (1964); (3) Cundiff et al. (1969, 1971); (4) Brackelsberg et al. (1971); (5) Dinkel and Busch (1973); (6) Koch (1978); (7) Benyshek (1981); (8) Koch et al. (1982); (9) Wilson (1987); and (10) Benyshek et al. (1988).

[b]Two analyses, first entry sires whose progeny carcass weights averaged < 685 lbs. and second entry (in parentheses) sires whose progeny carcass weights averaged ≥ 685 lbs.

[c]From data compiled on steers slaughtered on a weight constant basis (approx. 1,100 lb.).

[d]Cutability: estimated percentage of retail product from round, loin rib, and chuck.

[e]USDA quality grade reported instead of marbling score.

Table 3. Phenotypic correlations between performance characteristics from several literature sources[a]

Item[b]	Source	ADG to weaning	ADG in feedlot	Carcass wt.	Fat thickness	LMA	Marbling	Warner-Bratzler Shear
Birth wt.	1)	.12	.32	.41	-.07	.17	-.02	.05
	2)		.14	-.10	-.19	-.01	-.13	
ADG to weaning weaning wt.	1)		.11	.61	.31	.25	.10	.00
	2)		.16	.01	-.03	.05	-.04	
	3)		.70	.67	-.25	.05	-.21	.06
ADG feedlot[c]	1)			.72	.17	.32	.07	.02
	2)			.02	.03	-.07	-.03	
	3)			.96	-.32	.09	-.24	.03
Carcass wt.[d]	1)				.36	.43	.13	.00
	2)				.06	-.02	.00	
	3)				-.35	.18	-.21	.05
Fat thickness	1)					-.15	.24	-.01
	2)					-.25	.16	
	3)					-.30	.17	-.19
Longissimus muscle area	1)						.03	-.02
	2)						-.04	
	3)						-.15	-.06
Marbling	1)							-.12
	3)							-.27

[a]Source (1) Koch et al. (1982), (2) Benyshek et al. (1988), and (3) Wilson et al. (1976).

[b]Source 3, Wilson et al. (1976) reported slaughter weiht/d and carcass weight/d. Source 2 results reported on a slaughter weight constant basis.

[c]Source 2 ADG weaning to yearling.

[d]Source 1 results reported for cold side weight.

Table 4. Genetic correaltions between performance characteristics from several literature sources[a]

Item[b]	Source	ADG to wean-ing	ADG in feed-lot	Car-cass wt.	Fat thick-ness	LMA	Mar-bling	Warner-Bratzler Shear
Birth wt.	1)	.28	.61	.60	-.27	.31	.31	-.01
	2)		.32	-.40	-.52	.03	-.40	
ADG to weaning weaning wt.	1)		.49	.73	.04	.49	.31	-.05
	2)		.45	-.05	-.40	-.09	-.03	
	3)		.77	.52	-.12	-.39	-.85	-.83
ADG feedlot[c]	1)			.89	.05	.34	.15	.06
	2)			-.16	-.15	-.24	-.25	
	3)			1.00	-.38	-.16	-.88	.57
Carcass wt.[d]	1)				.08	.44	.25	.00
	2)				.04	-.07	.35	
	3)				-.42	-.06	-.19	.29
Fat thickness	1)					-.44	.16	.26
	2)					-.44	.05	
	3)					-.47	.37	-.29
	4)					-.40	.08	
						(-.44)	(-.30)	
Longissimus muscle area	1)						-.14	-.28
	2)						.06	
	3)						-.38	
	4)						-.05	
							(-.08)	
Marbling	1)							-.25
	3)							-.36

[a]Source (1) Koch et al. (1982), (2) Benyshek et al. (1988), (3) Wilson et al. (1976), and Wilson (1988).

[b]Source 2 results reported on a slaughter weight constant basis. Source 3 reported slaughter weight/d and carcass weight/d. Soruce 4 reported two analyses, first entry sires whose progeny carcass weight averaged < 685 lb. and entry two (in parentheses) for sires whose progeny averaged ≥ 685.

[c]Source 2 ADG weaning to yearling.

[d]Source 1 results reported for cold side weight.

genetic relationship between marbling and other carcass and production traits are varied and somewhat inconclusive. The most recent studies (Benyshek et al. 1988; Wilson et al., 1993) indicate that it is possible that fat thickness and marbling may be independent. If so, selection schemes to reduce subcutaneous fat while maintaining, or even increasing, marbling would be possible.

Environmental correlations (Table 5) reveal relationships between traits which are caused by environmental effects on those traits (Benyshek et al., 1988). None of the correlations in this table are very large which indicates producers may be able to vary environmental conditions and increase efficiency. For example, the environmental correlation between fat thickness and marbling is positive but small in magnitude, which indicates that the industry may be in error using its current procedure of feeding cattle for a longer period of time to ensure marbling once those cattle reach a certain fat thickness (Benyshek et al., 1988).

Of more importance are parameter estimates involving the two breeds of interest (Angus and Simmental). Wilson et al. (1993) reported h^2 estimates of hot carcass weight (HCW), marbling score, CLMA, and CFAT of .31, .26, .32, and .26, respectively, from Angus field data. The genetic correlation between HCW and CLMA is moderately high at .47, and the genetic relationship between HCW and CFAT was .38 (Wilson et al., 1993). Other trait genetic correlations were found to be small. For instance, the genetic correlation between marbling score and CFAT was estimated to

Table 5. Environmental correlations between performance characteristics from several literature sources[a]

Item[b]	Source	ADG to weaning	ADG in feedlot	Carcass wt.	Fat thickness	LMA	Marbling	Warner-Bratzler Shear
Birth wt.	1)	.10	.04	.26	.08	.04	-.25	.08
	2)		.08	.00	-.06	-.04	-.03	
ADG to weaning weaning wt.	1)		.03	.67	.41	.24	.07	.01
	2)		-.13	.03	.10	.10	-.05	
ADG feedlot[c]	1)			.57	.28	.30	.00	-.01
	2)			.06	.13	.05	.07	
Carcass wt.[d]	1)				.56	.42	.04	.00
	2)				.07	.00	-.13	
Fat thickness	1)					.11	.29	-.16
	2)					-.09	.24	
Longissimus muscle area	1)						.18	.17
	2)						-.11	
Marbling	1)							-.05

[a]Source (1) Koch et al. (1982) and (2) Benyshek et al. (1988).

[b]Source 2 results reported on a slaughter weight constant basis.

[c]Source 2 ADG weaning to yearling.

[d]Source 1 results reported for cold side weight.

be -.13, which is encouraging for breeders who desire to increase or maintain marbling levels while selecting for a decrease in external fat thickness at an age-constant end point (Wilson et al., 1993).

Woodward et al. (1992) reported h^2 estimates for retail cuts per day of age (RC), percent cutability (CU), and marbling score (MB) on an age-constant basis to be .28, .18, and .23, respectively, from Simmental field data. These estimates were virtually unchanged when using either a multiple trait model including growth and carcass traits or a single trait model. These results are generally lower than those presented in Table 1. In Woodward et al. (1992), correlations between CU and MB were all low and negative with genetic and phenotypic correlations of -.12 and -.15, respectively. Correlations between RC and MB were essentially zero, implying that increasing the weight of high priced cuts per day would not adversely affect MB. Correlations between carcass and growth traits were moderate and positive. For example, the correlations (.35 and .63) between RC and birth weight and weaning weight indicate that this information is beneficial in selection programs. Woodward et al. (1992) concludes that selection for weight traits may result in calves that yield more weight of retail cuts at younger ages with less external fat without adversely affecting marbling.

Ultrasound measured traits

Johnson (1992) reported h^2 estimates of age-constant weaning longissimus muscle area (WLMA) and yearling longissimus muscle area (YLMA) to be .39 and .40, respectively, with a genetic correlation (r_g)

of .66 between the two in Brangus bulls. McDonald et al. (1991) found a h^2 of .25 for age-constant ULMA in bulls. Arnold et al. (1991) reported that the h^2 of age-constant ULMA was .28 in yearling Hereford cattle, while Turner at al. (1990) found this h^2 to be .11 for Hereford bulls. Johnson's (1992) h^2 estimates for ULMA are not only higher than the other two studies but they are virtually identical to the average h^2 (.40) of LMA measured in carcass traits as summarized by Koch et al. (1982) and Benyshek et al. (1988). Johnson (1992) also found r_g between YLMA and weight-performance traits to be positive and mostly moderate in magnitude. The r_g of YLMA with birth weight (BW), weaning weight (WW), yearling weight (YW) and post-weaning gain (PWG) were .17, .29, .38, and .43, respectively. Arnold et al. (1991) reported somewhat higher r_g between age-constant ultrasound LMA and WW (.55), YW (.57) and average daily gain (ADG) (.33) in Hereford cattle. Turner at al. (1990), on the other hand, reported a r_g of -.07 between age-constant ultrasound LMA and yearling weight and suggested that the two traits had "independent genetic determination" in Hereford bulls.

Johnson (1992) found the r_g between frame score (FS) and WLMA (.18) and YLMA (.01) to indicate a weak, if any, relationship between muscling and skeletal size in Brangus bulls. This study also suggests that muscling and reproductive potential in Brangus cattle may be compatible as the r_g between scrotal circumference and WLMA (.04) and YLMA (.19) were small but positive. Turner et al. (1990) reported a much stronger (r_g = .48) positive relationship between age-constant LMA and SC.

Arnold et al. (1991) and Lamb et al. (1990) reported h^2 of .26 and .24, respectively, for age-constant UFAT in Hereford cattle. Australian work with purebred bulls yielded a similar h^2 (.25) for age-constant FAT (McDonald, 1991). Turner et al. (1990) reported that the h^2 of actual fat thickness in Hereford bulls was only .04. Johnson (1992) also reported a low h^2 estimate (.14) for UFAT in Brangus bulls and suggested that perhaps genetic differences in ability to deposit fat were not expressed in yearling bulls under moderate nutrition levels. Genetic correlations obtained for FAT with WLMA (.19) and YLMA (.12) were positive but low in Brangus bulls (Johnson, 1992), indicating that selection to increase LMA may cause a slight increase in FAT. Arnold et al. (1991) also found a positive relationship (r_g = .48) between age-constant UFAT and ULMA while Turner et al. (1990) reported a negative relationship between these two traits. Lamb et al. (1990) reported a small positive genetic relationship (r_g = .13) between ultrasound measured UFAT at 365 days and subsequent carcass LMA in Hereford bulls.

Johnson (1992) found the relationships between UFAT and growth traits hard to interpret. Yearling UFAT had a negative r_g with weaning and yearling weights of -.17 and -.53, respectively. While the r_g for UFAT with BW (.52) and PWG (.44) were moderate and positive. Other researchers (Arnold et al., 1991; Lamb et al., 1990; Turner et al., 1990) have reported that positive genetic relationships exist between UFAT and measures of weight. Johnson (1992) found that in Brangus bulls the r_g between UFAT and FS was .14. This study also indicates that the r_g between UFAT and SC of -.33 suggesting that bulls with more testicular development may be genetically predisposed to staying trimmer through the performance test. Turner et al. (1990) agrees with these findings and these two results suggest that composition in offspring could be indirectly affected by selection to change SC. Johnson (1992) also reported that phenotypic correlations between all growth traits and ultrasonically measured carcass traits were either very close to zero or moderately positive. Heritability estimates of growth traits in Brangus bulls were .75, .48, .31, .44, and .42 for BW, WW, PWG, YW, and FS, respectively. Also, the h^2 of SC was .48 and SC had a positive r_p and r_g with all growth traits measured (Johnson, 1992).

Johnson (1992) also reported that when the data were analyzed on a weight constant basis additive and phenotypic variances decreased from age-constant estimates, indicating that weight accounts for more of the variation in ultrasound measured traits than age. Heritability estimates decreased slightly to .36, .39, and .11 for WLMA, YLMA and FAT, respectively. Arnold (1991) also reported heritabilities on a weight-constant basis for FAT (.26) and LMA (.25) in yearling Hereford cattle, which is slightly lower (.25 vs. .28) for LMA and identical for FAT compared to age-constant estimates. Arnold et al. (1991) noted that when examined at a weight-constant or age-constant basis, UFAT measurements in yearling breeding cattle are positively correlated with growth rate and size rather than being an indication of maturity as in steer carcass data. This study also indicates that, on a weight-constant basis, h^2 estimates are lower for ultrasound measured carcass traits in Hereford bulls than for carcass measurements in Hereford steers, .26 vs. .49 and .25 vs. .46 for FAT and LMA, respectively.

In a second analysis, Johnson (1992) obtained estimates of maternal additive variance and maternal h^2 from the same data set with the embryo transfer calves removed. Direct heritabilities changed only slightly from those obtained from analysis using all records. Maternal heritabilities for WLMA and YLMA were both .01, indicating no maternal influence. The maternal h^2 of FAT (.10) was low, although virtually the same as the direct h^2 (.11) obtained from the same analysis indicating that preweaning maternal environment has an equal affect on FAT as an individual animal's own fattening ability (Johnson, 1992).

Response to selection

Using h^2 estimates and phenotypic standard deviations obtained in their respective analysis Johnson (1992) and Arnold et al. (1991) examined the response to selection based on age-constant and weight-constant ultrasound measures. Johnson (1992) reported that selection based on weight constant ultrasound measured traits should result in slightly less change than selecting for age-constant traits. Specifically, selection to change age-constant YLMA could potentially result in an improvement of .705 cm^2/yr compared to .623 cm^2/yr based on weight-constant selection. Selection to improve FAT would only result in a change of .003 cm/yr and .002 cm/yr based on age- and weight-constant selection, respectively. Arnold et al. (1991) reported a potential change of only .32 cm^2/yr due to selection based on YLMA, while FAT could be changed by as much as .005 cm/yr based on weight-constant parameters. Both of these studies suggest that response to selection based on FAT would be minimal. Johnson (1992) concludes that in Brangus bulls a reasonable amount of genetic change can be made in WLMA and YLMA, but he warns that "the relationship of this change to the carcass longissimus muscle area size in the offspring of selected animals is uncertain."

Adjustment of Carcass Traits

One of the difficulties in conducting a genetic evaluation for carcass merit using field records is the wide variety of endpoints at which the data is collected. For instance, in Angus field data, age at slaughter varies between less than 365 days of age to over 700 days of age. Compositional endpoint is also quite variable as 12th rib FAT varies between .2 and 3.8 cm (Wilson et al., 1993). Having no common endpoint makes it impossible to fairly compare sires for genetic merit of carcass traits. There is only a limited amount of information available in the literature concerning this area and much of it offers conflicting results. The three most logical endpoint possibilities to adjust carcass data are age-constant, weight-constant, compositional-constant endpoints or some combination of these. Again, the bulk of the work in this area deals with market animals and consequently will need to be adapted to breeding animals if ultrasound information is incorporated.

Cundiff et al. (1969) addressed three adjustment alternatives involving Angus, Hereford, and Shorthorn cattle: 1) age was included as a covariate to evaluate the variation in growth of retail product to a constant age; 2) carcass weight was used as a covariate to evaluate variation in proportion or yield of retail product for animals of different ages at the same carcass weight; 3) both age and carcass weight were included as covariates to evaluate the variation in yield attributable to differential growth. Traits evaluated were retail product (RP), fat trim (FT), and bone (B), as determined by physical separation of the carcasses.

Heritability estimates from the analysis in which age was held constant indicate that growth of RP was highly heritable (.64), while the weight-constant analysis indicated that proportion of RP is moderately heritable (.42) and similar to the h^2 of RP when both age and weight were fit as covariates (.43). This estimate of growth of retail product is in close agreement with that of .65 reported by Swinger et al. (1965). The h^2 for proportion of RP is higher than that reported by Swinger et al. (1965) (.24) but similar to estimates reported by Bush and Dinkel (1967) (.38) and Cundiff et al. (1964) (.40). Cundiff et al. (1969) reported that although the differences are not significant, they suggest that variation in proportion of RP is 20 to 30 percent lower in heritability than growth of RP.

Cundiff et al. (1969) also reported that the phenotypic standard deviations (SD) was about 2.4 times greater for growth of RP (age-constant) than for proportion (carcass weight-constant) or differential growth (age- and carcass weight-constant) of RP from the carcass. The larger phenotypic SD combined with higher h^2 estimates reported for growth of RP suggests that single trait selection would be much more effective for growth of RP than for proportion of RP at any level of selection intensity. However, selection for proportion of RP would gradually change carcass composition.

Fat trim from the carcass at a constant age, constant weight, and when both age and weight where held constant was moderately heritable, .46, .37, and .42, respectively. Although phenotypic variation was reported to be less for FT at a constant weight than at a constant age, the proportion of the phenotypic variance due to additive gene effects remained about the same. Combining these two findings suggests that on an age-constant basis phenotypic variation for growth of RP is greater than that for FT and a higher proportion of that variation is heritable. The phenotypic variances for FT and RP from carcasses were about equal when carcass weight was held constant and the estimates of h^2 were similar indicating that the genetic variance is comparable for proportion of FT and RP (Cundiff et al., 1969).

These researchers (Cundiff et al., 1969) also reported that selection for growth of RP could be very effective in increasing weight of RP. If age were standardized such selection would also lead to increased carcass weight and due to correlated responses, composition would remain essentially unchanged. However, it would be possible to maintain similar carcass weights if the animals were slaughtered at increasingly younger ages. Selection for growth of RP under this type of scheme has the potential to increase percent RP by about .6 percent and FT would be reduced by .6 percent in one generation if the selection differential was one phenotypic SD. On the other hand, by adjusting for carcass weight and selecting parents one SD above average for weight of RP would increase RP by .8% and decrease FT by 1.1% in one generation. Consequently, Cundiff et al. (1969) concludes that selection for proportion of RP leads to only slightly more improvement in percent RP than selection for growth of RP when carcass weight is held reasonably constant by reducing age at slaughter. Efficiency of production of RP should be greater in the later case because fewer days would be required on feed resulting in reduced maintenance costs. Cundiff et al. (1969) also warns that correlated responses to this type of selection program could lead to increased body size and potentially higher maintenance costs in the breeding cattle herd.

The above results are also supported by further analysis of these data by Cundiff et al. (1971). Together they (Cundiff et al. 1971; Cundiff et al., 1969) clearly suggest that adjustment of carcass composition data to an age-constant bases allows for more overall genetic improvement in production and carcass characteristics if carcass weight is held fairly constant by slaughtering the animals at younger ages.

Koch et al. (1976, 1979, 1982a) adjusted carcass characteristics to an equal: 1) age, 2) weight, 3) fat thickness, 4) fat trim percentage, and 5) marbling score end points. The main objective of these studies was to evaluate breed differences at each of these end points rather than to evaluate the alternative adjustment strategies. These studies suggest, however, that at a constant fat thickness breed group differences in composition were reduced by 50 percent relative to differences at a constant age. They also report that differences in composition of breed groups were greatest when adjusted to a common weight. But keep in mind they are dealing with breeds that exhibit a great deal more variation in size and rate of maturity than is likely to be observed within any particular breed. Koch et al. (1982b) examined carcass characteristics, of the above data sets combined, on an age- and weight-constant basis and reported results in general quite similar to those reported by Cundiff et al. (1969).

Benyshek (1981) reported that h^2 estimates of carcass traits from records adjusted to an age- or weight-constant basis were virtually identical from Hereford field data. In this study, linear and quadratic partial regression coefficients were fitted for slaughter age, days on feed, and hot carcass weight. The quadratic regression coefficients were generally not significant or small in magnitude and thus the relationships were assumed to be linear. He reported that from analysis of the partial regression coefficients, "it would be difficult to say which of the two methods is more appropriate" (Benyshek, 1981). Benyshek (1981) concludes, after examining several adjustment methods, that once the covariate slaughter age was included in the model little change in h^2 and variance component estimates resulted from further adjustment of the data.

Adjustment of Ultrasonically Measured Carcass Traits

Turner et al. (1990) reported potential adjustment procedures to be used on ultrasonically collected measurements of FAT and LMA. The variables analyzed were weight (WT), FAT, LMA, 365-day LMA (ALMA) and

ULMA per hundred of live weight (LMACWT). To develop the ALMA variable, ULMA was adjusted to a 365-day basis by determining the prediction equation for the linear regression of ULMA on age and calculating a multiplicative age adjustment factor as correction factor = predicted LMA at 365 days/predicted LMA using the actual animal age. The Correction factor X ULMA for each animal yielded ALMA. Turner et al. (1990) suggests that cattlemen are concerned with comparing LMA on an adjusted or relative basis and therefore ALMA and LMACWT are important variables. Dinkel et al. (1965) disagrees with at least part of this, finding that the use of ratios or percents involving weight as the denominator does little more than change the sign of the relationship between the trait and weight. Therefore, this is not a satisfactory weight adjustment procedure. Dinkel et al. (1965) also warns that effects of interest in carcass traits may actually be masked by the use of ratios or percents.

Turner et al. (1990) reported that neither ALMA or UFAT revealed any age regression effect ($P > .10$) and consequently UFAT was not adjusted. These researchers estimated genetic parameters with two models. Model 1 was a simple sire effect with linear regression on age. Model 2 included covariates of WT, UFAT, and age with linear and quadratic terms for the three muscle-related traits. Collectively, their results suggest that ALMA and LMACWT are not suitable as singular traits for selection. Also, ULMA measurements should be adjusted for linear effects of age and WT as well as linear and quadratic effects of FAT before being used for selection (Turner et al., 1990). Wilson et al. (1993), on the other hand, reported concern with this type of adjustment suggesting, "adjusting to an age-weight endpoint is an artificial endpoint that may not be genetically possible for many of the animals evaluated."

Arnold et al. (1991) regressed UFAT and ULMA on both age and weight in yearling Hereford breeding animals. These regression equations suggest that all quadratic effects were nonsignificant ($P > .10$) and consequently only linear covariates were used to adjust the data. As mentioned earlier, parameter estimates from these two (age and weight adjusted) data sets were similar (.28 vs. .25) for LMA and exactly the same (.26) for FAT. In a similar analysis of Brangus bull ultrasound data, Johnson (1992) found neary equal h^2 estimates for age-adjusted versus weight-adjusted FAT (.14 vs. .11) and LMA (.40 vs. .39). Johnson (1992) also reported a slightly larger response to selection for age-adjusted traits than weight-adjusted traits. Australian researchers (McDonald, 1991; Robinson et al., 1990) report that in their beef cattle carcass evaluation program's animal age is the common endpoint of adjustment.

Although the above reviewed literature is not conclusive as to the most appropriate endpoint to adjust carcass data, it appears that age adjustment may have the most advantages. Reported h^2 estimates of both carcass and ultrasound measures of FAT and LMA tend to either be similar for age- and weight-constant data or be slightly higher for age-constant traits. More importantly, interpretation of h^2, phenotypic SD and correlations of growth and carcass traits suggests that more genetic progress is possible when selection is based on age-constant evaluations. In the case of ultrasound evaluation of carcass traits in breeding animals, taking these measurements close to a year of age fits well with current management and performance evaluation practices of most seed-stock operations.

Carcass and Performance Traits of Bulls Versus Steers and Heifers

Several papers reviewed by Turton (1969) and Seidman et al. (1982) have shown intact males to gain faster and more efficiently and to produce leaner, heavier muscled carcasses than castrates. Reiling (1991) reported that when fed to comparable weights, bulls of similar genetics gain ten percent faster and more efficiently averaging twenty fewer days to reach similar weight endpoints. Additionally, these bulls possessed .36 cm less subcutaneous fat cover, nearly a half percent less internal fat and 7 cm^2 larger LMA. Overall, this translated into a greater quantity of fabricated lean cuts from young bull carcasses as compared to their steer mates. It must be noted that these bulls were fed as a lean supply of beef for the fast food industry and steers were fed for the conventional retail low choice market and both were slaughtered at similar weights.

A general review of the literature comparing bulls with steers and heifers for growth and carcass traits offers many straight forward points. As already mentioned, bulls exhibit superior performance and consequently, if bulls and steers are slaughtered at the same age, the bulls will yield heavier carcasses (Hedrick et al., 1969). Arthaud et al. (1969) showed the hot carcass weight of bulls to be 24.5 kg more than that of steers 240 days post-weaning. However, when evaluating cattle of the same sex, similar genetics, and environment, heavier carcasses will usually possess a greater fat thickness, more marbling and consequently have a smaller proportion of fat-free lean tissue (Kauffman et al., 1975).

The fat thickness of steer carcasses is usually much greater and more variable than that of similar sized bull carcasses (Warrick et al., 1970). Field (1971) reviewed 12 different bull/steer comparisons and found bulls to be on average 5 mm leaner over the 12th rib than steers. Much larger differences exist, however, as Gortsema et al. (1974) found steers to have 1.2 cm more FAT than bulls at 285 kg carcass weight. Hedrick et al. (1969) similarly found a difference of 0.8 cm in fat favoring bull carcasses. The magnitude of the difference in fat cover between the sexes varies greatly in the literature.

Area of the longissimus muscle is also greater in the bull (Jacobs et al., 1977) as compared to steers. Nichols et al. (1964) suggests that when LMA is expressed on a per hundred weight basis, bulls and lighter weight cattle show significant advantages. Hedrick et al. (1969) found bulls to possess a 17.7 percent and a 17.6 percent greater LMA than steers when compared on a constant weight or age basis, respectively. Similarly, Gortsema et al. (1974) reported that bulls have 19 percent more LMA than steers. In contrast Bailey and Hironaka (1969) did not find a significant advantage for bulls at 440 kg live weight.

Steers, however, exhibit significant advantages in quality related attributes (Jacobs et al., 1977). A review of eight different studies by Field (1971) suggests that steers consistently score one to two full marbling scores higher than bulls and that it is unlikely that a high percentage of bull carcasses could ever develop more than a small degree of marbling. Arthaud (1970) found bulls to grade two-thirds of a quality grade lower than steers and Bailey and Hironaka (1969) reported only 24 percent of bulls as compared to 77 percent steers graded choice. Garrett and Hinman (1971) found that heifer carcasses generally averaged 0.5 to 1.0 percent higher either extract than steer carcasses of the same quality and yield grade. Bulls appear to exhibit a more advanced physiological maturity at the same chronological age than steers as evidence by a darker colored, coarser textured lean (Nichols et al., 1964; Champagne et al., 1969; Glimp et al., 1971; Arthaud et al., 1977).

Serial Slaughter

Because of the high cost involved, the amount of serial slaughter information available in the literature is quite limited. Following is a brief description of some of the serial slaughter studies that are applicable to the changes in body composition during final stages of the feeding period. Zinn et al. (1970) fed 100 Hereford steers and 100 Hereford heifers an identical diet and starting at approximately 8 months of age slaughtered 20 animals every 30 days to examine changes in growth and carcass traits as influenced by time on feed. Stringer et al. (1968) fed 200 head of Angus, Hereford, and Polled hereford sired calves for 139 days post-weaning. From that time they slaughtered 40 head of the calves every 28 days providing five slaughter dates ranging from 139 to 251 days on feed. Jesse et al. (1976) fed 56 Hereford steers four different rations and evaluated them at four different weight endpoints (227, 341, 454, and 545 kg) for performance and composition which was determined by physical separation and chemical analysis. In this study, composition was not affected by diet. Cianzio et al. (1982) slaughtered eight steers from each of two predetermined size groups (sorted by 180-day weight) every two months from 11 to 19 months of age. They physically separated half of each carcass and were mainly concerned with changes in weight and percent of fat in specific fat depots. Nour et al. (1983) fed 145 large and small cattle (Holstein and Angus) two diets in either individual pens or in group housing. They slaughtered the steers at 45 kg intervals for both breeds, the Angus from 363 to 544 kg and the Holstein from 454 to 635 kg. Composition was not ($P > .05$) affected by diet and the only housing affect was a larger LMA ($P < .05$) for individually penned cattle. Barber et al. (1981) fed 56 Angus and 56 Charolais steers two diets of differing energy level. These steers were serially slaughtered at weight constant endpoints (Angus at 267, 409, 472, 534 kg and Charolais at 270, 516, 602, 681 kg). Lastly, Reiling (1991) reported that 100 steers and 99 bulls of two frame sizes (medium and large) and similar genetics were serially slaughtered at three dates. These cattle were spring-born (March and April) and were slaughtered in either June, July, or August of the following year.

Growth traits

Zinn et al. (1970) and Stringer at al. (1968) both report significant increases in live and carcass weight at each slaughter endpoint (days on feed). In general, these reports all suggest some decrease in average daily gain (ADG) towards the end of the feeding period. Zinn et al. (1970) found ADG to increase with days on feed to .93 kg at 180 days on feed and then level off or even decline slightly. This agreed with Stringer et al. (1968) who found a declining trend in ADG toward the end of the feeding period. Barber et al. (1981) reported that ADG for both Angus and Charolais steers decreased ($P < .01$) as weight increased and Reiling (1991) noted that ADG tended to increase early in the feeding period, plateaued, and then dropped off through the summer months for all sex and frame types. This decrease in ADG towards the end of the feeding period could be partially due to the heat of summer (Reiling, 1991), but much of this decrease in gain was likely due to increased fat composition of gain late in the feeding trial (Stringer et al., 1968). It is widely accepted that it requires two and a quarter times greater energy to produce a pound of fat relative to protein. Thus, it would appear that composition of gain is important in determining feedlot performance throughout the feeding period.

Barber et al. (1981) reported that there was a tendency ($P < .07$) for the Charolais steers to sustain a higher ADG than the Angus steers in the final periods. This is in agreement with Reiling (1991) who found that the larger-framed cattle maintained higher interval ADG throughout the trial. This would seem reasonable, since at the same age larger-framed cattle would likely be less advanced upon their growth curve as compared to smaller-framed cattle (Verde and Trenkle, 1987). The larger-framed cattle at the same point in time would be growing a larger percentage of protein or muscle relative to fat (Miller et al., 1987). Reiling's (1991) work indicates that large-framed cattle gained 13.6 percent faster ($P < .001$) through the first processing date and maintained a significant advantage ($P < .01$) in growth through the final two slaughter dates. This report also shows that bulls gained 7.6 percent faster ($P < .05$) than their steer mates through the first 173 days on feed, this advantage dropped to 5.8 percent ($P < .05$) through the second period and 5.1 percent ($P < .08$) after being fed 232 days. The increased growth performance of bulls in the feedlot is due in part to differences in hormonal secretions involved with nitrogen metabolism resulting in more lean tissue growth relative to adipose (Galbraith et al., 1978). However, many of these same hormone compounds stimulate the onset of sexual development and puberty which are, in part, responsible for managerial and production difficulties that can reduce performance as indicated above. Bailey and Hironaka (1968) also showed a trend, in both bulls and castrates, for gains to decline by approximately 32 percent from the growing to finishing phases of production. This is further supported by Reiling (1991) and Watson (1969) who found ADG of bulls to decrease near the perceived onset of puberty and the differences in ADG between bull and steer mates to narrow.

Muscle traits

Stringer et al. (1968) reported an increase in LMA in all slaughter periods except the third (out of five), but noted that the increase in LMA was not proportional to the increase in carcass weight, indicating a slowing of muscle deposition. Physical separation and chemical analysis work by Jesse et al. (1976) indicates that carcass protein decreased from 18.39 percent to 13.40 percent as live weight increased from 227 to 545 kg. Longissimus muscle area was larger for Charolais than Angus but increased in both breeds as slaughter age and weight increased, however, these progressively longer LMAs associated with increases in slaughter weight reflect increases in total amount of muscle rather than a change in muscle distribution or proportion of retail product (Barber et al., 1981). Reiling (1991), on the other hand, found only the large-framed bulls to increase ($P < .01$) in LMA over time and suggested that since these cattle did not change in fat cover, increased carcass weights were apparently due to this increased muscle mass.

Fat thickness

Reiling (1991) reported that steers showed a greater tendency to increase subcutaneous fat cover over time than bulls. Medium-framed steers produced carcasses with 0.38 cm ($P < .01$) more fat cover after 204 days on feed as compared to 173 days on feed. Differences for large framed steers between the first and second slaughter dates only approached significance ($P < .10$), but the 0.35 cm greater fat cover at slaughter three as compared to slaughter one was significant ($P < .05$). Stringer et al. (1968) reported that the greatest increase in 12th rib fat thickness was between 167 and 195 days on feed after that time fat did not significantly increase. Keep in mind that growth rate in this study also decreased at about this time.

Reiling (1991) reported that changes in fat cover especially of large-framed bulls over time were minimal and nonsignificant. Arthaud et al. (1977) processed bulls fed a high-energy diet at 12, 15, 18 and 24 months of age and found fat cover to increase by only 2 mm from 12 to 18 months of age and an additional 3 mm at 24 months of age.

Cianzio et al. (1982) reported that both medium- and large-frame steers followed a similar pattern of fat deposition and no significant differences were observed in the rate of fattening with respect to muscle plus bone. They also indicate that growth coefficients for disectable fat deposits with respect to total body fat were homogenous between frame sizes and that 12th rib fat thickness was highly correlated with subcutaneous fat (.88), intermuscular fat (.81) and total body fat (.82) weight. Jesse et al. (1976) found that carcass fat increased from 17.25 to 38.11 percent as weight increased from 227 to 545 kg. This study clearly indicates that the largest increase in fat cover is towards the end of the feeding period. The largest increase in fat content occurred after 341 kg. For example, fat gain as a percent of carcass gain changed from 27.48 to 48.57 percent as slaughter weight went from 341 to 545 kg. Finally, fat as a percent of empty body and carcass gain from 454 to 545 kg was 63.37 and 68.26 percent, respectively.

Retail yield

The above descriptions of the increase in thickness and percent fat make it clear that yield grade and percent retail yield decreases throughout the feeding period. Specifically, Reiling (1991) found that yield grades changed significantly from the first to second and third slaughters for medium and large framed steers. Bulls on the other hand had no significant (P > .01) change in yield grade during the described feeding period. These steer results agree with Zinn et al. (1970) who showed a significant decrease in the yield of boneless retail cuts after 270 days on feed, primarily due to an increase in fat trim. Stringer et al. (1968) reported that in market steers weight of retail cuts did not increase proportionately with carcass weight, hot carcass weight increased 53.1 kg while weight of retail cuts only increased 15.4 kg (29%). The first slaughter group had the highest percent retail cuts and each 28-day period showed a significant (P < .05) decline. Stringer et al. (1968) concluded that the most significant effect of extended feeding from 139 to 251 days of age was the increased percent fat and decreased percent retail product.

Quality grade

Reiling (1991) reported that both medium- and large-framed steers increased (P < .01) in marbling scores from the first to either the second or the third slaughter but not between the second and third. Stringer et al. (1968) supports this by noting that quality grade increased approximately one-third of a grade per slaughter period up until 195 days on feed, thereafter no average increase was observed. Likewise, Barber et al. (1981) reported quality grade improved (P < .01) for both breeds (Angus and Charolais) through the middle of the feeding period (472 for Angus and 602 kg for Charolais) after which no significant change was noted. Zinn et al. (1970) on the other hand reported that deposition of intramuscular fat is not a straight line process; rather that it increases in a step-wise manner at 60- to 90-day intervals. Cianzio et al. (1982) reports that marbling is not a later developing fat deposit and it increases as a percent of total body fat similar to other fat deposits.

Rates of change

Several of the research articles report the linear rate of change in carcass traits per kg of carcass weight. Barber et al. (1981) found fat cover to increase .008 and .004 cm/kg carcass weight in Angus and Charolais steers while Fahmy and Lalande (1975) report increases of .007 and .001 for Hereford and Charolais steers. Dinkel et al. (1969) and Jesse et al. (1976) found increases of .009 and .011 cm/kg carcass weight in British breed steers. Finally, Nour et al. (1983) report fat increases of .008 and .004 cm/kg carcass weight for Angus and Holstein steers and suggests that fat deposition certainly appears to be breed dependent.

Linear rates of LMA increase were reported to be .15, .12, .08, and .13 cm^2/kg carcass weight by Barber et al. (1981), Dinkel et al. (1969), Fahmy and Lalande (1975), and Jesse et al. (1976), respectively. Nour et al. (1993) reported that these rates of changes were .118 and .074 cm/kg carcass weight for Angus and Holstein steers, respectively.

Changes in marbling score per kg change in carcass weight appear quite consistent. Jesse et al. (1976) and Zinn et al. (1970) reported this increase to be .025 and .022 units/kg carcass weight, respectively, while Barber et al. (1981), Dinkel et al. (1969) and Nour et al. (1983) all found this change to be .027 units of marbling score/kg carcass weight.

PAPER I. THE RELATIONSHIP BETWEEN REAL-TIME ULTRASOUND AND CARCASS MEASUREMENTS OF 12-13TH RIB FAT THICKNESS AND LONGISSIMUS MUSCLE AREA IN BEEF CATTLE

ABSTRACT

Four hundred ninety-seven steers and 247 bulls were ultrasonically measured for subcutaneous fat thickness (UFAT) and longissimus muscle area (ULMA) between the 12th and 13th ribs just previous to slaughter over a three-year period to evaluate the accuracy of ultrasound measurements. Carcass measurements from experienced evaluators were then used as a basis from which to compare ultrasound. The cattle used were part of a serial scan and serial slaughter project and consequently a great deal of variation in carcass measurements was experienced. Overall, carcass means and (ranges) were as follows: carcass weight 342 kg (227-483 kg); fat thickness (CFAT) 1.16 cm (.13-4.06 cm); and longissimus muscle area (CLMA) 79.9 cm^2 (60.6-115.5 cm^2). The mean differences between carcass and ultrasound measurements, indicative of average bias, were .032 cm and -1.47 cm^2 for FAT and LMA, respectively, indicating that FAT was slightly underestimated and LMA was overestimated. Further evaluation of these differences indicates that, in general, fatter animals (CFAT > 1.27) were underestimated and leaner animals (CFAT < .76 cm) were overestimated. Also, animals with CLMA > 90.3 cm^2 were more likely to be underestimated by ultrasound while those with CLMA < 83.9 cm^2 were more likely to be overestimated. Mean absolute values of the differences between carcass and ultrasound measurements gave an indication of the average error and were .227 cm and 5.09 cm^2 for FAT and LMA, respectively. The thickness of CFAT had a significant ($P < .05$) effect on the error of UFAT measurements with leaner animals being more accu-

rately evaluated. This was likely to be responsible for the fact that bulls were evaluated for FAT with less error than steers. Correlation coefficients between carcass and ultrasound measurements of FAT and LMA were .86 and .78, respectively. The FAT correlations were fairly consistent across subclasses whereas LMA correlations were more variable and generally lower. Although correlation coefficients suggest that FAT is more accurately evaluated than LMA when expressed as a percentage of carcass measurements, the average absolute differences indicated proportional error rates of 22.6 percent for backfat and 6.5 percent for longissimus muscle area. Frequency analysis found that UFAT was within .25 cm of CFAT over 66 percent of the time while ULMA was within 6.5 cm^2 of CLMA over 71 percent of the time. Standard errors of prediction corrected for bias of ultrasound measurements were .29 cm and 6.25 cm^2 for FAT and LMA, respectively. Each of the above mentioned evaluations of accuracy were also compared within sex, fat thickness categories, and longissimus muscle area categories in an attempt to describe the accuracy of ultrasound in different classes of beef cattle.

INTRODUCTION

Consumer demand for a lean, health-oriented protein source has caused a great deal of discussion about change in the red meat industry. Since the National Consumer Retail Study (Savell et al., 1989), all segments of the beef industry have waited for the expected economic signals to crystalize in the marketing system so that they could respond. Packers and retailers have responded to consumers' demands for a leaner product by trimming excess fat from beef cuts before they reach the retail case. This short-term solution to the problem is inefficient and very costly to all segments of the industry. Although there has been a great deal of discussion about a value-based marketing system that would offer financial incentives for production of a superior product, the vast majority of today's fed cattle continue to be sold on averages. Until producers are presented a set of specifications and offered some type of financial incentive to produce a superior product, little change is likely to occur (Cross et al., 1992).

Even when these incentives become a reality, evaluation and improvement of carcass merit at the producer level is no small task. Collection of carcass information on an individual animal basis is time consuming, expensive, and requires packer cooperation. Additionally, the segmented structure of the cattle industry makes it very difficult to maintain identification and contemporary grouping that is so vital to the genetic evaluation of carcass merit. Finally, the past inability to measure carcass merit of breeding animals themselves requires that animals be progeny tested for carcass traits, which greatly increases cost and generation interval of carcass evaluation and reduces the potential genetic gain per year.

Real-time ultrasound is a tool that has the potential to aid producers in overcoming these obstacles. The use of ultrasonics was first reported by Wild (1950), who stated that the ultrasonic technique is nondestructive, humane, and provides a means of quantifying muscle and fatty tissues in live animals. Like most technology, ultrasound has advanced a great deal since the 1950s. The real-time ultrasound machines currently used to scan livestock were either adapted from the medical industry or developed specifically for animal use. These light weight, portable units have the potential to produce quick and accurate measurements of carcass merit at a moderate cost (Robinson et al., 1992).

The basic principle of ultrasound is to evaluate echoes rebounding from soft tissue. Ultrasound is a complex array of electronics that produce sound waves with frequencies above that detectable by the human ear (Perkins et al., 1992). When the ultrasound transducer is placed on the animal, these sound waves travel into the body and are reflected from boundaries between different densities of tissues (Houghton and Turlington, 1992). These reflected sound waves are then processed by the machine, producing a cross-sectional image of the tissue interfaces on the screen of the ultrasound unit. These images do not distinguish specific tissue types but they do map tissue boundaries. An understanding of the anatomy being scanned then allows the technician to interpret the image and take measurements such as fat thickness and longissimus muscle area from a cross-sectional image between the 12th and 13th ribs along the topline of beef cattle. Consequently, the usefulness of this technology in measuring carcass merit in beef cattle is very dependent on the technicians ability to collect and correctly interpret the images.

In a review article, Houghton and Turlington (1992) found that correlation coefficients between live animal ultrasonic and carcass measurements of fat thickness and longissimus muscle area varied from .42 to .92 and from .47 to .96, respectively. This report concluded that, with an experienced operator, real-time ultrasound technology has the potential to very accurately assess carcass fat thickness and in most cases accurately measures longissimus muscle area. Other assessments of accuracy that have been reported are frequency distributions of differences between carcass and ultrasound measurements (Houghton and Turlington, 1992; Perkins et al., 1992) and the standard error of prediction (Robinson et al., 1992) of ultrasound measurements. Quality grade as determined by marbling score is obviously one of the important traits evaluated in determination of carcass value. Although ultrasound technology also has great potential in this area of carcass evaluation, this work is in its early stages and will not be addressed in this report.

As an accurate measure of fat cover and longissimus muscle area, real-time ultrasound offers several avenues through which improvement in end product can be made. One would be as a tool to sort cattle for market based on composition. A second would be as a tool to perform instrument grading of beef carcasses, thus providing an objective evaluation of yield and quality grades. Perhaps the most important possibility is the evaluation of carcass merit in the live breeding animal itself. Thus, reducing the dependence solely on progeny testing and potentially shortening the generation interval required to evaluate carcass traits.

The objective of this study was to evaluate the accuracy of ultrasonic estimates of fat cover and longissimus muscle area in live beef cattle. Accuracy was evaluated by 1) correlation coefficients, 2) frequency distributions, and 3) standard errors of prediction. The influence of sex (bull vs. steer) as well as the magnitude of the carcass measurements were also examined for their effect on these three measures of accuracy.

MATERIALS AND METHODS

Real-time ultrasound technology was utilized to evaluate both steers (N = 497) and bulls (n = 247) for carcass merit over a three-year period. These cattle were part of the Iowa State University (ISU) beef cattle breeding project and were born and raised at either the Rhodes or McNay research centers. Three composite lines of cattle developed to differ in frame size (small, medium, and large) were represented. In 1990 and 1991, half of the males of each size line were fed as bulls and half as steers. In 1992, all animals in this study were fed as steers.

All cattle were born in the spring (March-April), weaned in the fall, and started on feed in November. Once on feed the cattle were gradually worked up to an 85 percent concentrate corn-corn silage diet which was maintained throughout the feeding period. Each frame by sex subclass was divided into two pens in the first two years such that the average age of the pens were similar within each subclass. In 1992, the steers were penned in a similar manner. These cattle were all part of a serial scan and serial slaughter project designed to evaluate changes in composition over time, sex differences, and ultimately genetic evaluation of carcass traits as measured by real-time ultrasound. Consequently, the cattle were scanned multiple times throughout the feeding period and were slaughtered over a three-month period each year. Because of the objectives of this paper only the scan information collected just previous to slaughter will be examined.

In 1990, an Aloka 633 (Corometric Medical Systems, Wallingford, CT) real-time ultrasound machine equipped with a 12.5 cm, 3.5-MHz linear array transducer was used to scan the cattle. Cross-sectional images were obtained using the split-screen display capability of this equipment because the transducer length did not allow the entire area of interest to be imaged with a single scan. In 1991 and 1992, an Aloka 500V (Corometrics Medical Systems, Wallingford, CT), equipped with a 17 cm, 3.5MHz linear array transducer, developed specifically for animal applications was used to scan the cattle. This new generation of equipment allowed the entire area of interest to be imaged at once, eliminating the need for the split-screen capability.

After being restrained in a squeeze chute, the scanning site, as determined by physical palpation, was located between the 12th and 13th ribs near the midline on the animals right side. Once located, this area was clipped, oiled and curried until it was free of dirt and debris and then oiled again for optimum image quality. Vegetable oil was used as a couplant to obtain adequate acoustic contact. A Superflab (Nicks Radio-Nuclear Instruments, Inc., Bronx, NY) transducer guide cut in the general shape of the area to be scanned was used to ensure proper contact between the rigid ultrasound transducer and the curvature of the animal's topline. The guide also aided in proper matching of the medial and lateral halves of the image when using the split-screen capability of the Aloka 633, as it was designed to be exactly twice as long as the scanning surface of the transducer.

After the scan site was prepared and when the animal was standing in a natural position and relatively still, the scan was taken. The guide and transducer were placed near the midline, parallel to the 12th and 13th ribs and moved laterally until the entire longissimus muscle came into view on the screen. The transducer was then physically manipulated until the image was as clear as possible. Care was taken to ensure that the image was, in fact, being taken between the ribs and that all anatomical boundaries were located. The captured image, containing the date and animal identification number, was then recorded on a standard one-half inch VHS video cassette recorder for later interpretation. With an experienced technician and adequate restraining facilities this process can be performed on approximately 25 to 30 animals per hour.

Recorded images were redigitized and interpreted using MEDMORPH (Woods Hole Educational Associates, Woods Hole, MA), a software package developed to allow technicians to make linear and area measurements on images, and directly record these measurements in a database. The technician measured ultrasound fat thickness (UFAT) at a point three-quarters of the distance from the medial to the lateral end of the longissimus muscle and perpendicular to the hide. Ultrasonic longissimus muscle area (ULMA) was then interpreted by tracing the periphery of the longissimus muscle from the digitized ultrasound image.

Throughout the three-year period there were two experienced technicians who actually collected the images. There were two technicians who interpreted all of the ultrasound images, one interpreted all images gathered in 1990 and the other performed all interpretations in 1991 and 1992. This second technician was also one of the two who actually collected the images. These technician effects, both collecting and interpreting images, however, cannot be addressed because they are confounded with year and more importantly the model of ultrasound unit used to collect the images.

The cattle were slaughtered at one of two commercial processing facilities within three days of the time the scans were obtained. In 1990 and 1991, carcass data were collected approximately 24 hours after slaughter. In 1992 the carcasses were chilled a minimum of 48 hours before data were collected. All routine carcass data were collected by faculty and graduate students experienced in carcass evaluation with the exception of marbling score and USDA quality grade which were evaluated by a USDA Grader. For this paper, the only carcass measurements of interest are carcass fat cover (CFAT) measured three-quarters of the distance from the medial end of the longissimus muscle and carcass longissimus muscle area (CLMA) measured at the 12th and 13th rib interface.

All statistical analyses were conducted using SAS (1989). Data were initially evaluated by analysis of variance using least squares procedures to evaluate sources of variation, including effects of sex of animal and the year the animal was scanned. Pearson correlation coefficients were used as one way to evaluate the relationship between specific carcass and ultrasound measurements.

Several variables were created in an attempt to evaluate differences between carcass and ultrasonic measurements of carcass traits and ultimately assess accuracy.

$$FDIFF = (CFAT - UFAT)$$

$$FDEV = |CFAT - UFAT|$$

PFDEV = (|CFAT - UFAT|/CFAT)

LDIFF = (CLMA - ULMA)

LDEV = |CLMA - ULMA|

PLDEV = (|CLMA - ULMA|/CLMA)

So that accuracy of ultrasound measurements can be compared within specific ranges of carcass measurement the data were also divided into five fat categories and five longissimus muscle area categories as follows:

FATCAT 1: CFAT ≤ .51 cm

2: CFAT > .51 and ≤ .76

3: CFAT > .76 and ≤ 1.02

4: CFAT > 1.02 and ≤ 1.27

5: CFAT > 1.27

LMACAT 1: CLMA ≤ 71.0 cm^2

2: CLMA > 71.0 and ≤ 77.4

3: CLMA > 77.4 and ≤ 83.9

4: CLMA > 83.9 and ≤ 90.3

5: CLMA > 90.3

The created variables (FDIFF, FDEV, PFDEV, LDIFF, LDEV, and PLDEV) were analyzed with the same analysis of variance procedure as the carcass data. Least squares means of these variables were calculated for the whole data set as well as by several subclasses (sex, year x sex, FATCAT and LMACAT). Interpretation of the difference means (FDIFF and LDIFF) will reveal the amount and direction of bias of the ultrasound measurement. The deviation means (FDEV and LDEV) are simply an indication of the average amount of difference (error) between the two measurements and the percent deviation variables (PFDEV and PLDEV) express these deviations as a percent of the carcass measurement. Frequency distributions of the deviation variables were created to evaluate the proportion of these deviations that are within a specified range.

The final assessment of accuracy is the standard error of prediction. This statistic is thought by some researchers (Robinson et al., 1992; Thallman, 1992) to be the primary measure of this technologies ability to correctly rank or predict differences between animals correctly. Robinson et al. (1992) reports that this measure of accuracy is appealing because by squaring differences, a few large errors are properly considered more serious than a greater number of small discrepancies.

$$SEPFAT = \sqrt{\sum_{i}\sum_{j} \frac{(CFAT-UFAT-BIAS*)^2}{n-1}}$$

*Bias = mean FDIFF in the subclass of interest.

$$SEPLMA = \sqrt{\sum_{i}\sum_{j} \frac{(CLMA-ULMA-BIAS*)^2}{n-1}}$$

*Bias = Mean LDIFF in the subclass of interest.

The standard error of prediction is one of the major criteria for evaluating accuracy of ultrasound measurements in current ultrasound certification clinics.

RESULTS AND DISCUSSION

Least squares means and standard deviations for carcass measurements relevant to this study are presented in Table 1. Based on the overall means this is a fairly representative sample of feedlot cattle. Although the means are similar to a typical set of feedlot cattle, the standard deviations indicate that there is a great deal of variation. The overall ranges for carcass parameters were: hot carcass weight (HCW) 227-483 kg, CFAT .13-4.6 cm and CLMA 60.6-115.5 cm^2. These standard deviations are larger (.56 and 9.6) than those reported in recent accuracy papers, .38 and 9.2 (Perkins et al., 1992); .45 and 8.0 (Smith et al., 1992) for CFAT and CLMA, respectively. The cattle in this study were part of a serial scan, serial slaughter study that was designed to examine compositional changes and sex differences over a wide range of end points, hence the amount of variation is larger than might be expected.

When examined by sex (Table 1) it is clear that bulls had heavier HCW (355 vs. 335 kg), larger CLMA (84.4 vs. 77.6 cm^2) and were leaner (.86 and 1.31 cm) than steers. Table 2 shows a highly significant ($p < .01$) sex effect for all three traits (HCW, CFAT, and CLMA). Studies by Hedrick et al. (1969) and Arthaud et al. (1970) agree with these results for HCW and suggest that if bulls and steers are slaughtered at the same age, bulls will yield heavier carcasses. Warrick et al. (1970) found that fat thickness in steer carcasses is usually much greater and more variable than that of similar sized bull carcasses. The magnitude of the difference in CFAT between sexes varies greatly in the literature but a

Table 1. Least Squares means and standard deviations of carcass measurements

Year	Sex	n	Hot carcass weight,kg	CFAT,cm	CLMA,cm^2
1990	Steers	191	340±47	1.37±.66	79.3±8.9
	Bulls	103	380±44	.91±.45	88.8±9.4
1991	Steers	151	322±42	1.15±.46	75.2±7.9
	Bulls	144	337±50	.82±.31	81.3±9.9
1992	Steers	155	342±40	1.40±.52	77.9±7.7
All Steers		497	335±44	1.31±.57	77.6±8.4
All Bulls		247	355±52	.86±.38	84.4±10.4
Overall		744	342±48	1.16±.56	79.9±9.6

Table 2. ANOVA F-values for the effects of year and sex[a,b]

	Effect		
Variable	Year	Sex	Error
CFAT	14.18**	85.31**	.254
UFAT	38.54**	112.90**	.203
FDIFF	12.14**	.24	.066
FDEV	14.89**	4.65*	.025
PFDEV	3.54⁺	5.65*	.055
CLMA	57.29**	105.58**	81.15
ULMA	54.03**	121.56**	71.68
LDIFF	1.02	.02	34.67
LDEV	16.11**	.57	12.78
PLDEV	21.82**	.25	.002

[a]F-value for each source of variation with error mean square given.

[b]Only 1990 and 1991 data were used, 1992 included steers only.

+P < .10.

*P < .05.

**P < .01.

review by Field (1971) found that on average bulls were .5 cm leaner than steers which is in close agreement (.45 cm) with these results. Hedrick et al. (1969) and Gortsema et al. (1974) report that bulls have 17.6 and 19.0 percent, respectively, more CLMA than steers. These data suggest a more moderate (8.8%) but significant ($p < .01$) advantage for bulls in CLMA.

Carcass measurement of 12-13th rib fat cover (CFAT) and longissimus muscle area (CLMA) will be the basis from which to compare ultrasound measurements. However, one must keep in mind that carcass measurements are not without error and this could have an effect on the perceived accuracy of ultrasound. For example, Smith et al. (1992) found the correlation between two types of CLMA measurements (standard dot grid vs. acetate tracing that was evaluated on an electronic digitizing board) to be .89. Similarly, Rouse et al. (1992) obtained correlations of .97 and .94 between two experienced carcass evaluators for CFAT and CLMA, respectively. Robinson et al. (1992) reported that there was an overall difference between two CLMA tracers of 1.3 cm^2, presumably due to the tendency of carcass evaluators to deviate either to the inside or the outside of the muscle boundary. Consequently, there are evaluator differences in carcass measurements, and although they are perhaps the best we can do, they are not without error.

Table 3 relates the product moment correlations (Pearson) between carcass and ultrasound measurements of FAT and LMA. The overall correlations for FAT (.86) and LMA (.78) are in close agreement with the average correlations presented in a review of recent accuracy studies adapted

Table 3. Correlations between carcass and ultrasound measurements of 12-13th rib fat cover and longissimus muscle area

Year	Sex	n	FAT	LMA
1990	Steers	191	.89	.82
	Bulls	103	.82	.83
1991	Steers	151	.85	.70
	Bulls	144	.77	.75
1992	Steers	155	.87	.59
	All Steers	497	.84	.72
	All Bulls	247	.79	.81
	Overall	744	.86	.78

from Houghton and Turlington (1992) of .86 and .73 for FAT and LMA, respectively. Although this review reveals some variation in accuracy values, it agrees with the current study that, from the standpoint of correlation coefficients, ultrasound is a very accurate estimator of CFAT. The range in correlations between carcass and ultrasound LMA is quite large in Houghton and Turlington (1992) (.20-.90) but results from this study ($r = .78$) as well as several others with very experienced operators (Moylan et al., 1991; Perkins et al., 1992, 1992b; Robinson et al., 1992; Waldner et al., 1992) suggests the relationship is quite strong ($r = .60$ to $r = .87$).

The vast majority of the studies evaluating the accuracy of ultrasound involve market animals (steers and heifers). Because of the intense interest and potential application of using ultrasound to evaluate carcass traits in breeding animals, it is important to compare accuracy by sex. Correlations in Table 3 suggest that, both within a year and across years, steers are more accurately evaluated for FAT than bulls. These differences are fairly small and are likely a function of the variation differences between the two sexes. Longissimus muscle area correlations, on the other hand, tend to favor the bulls. Again these differences are fairly small, especially within year. The authors hypothesize that a portion of this advantage for bulls stems from the fact that it seems easier to obtain a high quality image and suspect that this is related to the fact that bulls are leaner. This area will be addressed more closely later in this report.

The correlations between carcass and ultrasound measures of FAT by year are very similar. The LMA correlations on the other hand are not, and this decline in correlation is difficult to explain or understand. It could be partially due to sampling but is most likely due simply to a poorer job of collecting and interpreting both carcass and scan data.

Houghton and Turlington (1992) warn that although correlation coefficients are useful, it is important to understand the limitations associated with this method of reporting accuracy. These limitations include the fact that population variation influences correlation coefficients (i.e., a larger than normal amount of variation can produce higher correlation coefficients and visa-versa). Also, correlation coefficients do not reflect bias (i.e., an ultrasonic technique that consistently under- or overestimates carcass measurements). With these limitations in mind, alternate methods of reporting accuracy are presented.

Table 4 relates means of the created variables that describe differences between carcass and ultrasonic measurements of FAT. Over all years and sexes (n = 744) the bias in ultrasound measurement of FAT (FDIFF) was .032 cm which is in agreement with Perkins et al. (1992) who found that underprediction occurred more often than overprediction. In 1990, FDIFF suggests that both sexes were overestimated slightly. In 1991, however, the amount of bias is similar in magnitude, but opposite in sign between the sexes. There are no other steer versus bull studies to compare this with directly. However, Robinson et al. (1992), Smith et al. (1992), and Waldner et al. (1992) all found that, in general, leaner animals were overestimated and fatter animals were underestimated. These studies agree with the trend in 1990, knowing that from Table 1 bulls are leaner than steers, but are opposite of 1991. The FDIFF (.275 cm) in 1992 reveals that ultrasound grossly underestimated CFAT. The combination of fatter carcasses and longer chilling time between slaughter and carcass measurements may have contributed to this bias. Mechanical hide pullers tend to cause separation of the fat layers, especially in fatter cattle. The longer chill caused the fat to set up firmer which makes it more difficult for the carcass evaluators to restore the natural contour of the carcass fat and to compress the fat layers back together.

The average FDEV is a clearer indication of the amount of error in ultrasound measurements, as it simply represents the mean absolute value

Table 4. Least squares means of difference and deviation variables for 12-13th rib fat thickness

Year	Sex	FDIFF,cm	FDEV,cm	PFDEV,%
1990	Steers	-.057±.019	.241±.012	21.4±1.6
	Bulls	-.087±.025	.218±.017	29.6±2.1
1991	Steers	-.023±.021	.195±.014	21.2±1.8
	Bulls	.029±.021	.161±.014	22.3±1.8
1992	Steers	.275±.021	.306±.014	21.3±1.7
All Steers		.057±.013	.247±.008	21.3±1.0
All Bulls		-.019±.018	.184±.011	25.4±1.3
Overall		.032±.011	.227±.007	22.6±0.8

of the difference between the two measurements. The mean FDEV over all years and sexes (.227 cm) in Table 4 is similar to the results of Perkins et al. (1992) (.19 cm) and slightly larger than Brethour (1992) (.157 cm). Means within years for bulls and steers were not different ($p > .10$). In general, the smallest deviations of ultrasound from carcass measurements occurred in 1991 and the largest in 1992. Pooled means across years suggest that FAT in bulls is estimated with less ($p < .05$) error than in steers. Comparison of FDIFF and FDEV values by year reveals that the majority of the error (FDEV) in 1992 is a result of the bias (FDIFF) which is certainly not the case in the first two years.

Table 4 also presents the error (FDEV) as a proportion of the carcass measurement (PFDEV). It seems logical that these two variables may be related. The PFDEV over all years and sexes (22.6%) is again very similar to results presented by Perkins et al. (1992) (20.6%). In 1990, PFDEV was greater ($p < .05$) in bulls than in steers, the same result was found when the data was pooled across all years. Although 1992 represented the most bias (FDIFF) and error (FDEV) when this error is evaluated as a proportion of the actual amount of CFAT the PFDEV (21.3%) is virtually identical to 1990 and 1991, 21.4 percent and 21.2 percent, respectively.

Analysis of variance of these three created variables (FDIFF, FDEV, and PFDEV) are presented in Table 2 using data from years with both sexes represented. This analysis suggests that sex was not ($p > .05$) an important source of variation in bias (FDIFF) but that effect of sex was significant ($p < .05$) for both error (FDEV) and proportional error (PFDEV) variables. In a study evaluating accuracy of ultrasound in market steers and heifers, Perkins et al. (1992) found that sex was not a significant source of variation for either bias or error variables. But the mean carcass measurement between the two sexes (steers and heifers) in that study were quite similar.

Frequency distributions of FDEV in Table 5 are simply the cumulative percent of the measurements within .25, .51, and .76 cm of carcass measurements. In the total population ($n = 744$), 66.2 percent of the FDEV were $\leq .25$ cm and 93 percent were $\leq .51$ cm. In two studies reported by Smith et al. (1992), similar measures of accuracy yielded frequencies of 74 percent and 62 percent of UFAT measurements $\pm .25$ cm of CFAT.

Table 5. Frequency distribtuion of deviations between carcass and ultrasound measures of 12-13th rib fat cover[a]

			Cumulative percent within specified deviations, cm		
Year	Sex	n	.25	.51	.76
1990	Steers	191	66.7	93.8	98.4
	Bulls	103	63.1	94.2	99.0
1991	Steers	151	72.2	97.4	100.0
	Bulls	144	82.6	97.9	100.0
1992	Steers	155	46.8	82.7	96.2
	All Steers	497	62.1	91.4	98.2
	All Bulls	247	74.5	96.4	99.6
	Overall	744	66.2	93.0	98.7

[a]Values reported are the cumulative percent of FDEV within the specified range.

Perkins et al. (1992) found 70 percent of UFAT measurements to be ±.25 cm of CFAT. In 1990, a higher percentage of the UFAT measurements on steers were ±.25 cm than on bulls and the opposite is true in 1991. This frequency distribution also shows that steers in 1992 were the least accurately evaluated which is no surprise considering that Table 4 found this subclass to have the most bias and error. Across all years the large perceived advantage (74.5% vs. 62.1%) for bulls over steers is obviously affected by the extremely low values of the steers in 1992.

A similar analysis of created variables to describe differences in carcass and ultrasound measurements of LMA begins in Table 6. In the total population, ultrasound overestimated CLMA by 1.47 cm^2. Perkins et al. (1992) reported that their bias was to underpredict the CLMA with ultrasound. In 1990, LDIFF was larger in steers (-.97 cm^2) than in bulls (-.31 cm^2) while in 1991 the opposite was true, -.74 and -1.54 cm^2, respectively. These sex differences within year were not different ($p > .05$). Across all years the amount of bias was larger, but not significantly, for steers than bulls. A fairly large portion of this difference is likely attributable to the great overprediction of CLMA in 1992.

The mean absolute value of the deviation between CLMA and ULMA (LDEV) of the total population was 5.09 cm^2 which is far more accurate than the 7.4 cm^2 reported by Perkins et al. (1992). Mean LDEVs within year are not different ($p > .05$) between sexes. The largest LDEV occurred in 1992 which also had the most biased measurements. Mean PLDEV results are very consistent with LDEV when examined by year and sex as well as across years by sex. The overall mean PLDEV suggests that the average proportional error of ULMA measurements was 6.5 percent of CLMA, which again indicates a more accurate assessment of LMA than reported by Perkins et al. (1992) (PLDEV = 9.4%).

Analysis of data from 1990 and 1991 separately suggest that sex is not a significant source of variation for LDIFF, LDEV or PLDEV (Table 2). Consequently, steers and bulls can be ultrasonically measured for LMA

Table 6. Least squares means of difference and deviation variables for 12-13th rib longissimus muscle area

Year	Sex	LDIFF,cm	LDEV,cm	PLDEV,%
1990	Steers	-.97±.45	4.14±.27	5.3±0.4
	Bulls	-.31±.61	4.11±.37	4.7±0.5
1991	Steers	-.74±.50	5.09±.31	6.8±0.4
	Bulls	-1.54±.51	5.58±.32	7.0±0.4
1992	Steers	-3.50±.50	6.47±.31	8.5±0.4
All Steers		-1.69±.28	5.16±.17	6.8±0.2
All Bulls		-1.03±.40	4.97±.25	6.0±0.3
Overall		-1.47±.23	5.09±.14	6.5±0.2

with equal reliability as determined by differences and deviations between ULMA and CLMA.

Frequency distributions in Table 7 represent the cumulative percent of ULMA measurements within a specified range of CLMA. Over all subclasses, 71.3 percent of ULMA were ±6.5 cm^2, 95 percent were ±12.9 cm^2, and virtually all (99.8%) were ±19.4 cm^2 of CLMA. These results also suggest a slightly more accurate assessment of CLMA with ultrasound than reports by Perkins et al. (1992) and Smith et al. (1992) who found 53 percent and 40 percent, respectively, of scan measurements to ±6.5 cm^2 of

Table 7. Frequency distribution of deviations between carcass and ultrasound measures of longissimus muscle area[a]

			Cumulative percent within specified deviations, cm^2		
Year	Sex	n	6.5	12.9	19.4
1990	Steers	191	81.3	97.4	100.0
	Bulls	103	80.6	99.0	100.0
1991	Steers	151	68.9	97.4	99.3
	Bulls	144	68.1	93.8	100.0
1992	Steers	155	58.3	88.5	99.4
	All Steers	497	70.3	94.6	99.6
	All Bulls	247	73.3	96.0	100.0
	Overall	744	71.3	95.0	99.8

[a]Values reported are the cumulative percent of LDEV within the specified range.

CLMA. These frequency distributions also suggest very little difference in accuracy between sexes within a year, as was shown in Tables 2 and 6. The consistent decline over time in the percent of ultrasound measurements ±6.5 cm^2 of the carcass suggests that perhaps more care needs to be taken when measuring both CLMA and ULMA.

Another way of evaluating accuracy is by the standard error of prediction (SEP). This statistic has an advantage over the mean absolute differences (FDEV and LDEV) because, by squaring differences, a few large errors are properly considered more serious than a greater number of smaller discrepancies (Robinson et al., 1992; Thallman, 1992).

The SEP for FAT and LMA are presented in Table 8 by year and sex as well as overall. It is important to remember that these indicators of accuracy have been corrected for the mean bias in each particular subclass. One of the most interesting comparisons in this table is that of the SEPFAT values by year. Remember that 1992 had the most bias and error. However, after correction for bias, this indication of accuracy (SEPFAT) suggests that 1992 was very similar to 1990 and 1991 in terms of the accuracy of measuring FAT. The accuracy of LMA measurements as determined by SEPLMA has the same trend as previous statistics describing this accuracy, which is a decline in accuracy over time. The SEP by sex indicate that in both traits bulls were evaluated more accurately but only by a very small amount. This is consistent with the examination of differences and deviations previously described.

There is very little information in the literature to compare with these values. Robinson et al. (1992) reports mean SEPFAT of .09 cm and SEPLMA of 5.04 cm^2 for those technicians who passed their accreditation clinic. The maximum SEPLMA to be accredited in this system is 5.50 cm^2 and the maximum SEPFAT was not reported but it assumed to be slightly larger than the mean mentioned above (.09 cm). The SEP for both traits, especially FAT, are far lower than the results of this study. It is

Table 8. Standard errors of prediction for ultrasound measures of carcass traits

	n	SEPFAT,cm	SEPLMA,cm^2
1990	294	.28	5.40
1991	295	.23	6.49
1992	155	.26	7.11
Steer	497	.31	6.27
Bull	247	.23	6.18
Overall	744	.29	6.25

important to realize that Robinson et al. (1992) was dealing with a much different kind of cattle, they averaged only .43 cm CFAT and 55.5 cm^2 CLMA.

After analyzing data from proficiency certification programs in both the United States and Australia, Thallman (1992) suggested that there was a definite scale effect involved in the comparison of data from the two countries. Thallman (1992) suggested the following values for maximum SEP to be certified in the United States: 1) SEPFAT≤.30 cm and 2) SEPLMA≤7.74 cm^2. He went on to say that values of .20 cm and 6.45 cm^2 for SEPFAT and SEPLMA would be acceptable if all cattle had less than 1.27 cm of FAT. Results in Table 8 for the entire population (which certainly has cattle with over 1.27 cm FAT) indicate that, according to these recommendations, ultrasound measurements of FAT and LMA in this study are sufficiently accurate.

It has been reported that accuracy of ultrasound measurements of FAT and LMA may be affected by the magnitude of the carcass measurement (Brethour, 1992; Perkins et al., 1992; Robinson et al., 1992; Smith et al., 1992; Waldner et al., 1992). In general, these reports conclude that ultrasound overpredicts CFAT in leaner cattle and underpredicts it in fatter cattle. With the exception of Waldner et al. (1992) and Brethour (1992) those reports found the same trend in LMA, ultrasound tends to overpredict cattle with smaller LMA (< 71 cm^2) and underpredicts those with larger LMA (> 84.0 cm^2).

To evaluate this idea the current data set was divided into five categories based on CFAT and in a second analysis five categories based on CLMA. Analysis of variance results in Table 9 suggest that FATCAT was a highly significant ($p < .01$) source of variation for bias (FDIFF), error (FDEV) and proportional error (PFDEV). Suggesting that in general the magnitude of CFAT can affect the perceived accuracy of UFAT measures. This analysis also reveals that LDIFF and PLDEV are ($p < .01$) affected by LMACAT but that LDEV ($p > .10$) is not. It is perceived by many ultrasound technicians that the fatter the cattle are, the harder it is to get clear, high quality images and consequently accuracy of LMA estimation is suspected to be lower. Table 9 suggests that this is not true, at least within the ranges of this data, because FATCAT is not a significant source of variation for any of the LMA measures of accuracy.

Table 9. ANOVA F-values for the effects of fat cover and longissimus muscle area categories[a]

	Effect		
Measure	FATCAT	LMACAT	Error
CFAT	679.79**	2.25+	.064
UFAT	236.63**	.99	.104
FDIFF	42.89**	1.08	.066
FDEV	21.14**	1.25	.029
PFDEV	42.41**	1.89	.039
CLMA	1.32	1941.00**	7.75
ULMA	1.29	237.10**	36.77
LDIFF	1.66	27.55**	33.42
LDEV	.69	1.60	15.12
PLDEV	.87	9.26**	.003

[a]F-value for each source of variation with error mean square given.

+P < .10.

*P < .05.

**P < .01.

Least squares means of FDIFF by FATCAT in Table 10 indicate that leaner (< .76 cm CFAT) cattle are overpredicted and that fatter (> 1.27 cm CFAT) cattle are underpredicted with ultrasound. Means of FDEV by FATCAT suggest that the amount of error in ultrasound measurements is similar in all categories with CFAT < 1.02 cm (.176 to .194), when CFAT is between 1.02 and 1.27 cm the mean FDEV is slightly larger (.214 cm) and when CFAT > 1.27 cm FDEV jumps to .313 cm. Examination of PFDEV variables in Table 10 reveals that the proportional error of ultrasound measurements of FAT are very similar in the three fattest categories and then increase rather sharply as one moves to the two leaner categories. These two leaner categories are certainly affected to some degree by the scale of the measuring device, both carcass and ultrasound.

Figure 1 graphically represents the frequency distribution of FDEV by FATCAT and for the whole population. The cumulative frequencies of FDEV that are ≤.25 cm are quite similar in the first four FATCATs and then drop sharply to 50.9 percent when CFAT > 1.27 cm. Table 12 indicates that accuracy of FAT measurements is the best (SEPFAT = .16) when the cattle are leaner (< .51 cm) and the poorest (SEPFAT = .33) when the cattle are fatter (> 1.27 cm) with the change by FATCAT between these two points being fairly consistent.

These results agree with the previously referenced literature concerning bias of ultrasound measurements in different CFAT categories. Also the three alternative evaluations of accuracy (mean FDEV, frequency distributions, and SEP) generally suggest that the accuracy of ultrasound estimates of CFAT are not greatly affected by the amount of CFAT unless

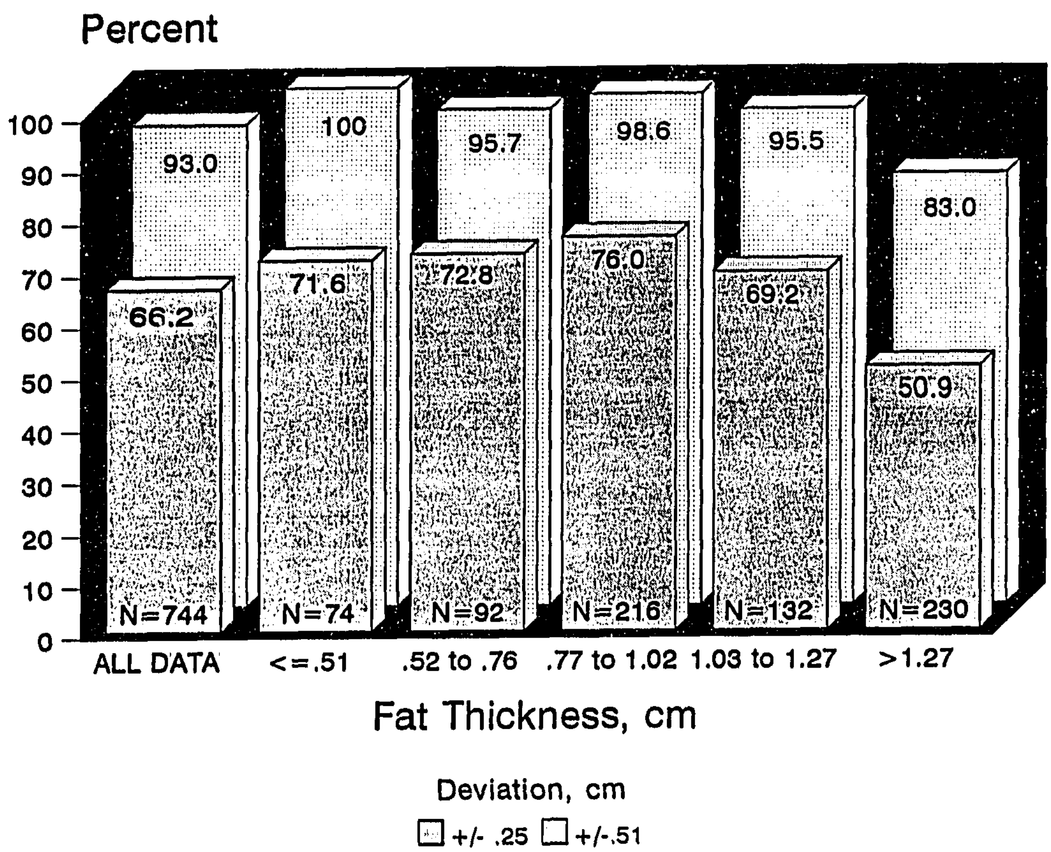

Figure 1. Frequency distributions (%) of deviations between carcass and ultrasound measurements of 12-13th rib fat cover by carcass fat category

Table 10. Least squares means and standard errors of 12-13th rib fat cover difference and deviation variables by fat category

FATCAT	n	FDIFF,cm	FDEV,cm	PFDEV,%
≤ .51 cm	74	-.176±.030	.194±.020	49.0±2.3
> .51 & ≤ .76 cm	92	-.140±.027	.184±.018	28.9±2.1
> .76 & ≤ 1.02 cm	216	-.013±.018	.176±.012	19.7±1.3
> 1.02 & ≤ 1.27 cm	132	.059±.022	.214±.015	18.0±1.7
> 1.27 cm	230	.185±.017	.313±.012	17.2±1.3

Table 11. Least squares means and standard errors of longissimus muscle area difference and deviation variables by longissimus muscle area category

LMACAT	n	LDIFF,cm^2	LDEV,cm^2	PFDEV,%
≤ 71.0 cm^2	159	-3.57±.48	5.52±.32	8.2±.4
> 71.0 & ≤ 77.4 cm^2	173	-2.43±.46	5.35±.31	7.1±.4
> 77.4 & ≤ 83.9 cm^2	189	-1.90±.43	4.66±.29	5.7±.4
> 83.9 & ≤ 90.3 cm^2	118	.04±.54	4.65±.36	5.3±.5
> 90.3 cm^2	105	3.50±.57	4.93±.38	5.1±.5

Table 12. Standard errors of prediction by fat and longissimus muscle area categories of carcass traits measured ultrasonically

Category	SEPFAT,cm	SEPLMA,cm^2
FATCAT		
≤ .51 cm	.16	6.08
> .51 & ≤ .76 cm	.19	5.80
> .76 & ≤ 1.02 cm	.22	6.20
> 1.02 & ≤ 1.27 cm	.26	6.42
> 1.27 cm	.33	6.21
LMACAT		
≤ 71.0 cm^2	.28	5.91
> 71.0 & ≤ 77.4 cm^2	.30	6.16
> 77.4 & ≤ 83.9 cm^2	.28	5.63
> 83.9 & ≤ 90.3 cm^2	.26	5.96
> 90.3 cm^2	.29	5.03

it is > 1.27 cm, at this point all three measures of accuracy decreased.

Least squares means of LDIFF by LMACAT (Table 11) are consistent with results presented by Perkins et al. (1992), Robinson et al. (1992) and Smith et al. (1992) in that ultrasound tended to overestimate LMA when CLMA was small (< 83.9 cm^2) and underestimate LMA when CLMA was large (> 90.3 cm^2). Examination of LDEV means in Table 11 indicate only small differences in the amount of error by LMACAT, which was expected considering the nonsignificance of this effect noted in Table 9. There is, however, a trend towards more accurate evaluation of LMA as CLMA increases in size. The small decrease in PLDEV then makes sense, if the trend is for error (LDEV) to decrease as CLMA increases the proportional error is bound to decrease from the smallest to largest LMACAT. The frequency distribution in Figure 2 shows graphically similar findings. The percent of ULMA that are within ± 6.5 cm^2 of CLMA does not change dramatically with LMACAT. There is, however, a very slight but positive trend in this graph as LMACAT increases from smallest to largest. Table 12 contains SEPLMA by LMACAT, these statistics indicate that accuracy is similar in the first four categories and then increases slightly when CLMA > 90.3 cm^2. In conclusion, the cumulative results do not indicate any strong evidence that accuracy of LMA measured ultrasonically is affected by the magnitude of the CLMA. If anything, there is a trend suggesting the larger LMAs are estimated ultrasonically with a slightly higher degree of accuracy.

Figures 3 and 4 and Table 13 evaluate more closely the effect that FATCAT may have on accuracy of ULMA measurements. Figure 3 suggests that there is not a large or consistent difference in the percent of LDEV ≤ 6.5 cm^2 by FATCAT. The trend was, however, for LMAs to be less accurately evaluated when the animals were fatter. Correlation coefficients in Figure 4 and SEPLMA by FATCAT in Table 12 indicate the same general trends and only small differences. Table 13 indicates that the amount of bias (LDIFF) increases as FATCAT increases. Fatter animals were increas-

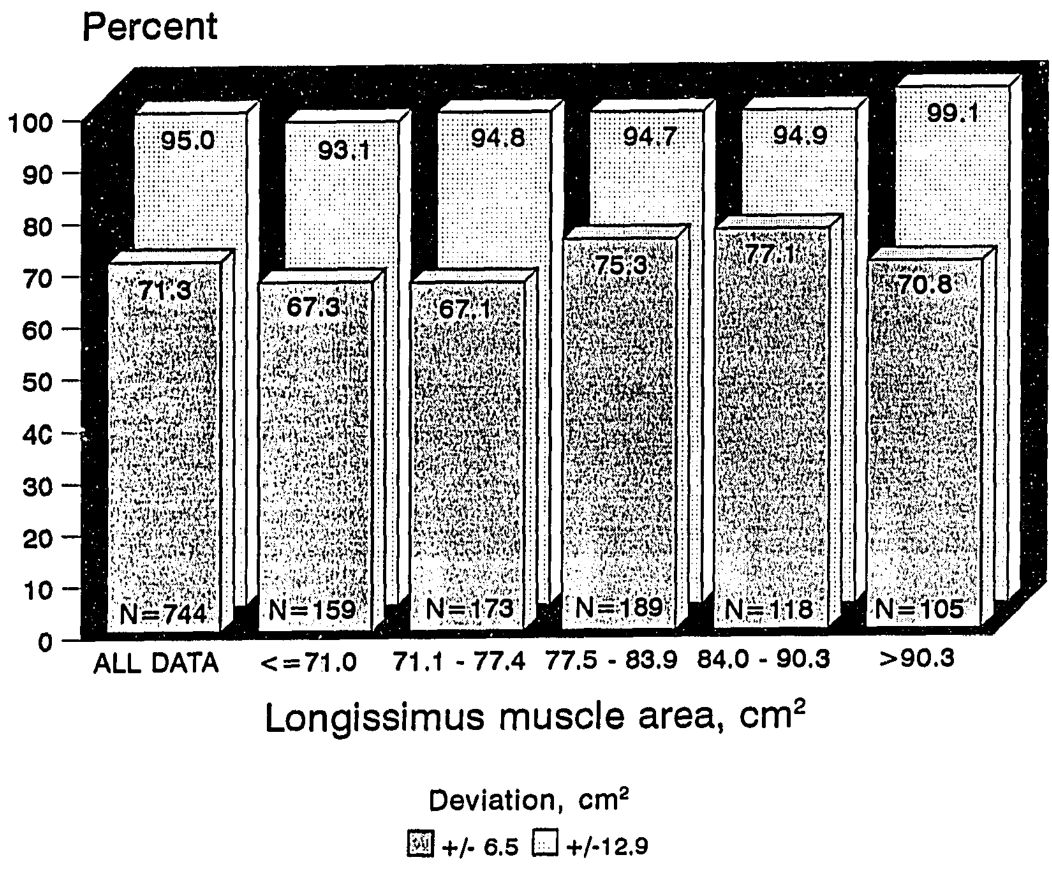

Figure 2. Frequency distribution (%) of deviations between carcass and ultrasound measurements of longissimus muscle area by carcass longissimus muscle area category

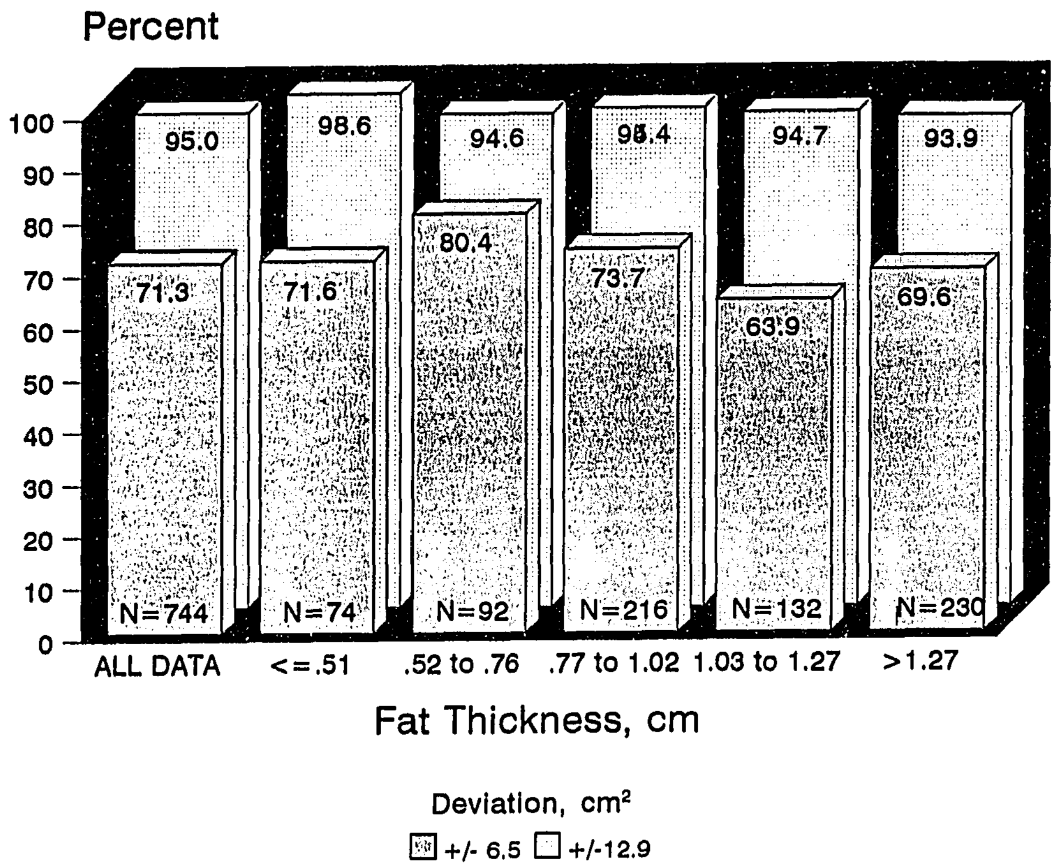

Figure 3. Frequency distributions (%) of deviations between carcass and ultrasound measurements of longissimus muscle area by carcass fat category

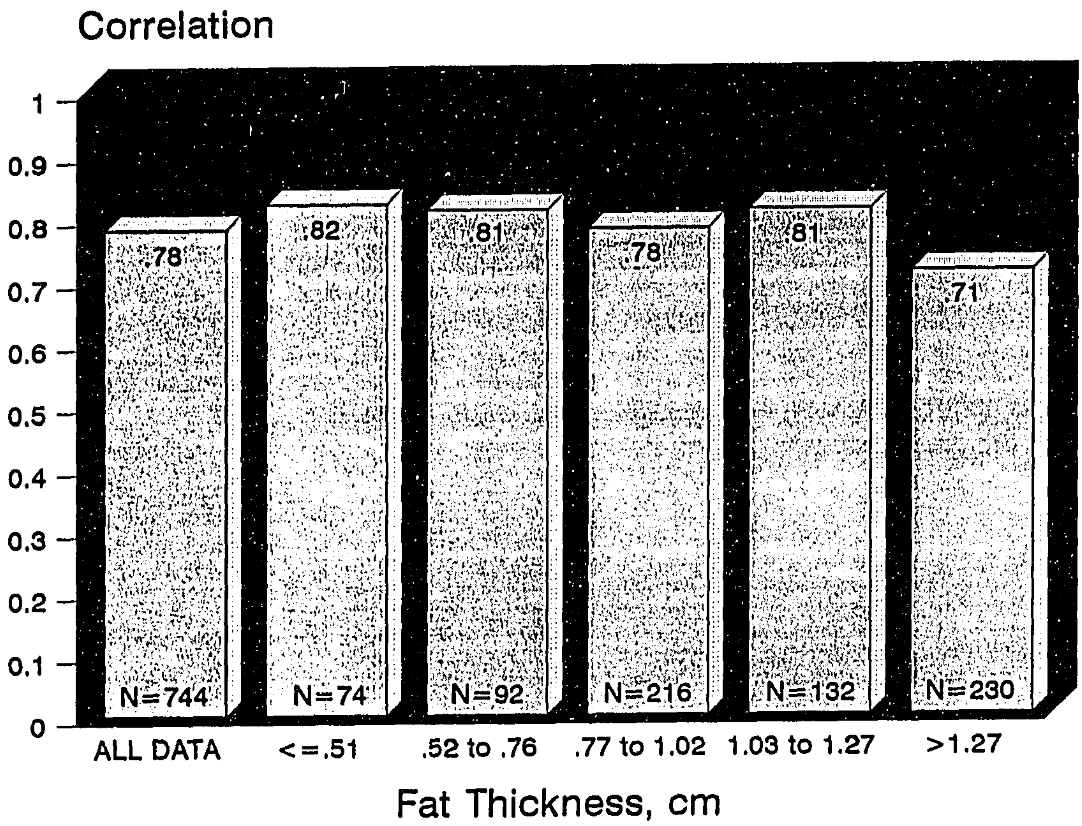

Figure 4. Correlation coefficients between carcass and ultrasound measurements of longissimus muscle area by carcass fat category

Table 13. Least squares means and standard errors of longissimus muscle area difference and deviation variables by fat category

FATCAT	n	LDIFF, cm^2	LDEV, cm^2	PLDEV,%
≤ .51 cm	74	.29±.67	4.98±.45	6.2±.6
> .51 & ≤ .76 cm	92	-.55±.61	4.55±.41	5.7±.5
> .76 & ≤ 1.02 cm	216	-.90±.40	4.98±.27	6.3±.3
> 1.02 & ≤ 1.27 cm	132	-1.30±.51	5.33±.34	6.7±.4
> 1.27 cm	230	-1.57±.39	5.26±.26	6.7±.3

increasingly overestimated for LMA with ultrasound. The differences in LDEV and PLDEV between FATCATS were small but the trend was for animals with >1.02 cm CFAT to be less accurately evaluated for LMA. Consequently, the perception of lower quality images; as a result of more fat cover, causing a less accurate evaluation of LMA cannot be conclusively demonstrated in this study.

IMPLICATIONS

Results of this study and the literature referenced indicate that ultrasound technology has the potential to determine fat thickness in live beef cattle with a high degree of accuracy. The accuracy of ultrasound evaluated longissimus muscle area is in general more variable than that of fat thickness. However, with a well trained technician very respectable accuracy results are possible. Although it may not be perfect, ultrasound can be a useful tool to evaluate carcass traits in live animals. Development and maintenance of technique, proper knowledge of the anatomy and equipment, and most importantly attention to detail on the part of the technician are all very critical to the usefulness of this technology.

Because of the potential variability in accuracy it seems crucial that the industry quickly define the level of precision or accuracy that must be met by commercial and research technicians. It also seems critical that there be some way to periodically monitor the accuracy of technicians especially those whose data may be contributing to some sort of national carcass evaluation.

The potential of ultrasound technology in evaluating carcass merit in breeding and market animals is great but its widespread use at this time in beef cattle is certainly in part slowed by the inability to evaluate marbling. Further enhancement of this area may be the key to ultrasounds acceptance in the beef cattle industry.

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PAPER II. EVALUATION OF GROWTH AND ULTRASONICALLY MEASURED COMPOSITIONAL CHANGES IN PERFORMANCE-TESTED YEARLING BULLS AS DETERMINED BY SERIAL MEASUREMENTS

ABSTRACT

Progeny groups of Angus and Simmental bulls from two cooperator herds were serially measured to evaluate changes in growth and composition of performance-tested yearling bulls. Beginning in January these spring-born bulls were measured at 30-day intervals for weight (WT), hip height (HT), 12-13th rib ultrasonic fat thickness (UFAT), and 12-13th rib ultrasonic longissimus muscle area (ULMA) providing a set of four measurements on each animal during the final 80 to 100 days on test. Linear as well as linear and quadratic regressions of each trait on animal age were performed on the pooled data within breed and on an individual animals basis. Pooled as well as means of individual animal regression lines were then plotted to assess the differences in growth curves/lines. This study suggests that although the quadratic effects are not all highly significant the mean individual animal linear and quadratic curves more clearly describe the actual changes that are taking place, especially in composition traits. These serial measurements quantify that compositional changes in yearling bulls fed a moderate energy diet are certainly different than results of other serial slaughter work involving market animals. Comparing the different growth curves for each trait clearly shows how growth curves created from pooled data can misrepresent the actual changes in growth and composition traits.

INTRODUCTION

Changes in the American diet, consumer attitudes towards beef, improvement of product quality and consistency, the competitiveness of beef as a protein source, value-based marketing and genetic evaluation of carcass traits are certainly some of the most discussed and pertinent issues facing the beef industry today. At the producer level much of this discussion centers around the management practices, production systems and genetic selection of beef cattle that have the potential to improve profitability and product acceptance in all segments of the cattle industry. Of these, genetic improvement of specific carcass characteristics offers both permanent and cumulative change and is one of the most critical areas to be addressed.

Progress in the genetic evaluation of carcass traits has certainly not kept pace with other traits of economic importance such as growth and maternal ability. Some of the reasons for this include: the expense and difficulty of collecting carcass information, maintaining animal identification and contemporary groups and the reliance on progeny testing because of the inability to measure the trait in the breeding animal itself. But, perhaps the most important reason for the slow adoption of carcass evaluation on a large scale basis is that the current pricing structure of fed cattle fails to provide much incentive for producing cattle superior in carcass merit.

Real-time ultrasound technology has the potential to alleviate some of the above-mentioned obstacles by evaluating carcass composition in the live animal thus paving the way for a more cost-effective genetic evaluation system. Several researchers have concluded that when operated by an experienced technician, real-time ultrasound technology provides an accurate assessment of fat cover and longissimus muscle area in beef cattle (Brethour, 1992; Houghton and Turlington, 1992; Perkins et al., 1992; Robinson et al., 1992; Paper I of this Dissertation).

Carcass measured traits are generally considered to be moderately to highly heritable (Koch et al., 1982; Benyshek et al., 1988); therefore, considerable potential exists for changing traits affecting carcass merit. Limited information suggests that heritability estimates of ultrasonically measured carcass traits are generally lower than carcass measured estimates (Lamb et al., 1990; Turner et al., 1990; Arnold et al., 1991; Johnson, 1992). It is imperative that each breed desiring to genetically evaluate carcass merit have reliable estimates of genetic parameters for both carcass and ultrasound measurements of carcass traits as well as any relationships that occur between the two.

However, before ultrasound or carcass information can be used in a genetic evaluation system compositional changes during the feeding period must be quantified so that accurate data adjustment procedures can be developed. Wilson et al. (1993) reports that one of the difficulties in conducting a genetic evaluation for carcass merit with field records is that animals have not been measured at a constant endpoint. Real-time ultrasound offers researchers the opportunity to serially evaluate the composition of animals throughout the feeding period. Quantifying compositional changes should allow more accurate adjustment of carcass measurements to a common endpoint. This is especially important when considering ultrasound measurements of carcass traits in breeding animals because to this point very little is known about this area of carcass evaluation.

The objective of this study was to characterize the growth and compositional changes of yearling Angus and Simmental bulls during the final stages of a performance test.

MATERIALS AND METHODS

Progeny groups of Angus and Simmental bulls from two cooperator herds were serially measured to evaluate changes in growth and composition during the performance test period. These spring born bulls were weaned in the fall, placed directly on a performance test and weighed off test in April at approximately a year of age. At 30-day intervals beginning in early January the bulls were measured for weight (WT), hip height (HT),12/13th rib ultrasonic fat thickness (UFAT), and 12/13th rib longissimus muscle area (ULMA), providing a set of four measurements on each animal during the final 80 to 100 days on test. The only exception to this was in 1992 when HT was not evaluated on the fourth measurement date. The bulls were fed a moderate energy diet formulated to allow average daily gains of approximately 1.36 kg/day. This diet was intended to allow the bulls to express their genetic ability to grow without becoming overly conditioned.

The number of bulls evaluated, number of sires represented and the average age of the bulls at each scan in each herd and year are presented in Table 1. In herd A sire groups with a minimum of 10 intact male progeny on test were selected for use in this study. Because of smaller numbers of progeny per sire in herd B, a minimum of five sons per sire group was used as a guideline. At least two sires within a breed were used across locations and adjacent years to provide ties between contemporary groups (CG) which were defined as breed-herd-year subclasses. A

Table 1. Number scanned, sires represented and average age of bulls at each measurement by year, herd and breed

Year	Herd	Breed	n	Sires	Measurements 1	2	3	4	SD[a]
1989	A	Simmental	48	5	243	295	330	359	12
1990	A	Angus	49	5	273	306	333	364	10
	A	Simmental	48	5	262	295	322	353	12
	B	Angus	64	13	273	304	333	364	20
1991	A	Angus	52	5	284	327	354	381	9
	A	Simmental	50	5	276	319	346	373	10
	B	Angus	60	8	273	306	342	372	19
1992	A	Angus	49	5	297	325	348	371	14
	A	Simmental	43	5	290	319	342	364	15

[a]Standard deviation of age in days.

total of 26 Angus and 14 Simmental sires were represented in nine CG over this four-year period.

In 1989, an Aloka 633 (Corometrics Medical Systems, Wallingford, CT) real-time ultrasound machine equipped with a 12.5 cm, 3.5 MHz linear array transducer was used to scan the bulls. Cross-sectional images were obtained using the split-screen display capability of this equipment because the transducer length did not allow the entire area of interest to be imaged with a single scan. From 1990 to 1992 an Aloka 500V (Corometrics Medical Systems, Wallingford, CT) equipped with a 17 cm, 3.5 MHz linear array transducer, developed specifically for animal applications was used. This new generation of equipment allows the entire ULMA to be imaged at once, eliminating the need for the split screen capability.

After the bulls were restrained in a squeeze chute, the scanning site, as determined by physical palpation, was located between the 12 and 13th ribs, near the midline on the animal's right side. Once located, this area was clipped, oiled and cured until it was free of dirt and debris and then oiled again for optimum image quality. Vegetable oil was used as a couplant to insure acoustic contact. A superflab (Nicks Radio-Nuclear Intruments, Inc., Bronx, NY) transducer guide, cut in the general shape of the surface to be scanned, was used to provide proper contact between the rigid ultrasound transducer and the curvature of the animals topline. This guide also aided in proper matching of the medial and lateral halves of the image when using the split screen capability of the Aloka 633.

After the scan site was prepared and when the animal was standing relatively still the image was collected. A cross-sectional image between the 12 and 13th ribs, near the animal's midline that clearly displayed the entire ULMA and related anatomy was then recorded on a standard one-half inch VHS video cassette recorder. The recorded images were later redigitized and interpreted using MEDMORPH (Woods Hole Educational associates, Woods Hole, MA), a software package developed to allow technicians to make linear and area measurements and directly record them in a database. The technician measured UFAT at a point three-quarters of the distance from the medial to the lateral end of the longissimus muscle perpendicular to the hide. ULMA was then interpreted by tracing the periphery of the longissimus muscle from the image.

Growth (WT and HT) and compositional (UFAT and ULMA) changes were evaluated by regression analysis for each breed. These regressions were performed on the pooled data within breed as well as on an individual animal basis. Each of the four traits (WT, HT, UFAT, and ULMA) were regressed on animal age in days, first fitting both the linear and quadratic effects of age and secondly by fitting only the linear effect. These regression procedures were then compared to determine the most appropriate description of the changes in growth and composition of performance tested Angus and Simmental bulls.

RESULTS AND DISCUSSION

Least squares means for each of the four mesurements are presented by breed in Figures 1, 2, 3, and 4 for WT, HT, UFAT, and ULMA, respectively. These means are calculated across all years and sires and represent the mean of each breed by measurement. Figure 1 indicates that the two breeds were not different ($P > .05$) in WT at the time of the first measurement. However, at measurements 3 and 4, Simmental bulls were 9 and 13 kg heavier ($P < .05$) than Angus. Both breeds showed an increase ($P < .01$) in weight between each measurement date. Figure 2 shows that at measurement one Simmental bulls were 3.36 cm taller ($P < .01$) than Angus and that this difference increased to 4.41 cm by measurement four. Frame growth increased ($P < .01$) between each measurement period but it appears that this growth is beginning to slow over the period of time evaluated. Angus bulls were fatter ($P < .01$) than Simmentals (Figure 3) at each measurement and this difference increased from the first to the last scan. It should be noted that the Simmental bulls were very lean at all scans and that there was very little change in UFAT over time. Angus bulls increased in UFAT by a small (.14 cm) but significant amount ($P < .01$) up until the third scan after which they changed very little. At the first scan Simmental bulls had a 2.8 cm^2 advantage ($P < .01$) over Angus bulls in ULMA at a similar WT (Figure 4). The differences in ULMA between the two breeds got increasingly larger over time, the most noted change came between the last two scans, where, although both breeds seemed to be leveling off, the Angus bulls increase in ULMA was markedly reduced.

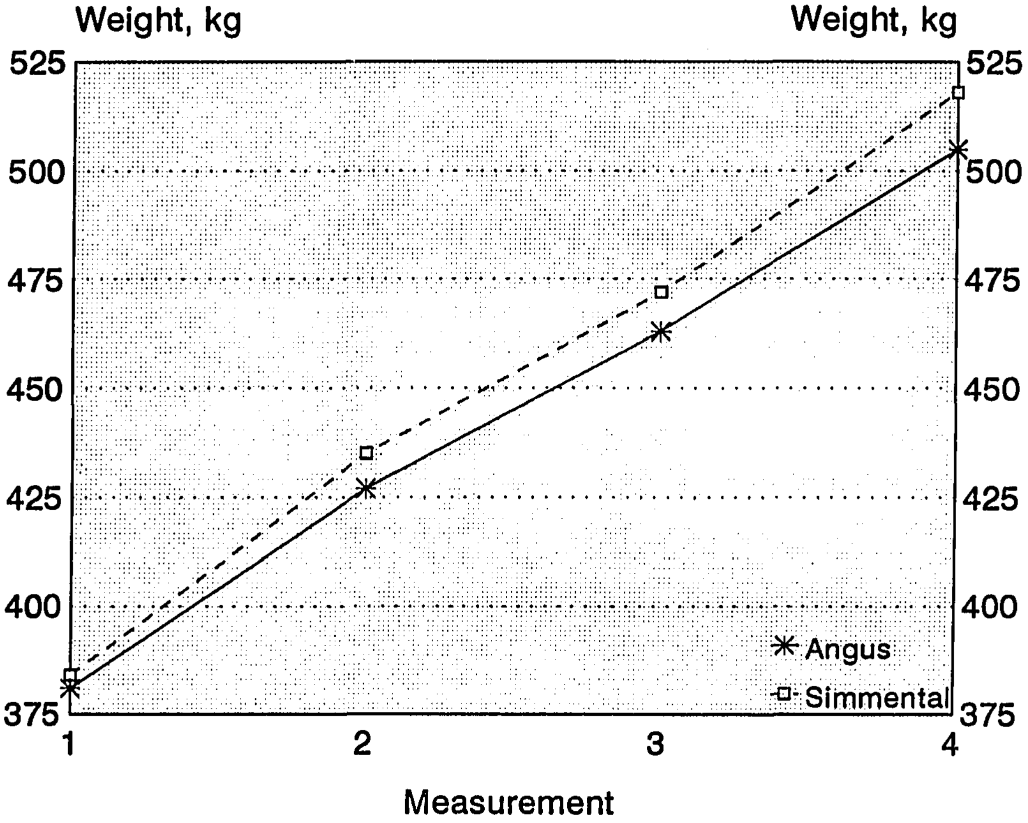

Figure 1. Mean weight of Angus and Simmental bulls at each of the four measurements

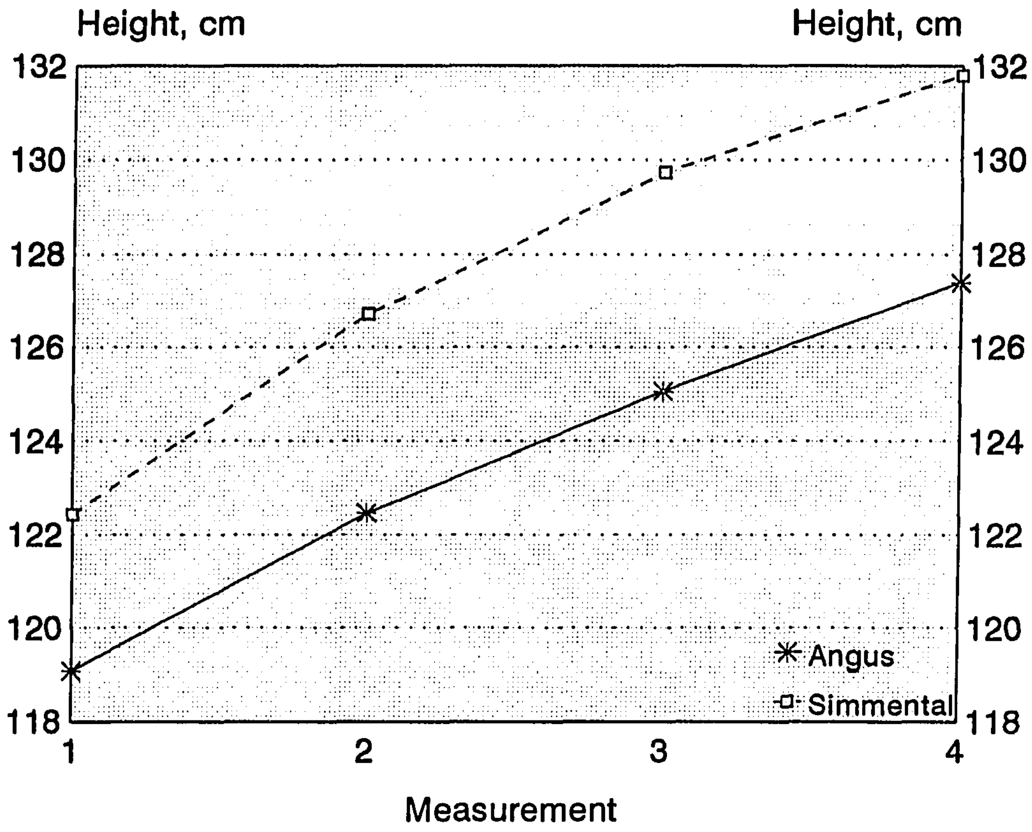

Figure 2. Mean height of Angus and Simmental bulls at each of the four measurements

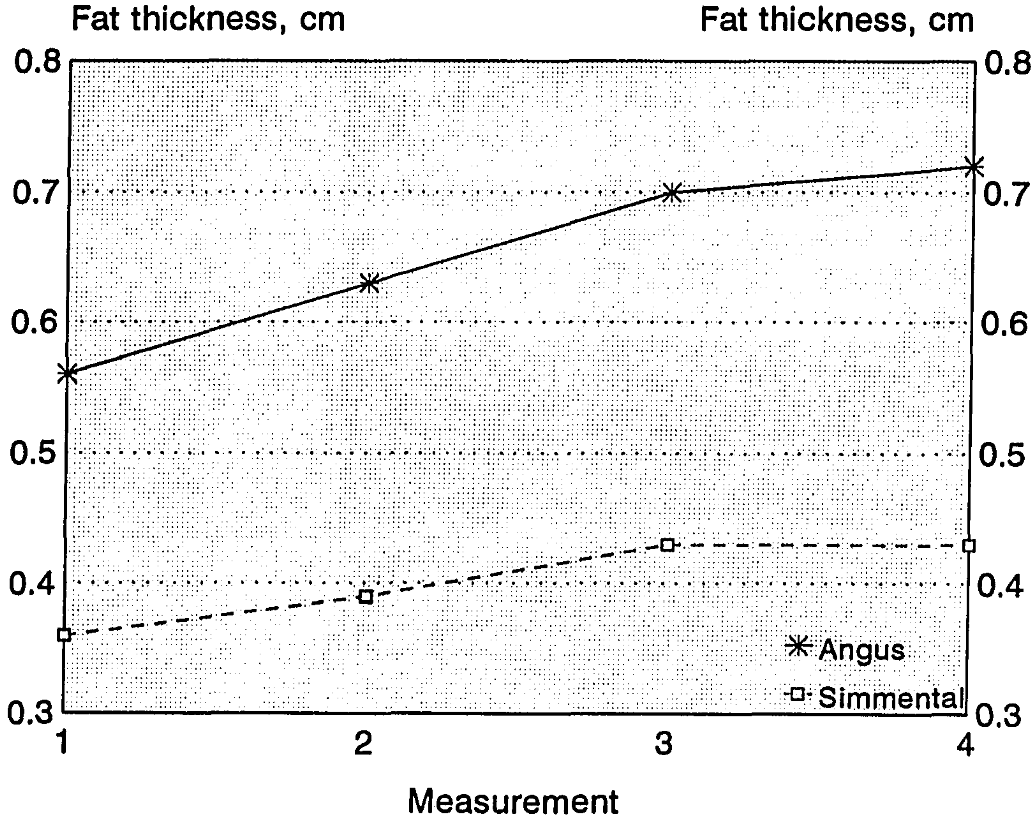

Figure 3. Mean 12-13th rib fat thickness of Angus and Simmental bulls at each of the four measurements

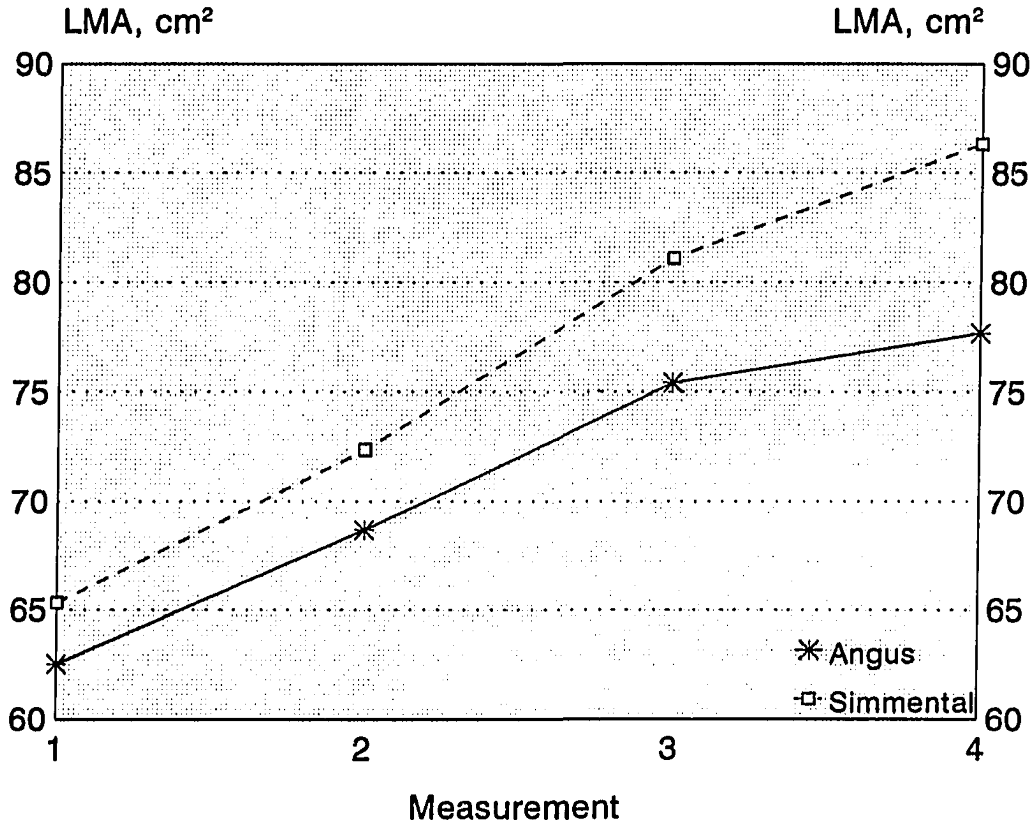

Figure 4. Mean 12-13th rib longissimus muscle area of Angus and Simmental bulls at each of four measurements

The combined mean change in UFAT and ULMA during the test period suggests that there are differences in composition and compositional changes between the two breeds. In general, Simmentals were taller, heavier, had more muscle, and stayed leaner, especially late in the test period.

The four traits (WT, HT, UFAT, ULMA) were regressed on age, on an individual animal basis, to determine the best fitting line through the four points. These regressions were performed by first fitting the linear and quadratic effect of age and then fitting the linear effect alone. Table 2 contains means of the individual animal linear and quadratic regression coefficients by breed. These values reflect the average of individual animal growth curves for each trait. The magnitude of the mean quadratic is small but does suggest an upward curvature in WT in both breeds. The negative quadratic effect associated with HT and UFAT in both breeds suggests that on average the growth of these two traits levels off over time. Quadratic effects for ULMA are opposite in sign. This indicates that while Simmental bulls ULMA growth is described with an upward curvature, Angus bulls ULMA growth is leveling off at some point over the range of ages evaluated. Table 3 contains the means of individual animal linear regression coefficients by breed. These slopes represent the average linear change in each trait per day of age. Simmental bulls were gaining WT and increasing in HT and ULMA at a slightly faster rate per day than Angus. Examination of the slope for UFAT suggests that the mean change in UFAT per day in Simmental bulls is very small (.0009 cm ± .0001). This value (.0019 cm ± .001) in Angus

Table 2. Mean parameters of individual animal linear and quadratic regressions of growth and ultrasonically measured carcass traits on age

			Mean regression parameters and standard errors					
Breed	Trait	n	Intercept	SE[a]	L[b]	SE[a]	Q[c]	SE[a]
Angus	WT,kg	269	86.44	34.15	.79	.21	.0009141	.0003120
	HT,cm	216	85.07	6.93	.144	.044	-.0000796	.0000696
	UFAT,cm	267	-1.09	.29	.0086	.0018	-.0000103	.0000027
	ULMA,cm^2	264	-69.52	17.10	.6931	.1060	-.0008062	.0001647
Simmental	WT,kg	182	163.62	41.51	.34	.25	.0017666	.0003794
	HT,cm	141	78.33	8.58	.210	.054	-.0001679	.0000861
	UFAT,cm	173	-.52	.36	.0049	.0022	-.0000061	.0000033
	ULMA,cm^2	181	26.86	20.65	.0632	.1281	.0002777	.0001989

[a]Standard error of the mean of individual animal regression parameters.

[b]Mean slope of individual animal linear and quadratic regression on days of age.

[c]Mean quadratic parameter of individual animal linear and quadratic regression on days of age.

Table 3. Mean parameters of individual animal linear regressions of growth and ultrasonically measured carcass traits on age

			Mean regression parameters			
Breed	Trait	n	Intercept	SE[a]	L[b]	SE[a]
Angus	WT,kg	275	-3.24	4.30	1.37	.01
	HT,cm	272	92.45	.76	.096	.002
	UFAT,cm	274	.04	.03	.0019	.0001
	ULMA,cm^2	275	13.31	2.25	.1754	.0065
Simmental	WT,kg	189	-.45	5.18	1.42	.02
	HT,cm	186	94.57	.92	.104	.003
	UFAT,cm	179	.11	.04	.0009	.0001
	ULMA,cm^2	189	2.13	2.71	.2309	.0079

[a]Standard error of the mean of individual animal regression parameters.

[b]Mean slope of individual animal linear regression on days of age.

bulls is double that of Simmental but still very small. Indicating that although neither breed changed very much on average, there certainly appeared to be differences between them.

Table 4 contains F-values and significance levels from a general linear model (GLM) regression analysis (SAS, 1989) of the pooled data set for each breed. These pooled data sets include the four measurements on each animal. The effects of contemporary group (CG) and animal were highly significant (P < .0001) sources of variation. Table 4 presents the levels of significance of the linear (L) and quadratic (Q) regressions of each of the four traits on age in days from analysis of the

Table 4. F-values and significance levels for pertinent sources of variation by breed

	CG	P>F	Animal	P>F	L[a]	P>F	Q[b]	P>F	AnimalxL[c]	P>F	AnimalxQ[d]	P>F
Angus												
WT	5692.46	.0001	102.16	.0001	9476.09	.0001	32.47	.0001	3.93	.0001	2.11	.0001
HT[e]	16.64	.0001	8.62	.0001	2464.75	.0001	5.29	.0224	.80	.9478	.95	.6426
UFAT	1130.00	.0001	16.37	.0001	186.54	.0001	8.19	.0045	4.13	.0001	1.10	.2236
ULMA	120.94	.0001	7.47	.0001	607.19	.0001	6.42	.0119	2.77	.0001	1.32	.0124
Simmental												
WT	356.21	.0001	143.02	.0001	6178.24	.0001	116.15	.0001	7.68	.0001	1.45	.0063
HT[e]	316.03	.0001	21.90	.0001	1465.70	.0001	.59	.4441	2.88	.0001	1.98	.0001
UFAT	101.39	.0001	8.90	.0001	88.65	.0001	5.21	.0235	1.92	.0001	1.15	.1705
ULMA	129.43	.0001	5.09	.0001	952.84	.0001	58.80	.0001	1.49	.0037	.65	.9981

[a]Linear effect of age: F-test uses AnimalxL Type I Sums of Squares (SS) as an error term, tests the significance of the linear effect of age in the pooled data.

[b]Quadratic effect of age: F-test uses AnimalxQ Type I SS as an error term, tests the significance of the quadratic effect of age in the pooled data.

[c]Animal by linear effect of age interaction: F-test uses residual SS as an error term, tests the significance of individual animal linear regressions.

[d]Animal by quadratic effect of age interaction: F-test uses residual SS as an error term, test the significance of individual animal quadratic effects.

[e]1992 data were not used in this analysis because the fourth height measurement was not taken.

pooled data. The linear effect of age was highly significant ($P < .0001$) for all four traits in both breeds. With the exception of HT in Simmentals the quadratic effect of age was also significant ($P < .05$) suggesting curvilinear growth in these traits when examining the pooled data. Animal by linear (Animal x L) and animal by quadratic (Animal x Q) interaction levels of significance are also shown in Table 4. Significance of these interactions suggest that individual animal regressions on age better explain the linear and/or curvilinear changes in each of the traits than regressions performed on the pooled data.

Table 5 contains parameters of the linear and quadratic regressions of growth and ultrasonically measured carcass traits on days of age by breed from the pooled data. In several cases, these regression equations are quite different than the means of individual animal linear and quadratic regression equations in Table 2. The most notable difference is the opposite sign of the quadratic for WT and ULMA in Angus and HT and UFAT in Simmental.

Table 6 presents parameters of the linear regression of growth and ultrasonically evaluated carcass traits on age by breed from the pooled data. The most noted difference between these regression equations and the mean individual animal linear regression equations in Table 3 is the difference in WT change per day between the breeds. Table 3 suggests that Simmental bulls are gaining faster than Angus and Table 6 suggests the opposite. Also, Table 3 indicates more difference in the rate of ULMA growth between the breeds than found in Table 6.

Table 5. Parameters from linear and quadratic regressions of growth and ultrasonically measured carcass traits on days of age from the pooled data of each breed

Breed Trait	n	Intercept	SE	L[a]	SE	Q[b]	SE	R^2
Angus								
WT,kg	1094	-174.32	92.57	2.410	.58	-.0015591	.0008952	.58
HT,cm	1039	80.74	7.24	.181	.045	-.0001519	.0000703	.45
UFAT,cm	1092	-.46	.45	.0046	.0028	-.0000035	.0000044	.14
ULMA,cm^2	1089	53.29	17.21	-.0654	.1076	.0003630	.0001665	.36
Simmental								
WT,kg	755	240.28	79.26	.005	.514	.0020495	.0008247	.64
HT,cm	711	117.25	8.87	-.025	.058	.0001787	.0000934	.40
UFAT,cm	755	.28	.24	-.0002	.0015	.0000019	.0000025	.10
ULMA,cm^2	754	140.36	21.52	-.6035	.1396	.0012455	.0002240	.32

[a]Linear regression coefficient from pooled data by breed.

[b]Quadratic regression coefficient from pooled data by breed.

Table 6. Parameters from linear regression of growth and ultrasonically measured carcass traits on days of age from the pooled data of each breed

Breed	Trait	n	Intercept	SE	L[a]	SE	R^2
Angus	WT,kg	1094	-14.44	11.98	1.41	.04	.58
	HT,cm	1039	96.24	.94	.084	.003	.45
	UFAT,cm	1089	-.11	.06	.0023	.0002	.14
	ULMA,cm^2	1092	16.07	2.23	.1687	.0068	.36
Simmental	WT,kg	755	45.26	11.18	1.28	.03	.64
	HT,cm	711	100.45	1.25	.086	.004	.40
	UFAT,cm	755	.10	.03	.0010	.0001	.10
	ULMA,cm^2	754	21.83	3.09	.1713	.0096	.30

[a]Linear regression coefficient from pooled data by breed.

Comparison of Tables 2 and 3 with 5 and 6, respectively, suggests that there may be differences in the growth curves both within and between breeds depending on which regression procedure one uses (i.e., mean of individual animal regressions or regressions from the pooled data). These potential differences may be more clearly demonstrated graphically. Figures 5-12 represent four different growth curves for each of the four traits by breed. These curves represent the projected value of the four traits over the range of ages found in this study, 205 to 405 days of age (Table 1) as determined by the regression equations in Tables 2, 3, 5, and 6. Again, Table 2 contained the mean of individual animal linear and quadratic regressions (Mean-LQ). Table 3 presented the mean of individual animal linear regressions (Mean-L). Table 4 contained the linear and quadratic regression equations obtained from the pooled data within breed (Pooled-LQ) and Table 5 was the linear regression equations from the pooled data within breed (Pooled-L).

Figure 5 shows that the four different WT curves for Angus bulls are basically indistinguishable through the middle two-thirds of the ages evaluated. The differing sign of the quadratic for WT in Tables 2 and 5 is becoming evident during the final 25 days of the projected period. The Mean-LQ line is continuing to curve upward slightly while the Pooled-LQ line is starting to level off. Table 4 indicates a significant ($P < .0001$) quadratic effect in both the pooled and individual animal regressions. The magnitude of the quadratics are small and both the Mean-LQ and Pooled-LQ lines are very similar to the linear lines (Mean-L and Pooled-L) over this age range. The WT curves for Simmentals in Figure 6

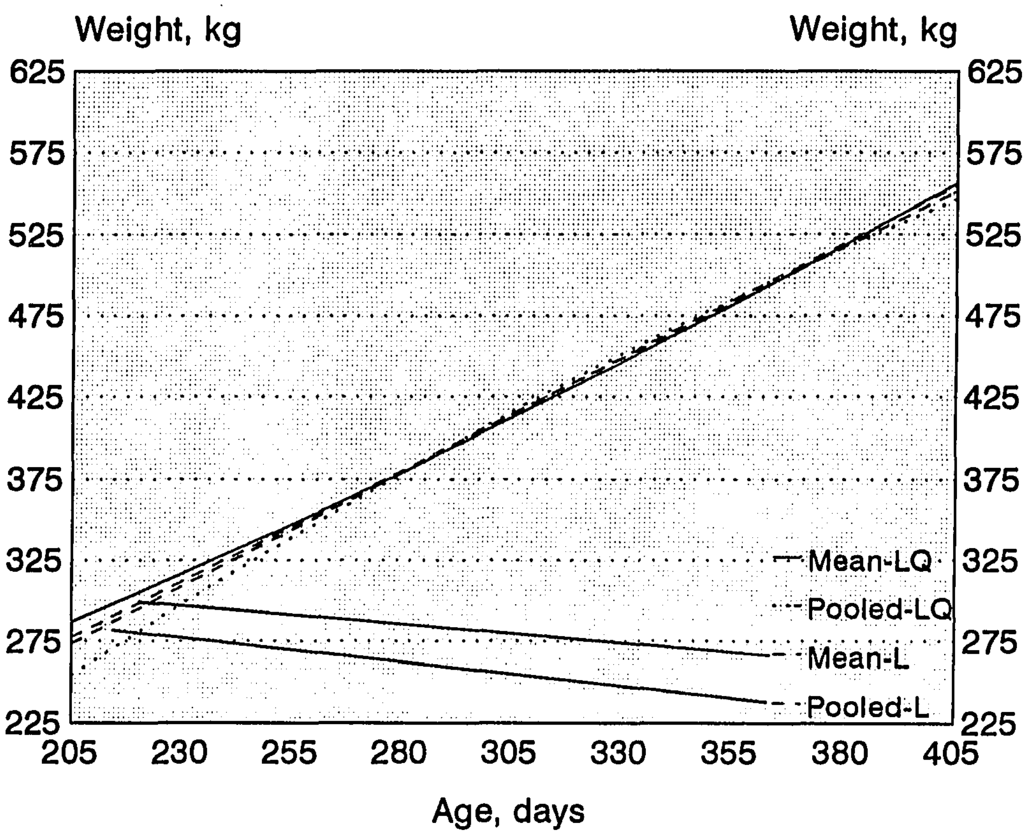

Figure 5. Projected change in live weight for Angus bulls as determined by four different regression procedures

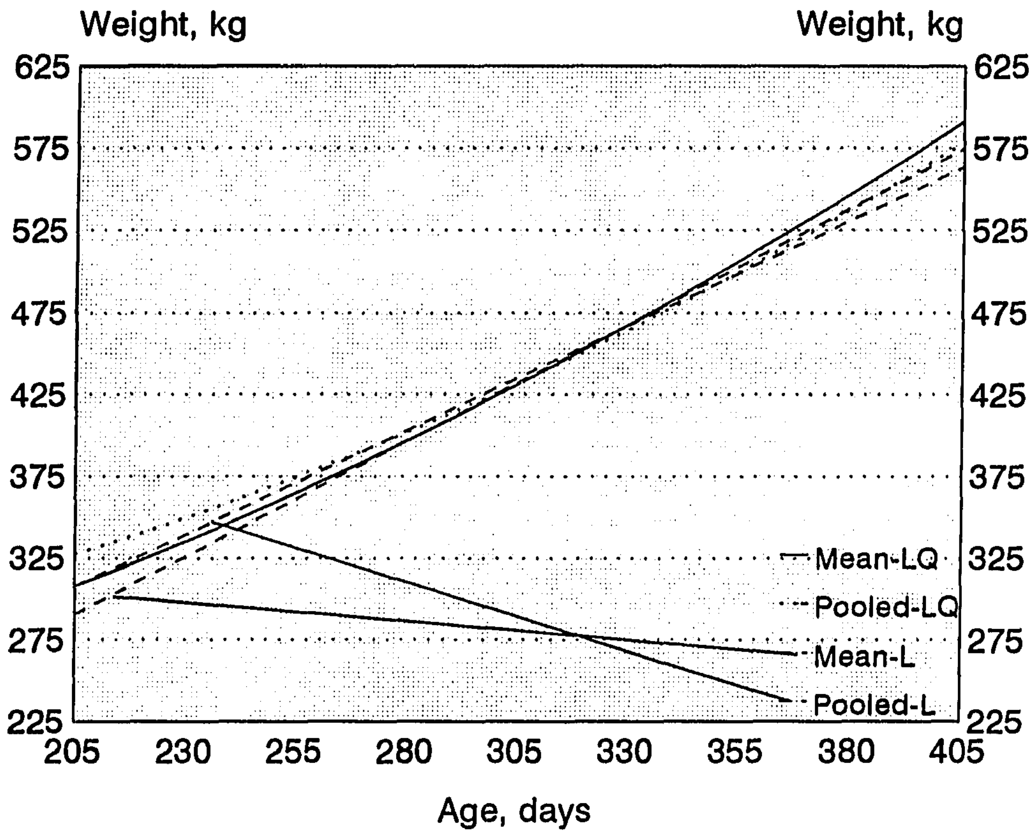

Figure 6. Projected change in live weight for Simmental bulls as determined by four different regression procedures

are also quite similar through the center of the figure and begin to differentiate on both ends.

Figure 7 shows that the four HT lines of Angus bulls are quite similar over this range of ages. More differences between the lines can be seen for Simmental bulls in Figure 8. The fact that the quadratic was similar in magnitude and opposite in sign for Mean-LQ and Pooled-LQ can be clearly seen in this figure. Evaluation of the mean HT measurements at each measurement for Simmental bulls in Figure 2 certainly suggests that the bulls were beginning to level off in frame growth agreeing more closely with the Mean-LQ line.

The type of regression procedure used to describe changes over time in Angus bulls certainly affects the appearance of the growth curve more for UFAT (Figure 9) than WT (Figure 5) or HT (Figure 7). The Mean-LQ line for UFAT clearly depicts the negative quadratic described in Table 2. The Mean-LQ line in Figure 9 suggests that change in UFAT towards the end of this period has virtually ceased while all three of the other lines continue to increase. Similar trends with less variation between lines for Simmental bulls can be seen in Figure 10. The only difference is that Table 5 and Figure 10 indicate a small but positive quadratic for UFAT in Simmental and a small negative quadratic for Angus. Remember, UFAT means by scan (Figure 3) clearly indicate that UFAT changed very little between the final two scans for both breeds. This indicates that the Mean-LQ line for UFAT better describes the actual compositional changes that are taking place in both breeds. It is also interesting to note that when projected back to 205 days of age Angus (Table 9) and

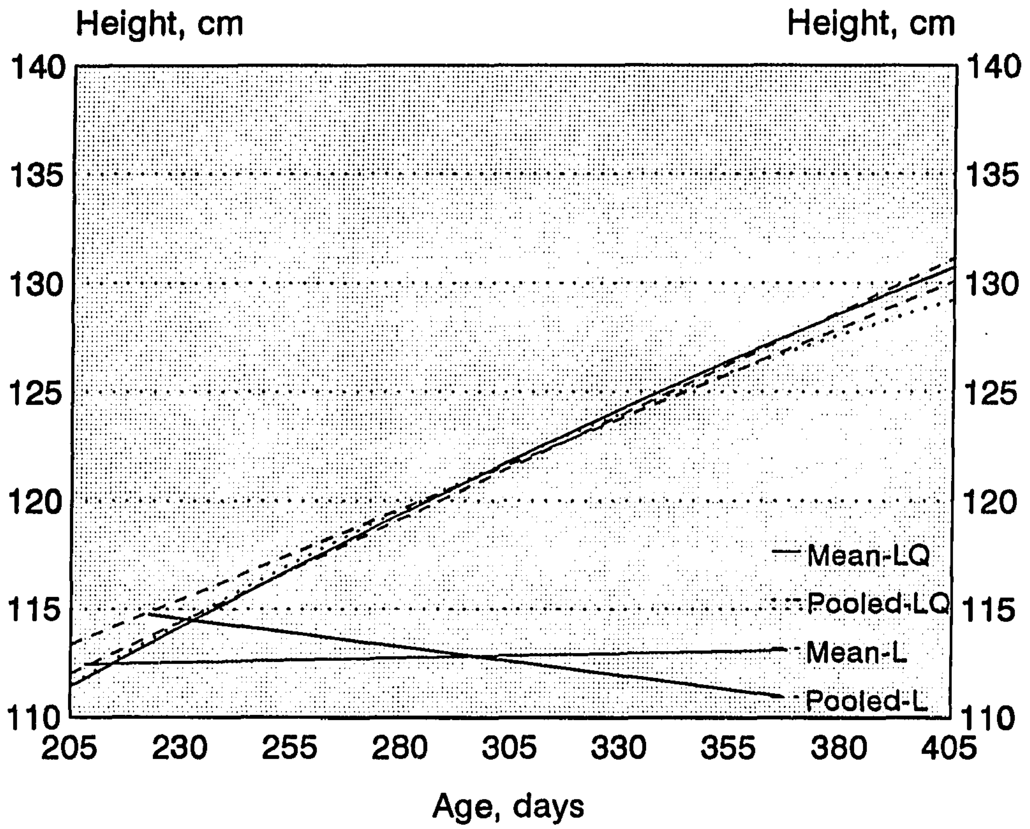

Figure 7. Projected change in hip height for Angus bulls as determined by four different regression procedures

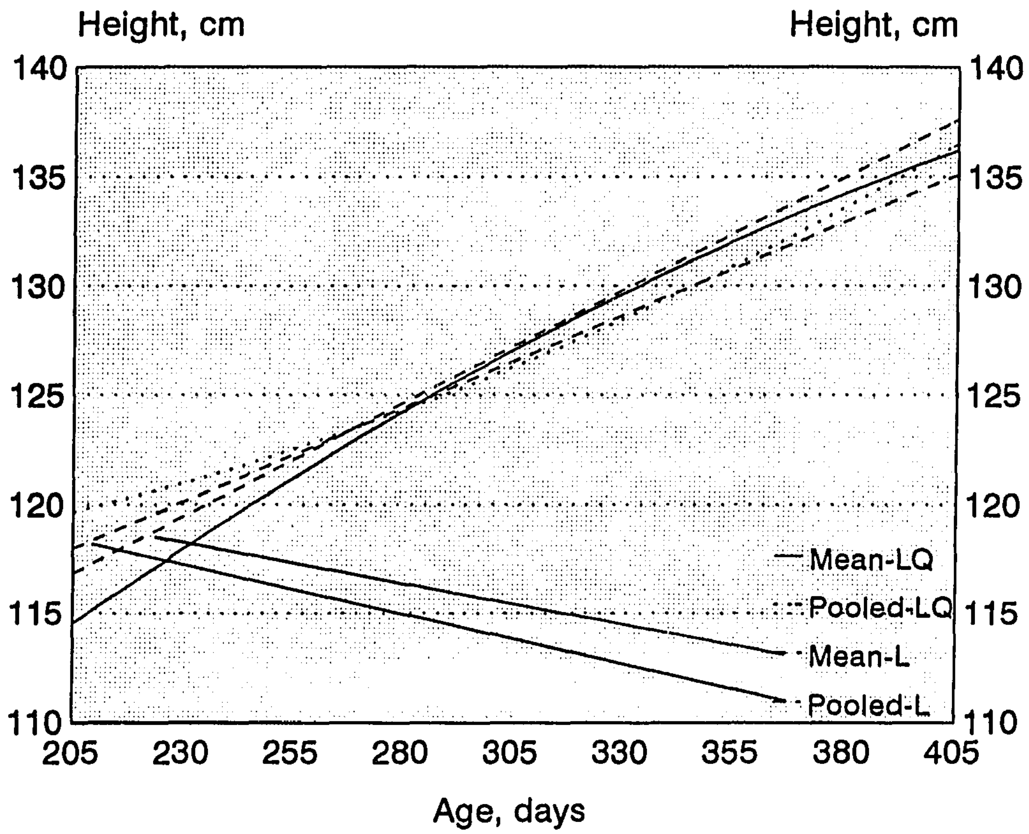

Figure 8. Projected change in hip height for Simmental bulls as determined by four different regression procedures

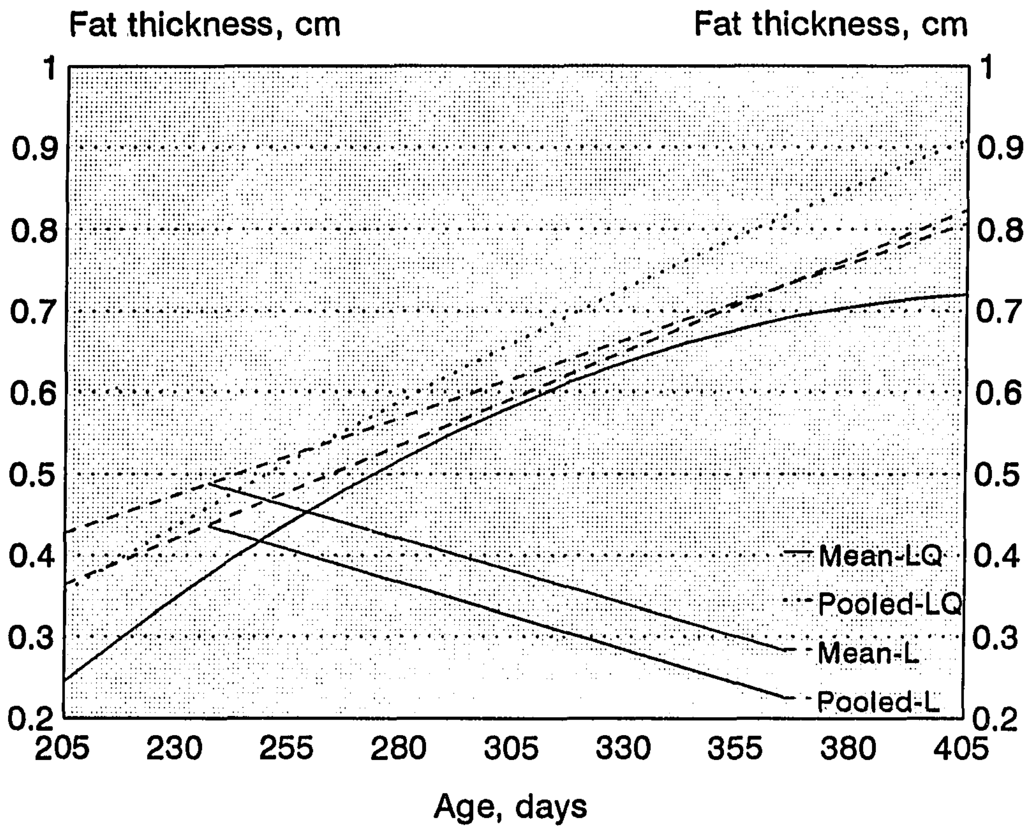

Figure 9. Projected change in 12-13th rib fat thickness for Angus bulls as determined by four different regression procedures

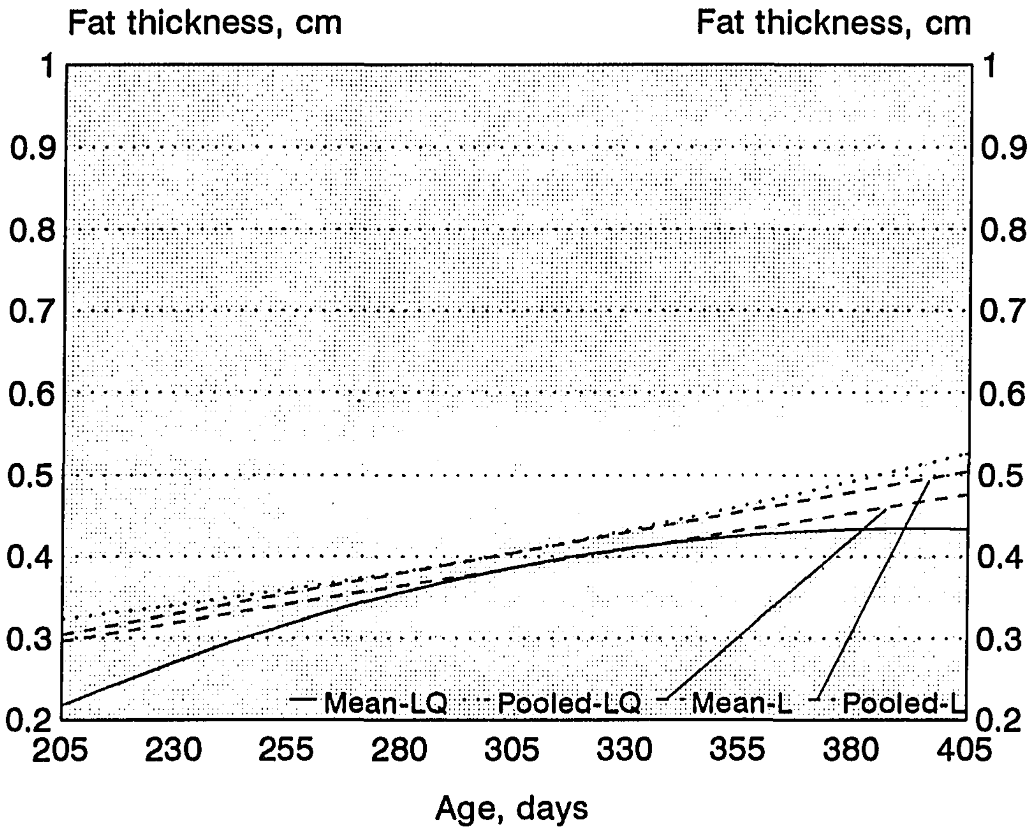

Figure 10. Projected change in 12-13th rib fat thickness for Simmental bulls as determined by four different regression procedures

Simmental (Table 10) bulls are quite similar in UFAT. However, Angus bulls in this study deposited UFAT throughout the test whereas the Simmentals remained nearly constant.

The Mean-LQ line depicting ULMA changes in Angus bulls (Figure 11) indicates a leveling off of muscle deposition towards the end of the test period while the other three lines indicate a continued increase. In fact, Table 5 indicates the quadratic for ULMA in the pooled Angus bull data is positive. Figure 11 shows that this quadratic is so small that from about 280 to 405 days of age the Pooled-LQ line is hardly distinguishable from the two linear lines (Mean-L and Pooled-L). Again, the Mean-LQ line more closely describes the changes in ULMA that appear to be taking place when the means by scan are evaluated for Angus bulls in Figure 4. Although the sign of the quadratic for ULMA change in Figure 12 is the same, the appearance of the Mean-LQ and Pooled-LQ curves differ greatly. In fact, the Pooled-LQ curve in Figure 12 actually decreases slightly over the first 50 days of this time period, which certainly is not evident in Figure 4. This is likely a function of a small number of Simmental bulls scanned between 205 and 255 days of age that had large ULMAs relative to their age which distorts the Pooled-LQ line early in given time period. It is also suspected that this problem is responsible for a large part of the differences in slope between the Mean-L and Pooled-L lines in Figure 12.

Considering only the Mean-LQ curves for Angus bulls in Figures 5, 7, 9, and 11 the changes in WT (Figure 5) are difficult to explain with the other three variables. In general, over this period of time, the Angus

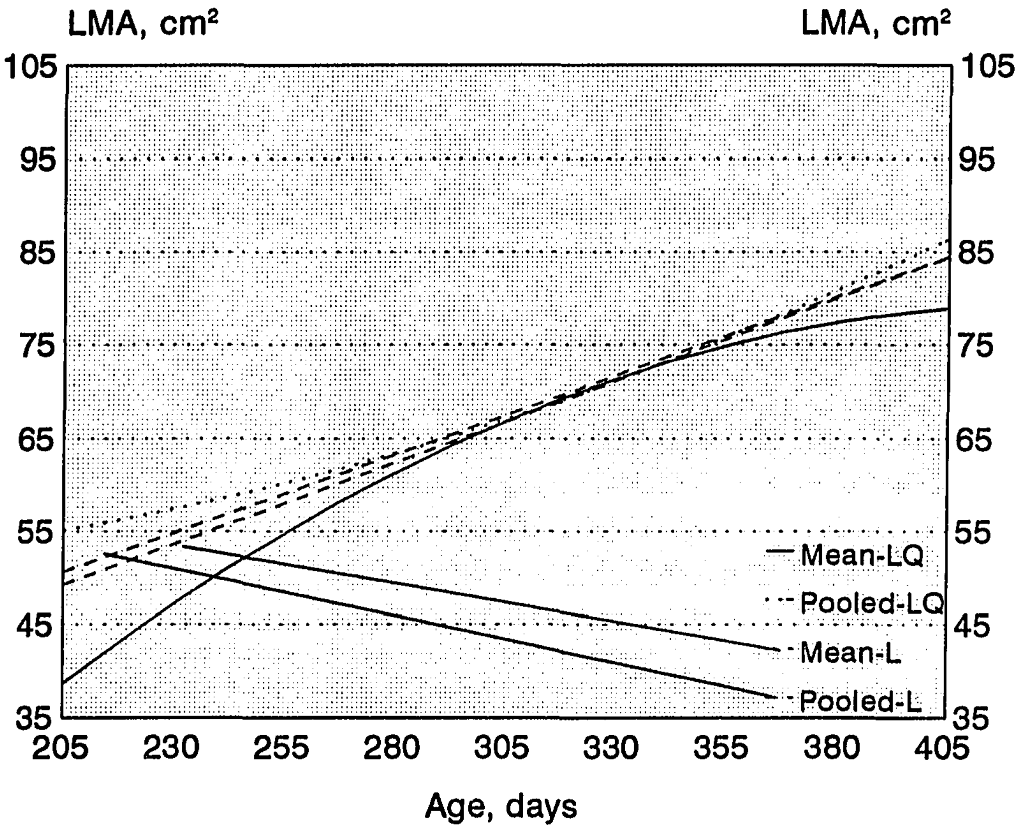

Figure 11. Projected change in 12-13th rib longissimus muscle area for Angus bulls as determined by four different regression procedures

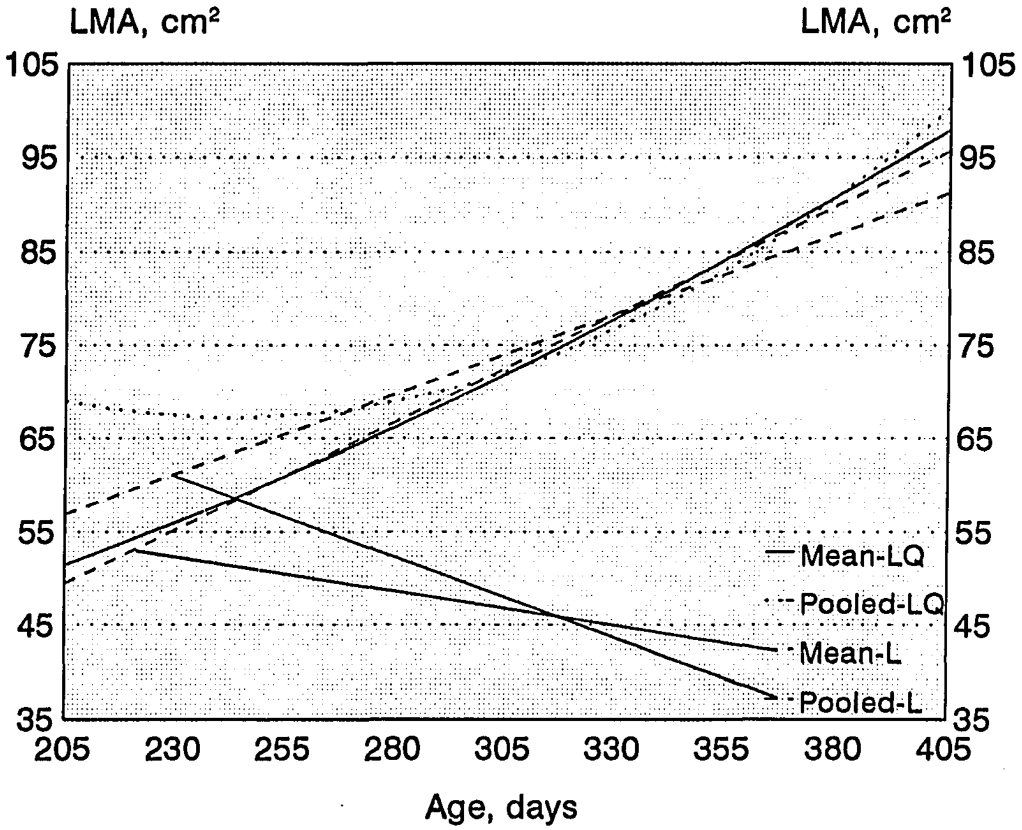

Figure 12. Projected change in 12-13th rib longissimus muscle area for Simmental bulls as determined by four different regression procedures

bulls continued to increase in WT. At the same time the Mean-LQ line for HT (Figure 7), UFAT (Figure 9) and ULMA (Figure 11) indicate that the change in these traits per day began to slow towards the end of the test period. We know that ULMA weather measured ultrasonically or on the carcass is not a very good predictor of retail product in the carcass (Wallace et al., 1977; Koch et al., 1982). Thus, there is the possibility that even though ULMA growth appears to be slowing, total lean deposition may not be.

When all the Mean-LQ lines for Simmental bulls are examined together they make more sense. Here the WT Mean-LQ line (Figure 6) and the ULMA Mean-LQ line (Figure 12) are nearly identical in shape, the HT Mean-LQ line (Figure 10) has only a very small negative quadratic and the UFAT Mean-LQ line (Figure 10) indicates very little change in UFAT over the ages evaluated. Consequently, the amount of UFAT deposited during this time period has very little effect on WT and the combined changes in HT and ULMA growth closely mimic changes in WT.

Examination of Mean-LQ lines of all traits for both breeds also indicates that the Simmental bulls are later maturing than the Angus. The Simmentals continue to increase in WT, HT and ULMA and change very little in UFAT while Angus are clearly fatter and ULMA growth is beginning to level off as age increases.

It is also interesting to note that with the exception of Figure 10 the Mean-L and Pooled-L lines cross at some point in time in Figures 5-12. Although in general, the differences in intercept and slope are small they do suggest different rates of change depending on the regression procedure used.

There are virtually no reports in the literature to directly compare with these. The acceptance of ultrasound as a way to measure composition has greatly enhanced the ability to study changes in composition. Until now, the only way to evaluate these changes were through serial slaughter studies. The majority of serial slaughter work reported involves steers and heifers fed for slaughter and consequently is not very helpful in verifying these results. Reiling (1991) reports on a serial slaughter project involving bulls and steers of two frame sizes. However, it must be noted that these cattle were fed a high energy finishing diet and their first slaughter was at about the same age that the purebred bulls of this study came off test. Nevertheless, a limited review of past serial slaughter work might prove informative.

In serial slaughter studies involving market steers, Zinn et al. (1970) and Stringer et al. (1968) both report some decrease in average daily gain towards the end of the feeding period. Barber et al. (1981) likewise reported that ADG for both Angus and Charolais steers decreased ($P < .01$) as weight increased and Reiling (1991) noted that ADG tended to increase early in the feeding period, plateaued, and then dropped off late in the feeding period for both sex and frame types. This type of change in ADG is certainly not evident in this study but this study is dealing with younger and leaner animals. Stringer et al. (1968) reports that much of the decrease in gain described previously was likely due to the increased fat composition of gain late in the feeding period, which is not the case in the purebred bulls of this study. Both Barber et al. (1981) and Reiling (1991) found that larger framed cattle maintained a higher ADG throughout the trial. Verde and Trenkle (1987) suggest that this is because the larger framed cattle are generally less advanced on their growth curve than smaller steers. The results of the larger framed Simmental bulls versus the Angus bulls of this study tend to agree with this conclusion.

Both Stringer et al. (1968) and Barber et al. (1981) report the ULMA generally increased between slaughter dates but noted that this increase was not proportional to the increase in carcass weight, indicating a relative slowing of muscle deposition. This agrees with the changes in ULMA in Angus bulls seen in Figure 4 and the Mean-LQ line for ULMA in Figure 11. The Simmental bulls in this study, however, continue to increase in ULMA at a rate that suggests they may not have reached the point in their growth curve where muscle growth begins to slow.

Stringer et al. (1968), Jesse et al. (1976) and Cianzio et al. (1982) all report that FAT increased in serially slaughtered steers as live weight and time increased. Reiling (1991) reported that when fed a similar diet steers showed a greater tendency to increase in FAT than bulls. Reiling (1991) went on to report that changes in FAT, especially in large framed bulls, were minimal and nonsignificant over time. Arthaud et al. (1977) reported similar results when slaughtering bulls fed a high energy diet at 12, 15, 18, and 24 months of age finding that FAT increased only by 2 mm from 12 to 18 months of age and an additional 3 mm at 24 months of age. Again, although these bull serial slaughter studies start about where this study ends in terms of animal age they suggest the leveling off trend found in the Mean-LQ UFAT line of both Angus and Simmental bulls seen in Figures 9 and 10. Also remember that the bulls in the current study were fed a moderate energy diet as opposed to a finishing diet which likely even further reduces the increase in UFAT relative to other studies. It is suspected that the onset of puberty in these bulls has a large impact on how UFAT changes throughout the test period. The Mean-LQ UFAT lines became fairly flat about the time we would expect both breeds of bulls to reach puberty.

Comparison of the raw data means in Figures 1-4 with their respective plotted regressions in Figures 5-12 suggests that if there is much variability between the four regression lines, the Mean-LQ line most closely describes how the cattle actually changed throughout the test period. This is particularly true when comparing the Mean-LQ and Pooled-LQ lines. When comparing the Mean-LQ line with either of the linear lines (Mean-L or Pooled-L) for UFAT in both breeds and ULMA in Angus, the Mean-LQ line appears to be a much better description of the actual changes occurring.

Table 4 suggests that individual animal linear and quadratic regressions are not significantly better than pooled linear and quadratic regression for some traits. The means of individual animal regression equations certainly better describe the actual changes in growth and composition that appear to be taking place, especially in UFAT. The author suspects that if the serial scan period were longer these quadratic effects would be significant. To examine the changes in growth and composition for an additional 60 to 90 days may prove most useful. This, however, was not practical in this study because of the merchandising program of the cooperator herds.

It is inevitable that at some point in the production cycle increases in each of these traits will level off. This point is likely influenced by many factors including energy level and physiological and sexual maturity. Ultrasound technology offers a never before opportunity to understand these changes in growth and composition in both market and breeding animals. Although they are not all significant, the trends suggest that means of individual animal growth curves are better descriptions of the true changes taking place than regression equations derived from pooled data.

IMPLICATIONS

As an accurate and accepted tool to evaluate composition in beef cattle, ultrasound technology offers a great deal of potential to the beef cattle industry. Before ultrasound data collected on breeding animals can be incorporated into a national carcass evaluation system, adjustment procedures which allow animals to be compared at an equal endpoint must be developed. This study demonstrates that the compositional changes taking place in performance tested yearling bulls are in most cases far different than results of previous serial slaughter work done with market animals. The insight gained in this evaluation of growth and compositional changes will certainly aid in the development of breed specific data collection protocols, adjustment procedures, and eventually carcass trait EPDs from ultrasound measurements.

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APPENDIX

Table 7. Mean growth and composition measurements by scan

Breed	Scan	WT,kg	HT,cm	UFAT,cm	ULMA,cm^2
Angus	1	381	119.08	.56	62.53
	2	427	122.47	.63	68.67
	3	463	125.06	.70	75.42
	4	505	127.38	.72	77.69
Simmental	1	384	122.44	.36	65.33
	2	435	126.71	.39	72.38
	3	472	129.73	.43	81.12
	4	518	131.79	.43	86.34

Table 8. Predicted measurements at a given age calculated from the mean parameters of individual animal linear and quadratic regression equations by breed

Breed	Age	WT,kg	HT,cm	UFAT,cm	ULMA,cm^2
Angus	205	286.8	111.4	.24	38.67
	230	316.5	114.2	.35	47.22
	255	347.3	116.9	.44	54.77
	280	379.3	119.4	.52	61.30
	305	412.4	121.9	.58	66.83
	330	446.7	124.3	.64	71.35
	355	482.1	126.5	.68	74.86
	380	518.6	128.7	.71	77.36
	405	556.3	130.7	.72	78.86
Simmental	205	307.6	114.5	.22	51.45
	230	335.3	118.0	.27	56.05
	255	365.2	121.2	.32	60.99
	280	397.3	124.2	.36	66.28
	305	431.7	127.1	.39	71.92
	330	468.2	129.7	.41	77.90
	355	507.0	132.1	.43	84.24
	380	547.9	134.3	.43	90.91
	405	591.1	136.2	.43	97.94

Table 9. Predicted measurements at a given age calculated from the mean parameters of individual animal linear regression equations by breed

Breed	Age	WT,kg	HT,cm	UFAT,cm	LMA,cm^2
Angus	205	277.6	112.0	.43	49.27
	230	311.9	114.4	.48	53.66
	255	346.1	116.8	.52	58.04
	280	380.4	119.2	.57	62.43
	305	414.6	121.6	.62	66.82
	330	448.9	124.0	.67	71.21
	355	483.1	126.4	.71	75.59
	380	517.4	128.8	.76	79.98
	405	551.6	131.1	.81	84.37
Simmental	205	290.7	116.9	.30	49.49
	230	326.2	119.5	.32	55.26
	255	361.7	122.1	.34	61.04
	280	397.2	124.7	.36	66.81
	305	432.7	127.3	.39	72.59
	330	468.2	129.8	.41	78.36
	355	503.7	132.4	.43	84.14
	380	539.2	135.0	.45	89.91
	405	574.7	137.6	.48	95.69

Table 10. Predicted measurements at a given age based on linear and quadratic regression parameters from the pooled data within a breed

Breed	Age	WT,kg	HT,cm	UFAT,cm	ULMA,cm^2
Angus	205	254.5	111.5	.35	55.14
	230	297.9	114.4	.44	57.45
	255	339.2	117.1	.52	60.21
	280	378.7	119.6	.59	63.44
	305	416.2	121.9	.66	67.11
	330	451.7	124.0	.73	71.24
	355	485.3	125.9	.79	75.82
	380	516.9	127.7	.85	80.85
	405	546.6	129.2	.91	86.34
Simmental	205	327.5	119.7	.32	69.00
	230	349.9	121.0	.34	67.46
	255	374.9	122.5	.36	67.49
	280	402.4	124.3	.38	69.06
	305	432.5	126.3	.41	72.20
	330	465.2	128.5	.43	76.89
	355	500.4	131.0	.46	83.14
	380	538.2	133.6	.49	90.95
	405	578.6	136.5	.53	100.31

Table 11. Predicted measurements at a given age based on linear regression parameters from the pooled data within a breed

Breed	Age	WT,kg	HT,cm	UFAT,cm	ULMA,cm^2
Angus	205	273.8	113.4	.36	50.65
	230	308.9	115.5	.42	54.87
	255	344.1	117.6	.48	59.09
	280	379.2	119.6	.54	63.30
	305	414.4	121.7	.59	67.52
	330	449.5	123.8	.65	71.74
	355	484.7	125.9	.71	75.96
	380	519.8	128.0	.77	80.17
	405	555.0	130.1	.82	84.39
Simmental	205	307.6	118.0	.31	56.95
	230	339.6	120.1	.33	61.23
	255	371.6	122.3	.35	65.51
	280	403.6	124.4	.38	69.79
	305	435.6	126.6	.40	74.08
	330	467.6	128.7	.43	78.36
	355	499.6	130.8	.45	82.64
	380	531.6	133.0	.48	86.93
	405	563.6	135.1	.50	91.21

PAPER III. ADJUSTMENT PROCEDURES AND GENETIC PARAMETER ESTIMATES OF SERIAL GROWTH AND ULTRASONICALLY MEASURED CARCASS TRAITS IN PERFORMANCE TESTED YEARLING BULLS

ABSTRACT

Serially collected growth and ultrasonic carcass trait measurements from performance tested Angus and Simmental bulls in two cooperator herds were used to evaluate data collection and adjustment procedures. Additionally, restricted maximum likelihood (REML) estimates of variance components, heritability (h^2) and sire expected progeny differences (EPDs) were generated. Several adjustment procedures involving one, two or all four of the measurements on each animal were compared. Results indicate that two measurements taken 30 to 60 days apart when the contemporary group average age is near 365 days provides age adjusted values that rank the most like adjustments determined by the best fitting linear and quadratic regression line through all four data points on each individual animal. Single trait h^2 estimates for weight (WT), height (HT) and ultrasound longissimus muscle area (ULMA) for Angus bulls were .52, .57, and .64. The sire variance was zero for ultrasound 12-13th rib fat thickness (UFAT) in Angus bulls and consequently h^2 could not be calculated. Single trait h^2 estimates were .37, .23, .21, and .87 for WT, HT, UFAT, and ULMA, respectively, in Simmental bulls. Multiple trait h^2 estimates of WT HT, and ULMA in Angus bulls were very similar to their respective single trait estimates. Multiple trait h^2 estimates of WT, UFAT, and ULMA in Simmental bulls were slightly larger than single trait estimates for WT and UFAT and exactly the same for ULMA. Genetic correlations (r_g) suggest a strong genetic relationship between WT and ULMA in both Angus and Simmentals (.67 and .80). In Simmentals, the r_g

between WT and UFAT was -.29 and between UFAT and ULMA was -.03. In Angus bulls, the r_g between WT and HT was .40, the r_g between HT and ULMA was .13.

INTRODUCTION

As a result of consumer concerns about leanness, quality and consistency of beef it is likely more important now than ever before that all segments of the beef industry respond to consumer needs. It is obvious that if beef is to remain the protein source of choice among most American consumers more attention must be paid to product specifications. The particular needs of potential export markets also dictate several narrow specification windows that could be filled with American beef. It is also obvious that feeding and management alone cannot assure consumer acceptance or product specification. The solution will require genetic improvement of the raw product utilized by the packing and retail segments of the industry (Benyshek et al., 1988).

Genetic improvement of carcass traits in beef cattle has been a slow process. This stems, in part, from the lack of an organized industry-wide evaluation system and, in part, from a fed beef marketing system that fails to provide financial incentive for producing a superior product. The concepts of instrument grading and value-based marketing are certain to become a reality and consequently beef producers must prepare themselves to respond. Producers and breed associations with knowledge of their genetic base as it relates to carcass merit and with genetic evaluation systems in place are likely to be in a better position to capitalize on premiums associated with genetics capable of producing a superior product.

Real-time ultrasound technology offers a relatively low-cost alternative to expensive and time-consuming progeny testing of beef sires for carcass merit. The accuracy of this technology for measuring fat thickness and longissimus muscle area in beef cattle has been verified and documented by several researchers (Brethour, 1992; Houghton and Turlington, 1992; Perkins et al., 1992; Robinson et al., 1992; Paper I of this Dissertation). Consequently, this technology has the potential to play a key role in the genetic evaluation and improvement of carcass merit, especially as it relates to the never-before available opportunity to directly evaluate carcass merit in the breeding animal itself.

Before industry-wide genetic evaluation of carcass merit as determined by ultrasonic measurements can become a reality reliable breed specific estimates of heritabilities as well as genetic and environmental relationships between important traits must be obtained.

The objectives of this study were to first evaluate different data adjustment strategies such that animals can be fairly compared at a common endpoint and from this suggest ultrasound data collection protocols for yearling bulls. Secondly, to estimate genetic parameters for growth and ultrasonically measured carcass traits with data collected from yearling Angus and Simmental bulls. Finally, to generate growth and carcass trait expected progeny differences (EPD) for the sires of these bulls.

MATERIALS AND METHODS

Serial ultrasound scan data collected on Angus and Simmental bulls described in Paper II of this Dissertation were used in this study. In review, Angus and Simmental bulls were measured for weight (WT), hip height (HT), 12-13th rib ultrasonic fat thickness (UFAT), and 12-13th rib ultrasonic longissimus muscle area (ULMA) four times at monthly intervals during the final 80 to 100 days on test at two cooperator herds over a four-year period. Sire progeny groups in different herds and in adjacent years were tied by at least two common sires in each breed. Ultrasound measurements were collected by experienced technicians using either an Aloka 633 (Corrometrics Medical Systems, Wallingford, CT) with a 12.5 cm, 3.5 Mhz linear array transducer (1989) or an Aloka 500V (Corometrics Medical Systems, Wallingford, CT) equipped with a 17 cm, 3.5 MHz linear array transducer (1990-1992). Data collection procedures are described more thoroughly in Paper II of this Dissertation.

These serial measurements were then used to evaluate the changes in growth and composition of performance tested yearling bulls (Paper II of this Dissertation) which should lead to a clearer understanding of possible data adjustment strategies. The following adjustment procedures will be evaluated for the traits of WT, HT, UFAT, and ULMA:

1. Adjusting an animal to a year of age along the best fitting curve through its four measurements (fitting both the linear and quadratic effect of age on an individual animal basis) (WT365LQ, HT365LQ, FAT365LQ, LMA365LQ);

2. Adjusting an animal to a year of age along the slope of the best fitting straight line through its four measurements (fitting the linear effect of age on an individual animal basis) (WT365L, HT365L, FAT365L, LMA365L);
3. Adjusting an animal to a year of age along the slope of the line between two measurements on an individual animal basis;
   a. between measurements three and four (WT36534, HT36534, FAT36534, LMA36534);
   b. between measurements two and four (WT36524, HT36524, FAT36524, LMA36524);
   c. between measurements one and four (WT36514, HT36514, FAT36514, LMA36514);
4. Adjusting an animal to a year of age using only a single measurement (simply determine the change in the trait per day of age with a breed constant intercept at birth and adjust to a year of age) ([(measurement - intercept)/age] x 365 + intercept);
   a. using measurement four (WT365B4, HT365B4, FAT365B4, LMA365B4);
   b. using measurement three (WT365B3, HT365B3, FAT365B3, LMA365B3);
   c. using measurement two (WT365B2, HT365B2, FAT365B2, LMA365B2);
   d. using measurement one (WT365B1, HT365B1, FAT365B1, LMA365B1);

These adjustment procedures were compared with Spearman rank correlations (SAS, 1989) to determine how animal rank was affected by the different adjustments.

Genetic parameters were estimated from the restricted maximum likelihood (REML), algorithm of VanRaden (1986) for WT, HT, UFAT, and ULMA adjusted to a year of age by adjustment procedures 1, 2, 3a, and 4a. This set of FORTRAN programs compute REML estimates of sire and error variance and covariance components, as well as estimates of sire EPD (Wilson et al., 1993). Sire and maternal grandsire additive genetic relationships were incorporated into the analysis using software developed by Boldman (1989) to increase prediction accuracies. This set of FORTRAN programs was used to build the inverse of the numerator relationship matrix among sires and maternal grandsires (Wilson et al., 1993).

Finally, the effect of adjustment procedure on the rank of sire EPDs was evaluated with Spearman Correlations (SAS, 1989) for each of the four traits, adjusted via procedure 1, 2, 3a, and 4a.

RESULTS AND DISCUSSION

One of the difficulties in conducting a genetic evaluation for carcass merit using field records is the wide variety of endpoints at which the data are collected. Not having a common endpoint makes it impossible to fairly compare sires for genetic merit of carcass traits (Wilson et al., 1993). The three most logical endpoint adjustment possibilities are age-constant, weight-constant, and compositional-constant endpoints or some combination of these. The literature concerning the most appropriate endpoint is inconclusive for measurements made on carcasses and extremely limited for ultrasonically measured carcass traits. Also, the majority of this adjustment work deals with market animals and will need to be adapted to breeding animals if ultrasound information is incorporated into carcass merit evaluation programs.

Cundiff et al. (1969) evaluated retail product (RP) and fat trim (FT) at age, weight and age and weight constant endpoints. In this study, age constant RP was highly heritable (.64) while weight constant RP was only moderately heritable (.42) and very similar to the heritability (h^2) of RP when both age and weight were held constant (.43). This study also reports that the phenotypic standard deviation (SD) was about 2.4 times greater for age adjusted RP than either of the other two adjustment strategies. The larger phenotypic SD combined with the higher h^2 estimate suggests that single trait selection of age constant RP would allow more improvement in RP at any level of selection intensity. Fat trim from the carcass at a constant age, weight and when both age and weight were held constant was moderately heritable, .46, .37, and .42, respectively. Here again, phenotypic variation was reported to be less for FT at a constant weight than at a constant age. When these results were combined with the genetic and phenotypic correlations between production and carcass traits Cundiff et al. (1969) and Cundiff et al. (1971) conclude that adjustment of carcass composition data to an age constant basis allows for more overall genetic improvement in both production and carcass traits if carcass weight is kept from increasing greatly by slaughtering animals at younger ages.

Koch et al. (1982b) reports that when adjusted to a common fat thickness, breed group differences in composition were reduced by 50% relative to differences at a constant age. They also reported that differences in composition of breed groups were greatest when adjusted to a common weight. But, they were dealing with breeds that exhibit a great deal of variation in size and rate of maturity.

Benyshek (1981) reported that h^2 estimates of carcass traits from records adjusted to an age- or weight-constant basis were virtually identical from Hereford field data. This report suggests that it would be difficult to say which of the two methods is more appropriate and concludes that once the covariate slaughter age was included in the model little change in h^2 or variance component estimates resulted from further adjustment of the data.

Although it is most likely that ultrasound data collected from potential breeding animals will be less variable in terms of endpoint, how this data is adjusted is very important. Turner et al. (1990)

reports that cattlemen are concerned with comparing ULMA on adjusted or relative basis and suggest that adjusted ULMA and ULMA per unit body weight are important variables. Turner et al. (1990) conclude that ULMA measurements should be adjusted for linear effects of age and weight as well as linear and quadratic effects of fat before being used for selection. Wilson et al. (1993) on the other hand, report concern with this type of adjustment because an age-weight endpoint is an artificial endpoint that may not be genetically possible for many of the animals evaluated. Concerning LMA per unit body weight, Dinkel et al. (1965) report that the use of ratios or percents involving weight as a denominator does little more than change the sign of the relationship between the trait and weight. Dinkel et al. (1965) also warns that effects of interest in carcass traits may actually be masked by use of ratios or percents.

Both Arnold et al. (1991) and Johnson (1992) evaluated UFAT and ULMA at age and weight constant endpoints in yearling bulls and found very little difference in h^2 estimates. Johnson (1992) does, however, report that because of differences in phenotypic SD, slightly more progress in ULMA is possible with selection based on age-constant ULMA.

Turner et al. (1990) reported that UFAT did not reveal any age regression effect ($P > .10$) and consequently was not adjusted. Both Arnold et al. (1991) and Johnson (1992) fit the linear effect of age as a covariate in their UFAT genetic evaluation models.

Although the above reviewed literature is not conclusive as to the most appropriate endpoint to adjust carcass data, it appears that age adjustment may have the most advantages. Consequently, this study will only address adjustment to an age-constant endpoint of 365 days.

The serially collected measurements of WT, HT, UFAT, and ULMA allow a unique opportunity to evaluate several different adjustment procedures. Having four measurements on each animal allows the evaluation of both linear and quadratic effects of age on each trait providing a growth curve for each animal. However, scanning the animals four times is not practical in the field. Consequently, a more simplified procedure must be developed that still allows for accurate adjustment and evaluation of the traits of interest. The values obtained by adjusting an animal to 365 days of age along individual animal linear and quadratic regression curves (WT365LQ, HT365LQ, FAT365LQ and LMA365LQ) will be used as the basis of comparison for other adjustment procedures in this study. The regression lines from which these adjustments are based make use of all the serially collected information available to describe changes in growth and composition on an individual animal basis. Also, Paper II of this Dissertation concluded that the within breed means of these individual animal linear and quadratic regressions better describe the actual changes in growth and composition in this set of yearling bulls than individual animal linear regressions or regressions performed on the pooled data within breed.

It is not the intent of this study to suggest alternative adjustment procedures for WT and HT. However, to be consistent in evaluating changes in both growth and composition these variables will be analyzed the same as UFAT and ULMA.

The first data collection and adjustment option was to evaluate whether or not two of these four scans could be used to accurately adjust an animal to 365 days of age and if so how far apart should these two measurements be taken. Table 1 presents the rank correlations between individual animal linear and quadratic adjustments described by adjustment procedure 1 and each of the possible two scan adjustments described by adjustment procedure 3. The rank correlations between the WT variables in both breeds are close to one in all cases and suggest that any of the two measurement adjustment procedures yield results nearly identical to the basis of comparison. The rank correlations for HT in Simmentals are quite consistent while those for HT in Angus suggest that the two measurements need to be between 30 and 60 days apart. The rank correlations relating to UFAT variables in this table indicate that within breed the rank correlations are similar and that Angus are ranked more like the basis of comparison than Simmentals. Finally, two ULMA measurements taken 30 to 60 days apart in both breeds yield results most like the basis of comparison.

It is important to remember from Paper II of this Dissertation that the average age of these animals at the time of the fourth measurement was very close to 365 days of age and the SD of age in each of the contemporary groups ranged from 9 to 20 days. This combined with the results of Table 1 suggest that as long as the CG has a reasonably small amount of age variation and one of the two measurements (preferably the second) is made when the average age of the CG is close to 365 days two measurements can take the place of four. The rank correlations of .95 or

Table 1. Rank correlations between the individual animal linear and quadratic adjustment and all possible two measurement adjustment procedures[a,b]

	WT365LQ	WT36534	WT36524	WT36514
WT365LQ		1.0	.99	.97
WT36534	.99		.99	.98
WT36524	1.0	.99		1.0
WT36514	.99	.99	1.0	
	HT365LQ	HT36534	HT36524	HT36514
HT365LQ		.95	.95	.90
HT36534	.97		.95	.95
HT36524	.98	.98		.97
HT36514	.96	.98	.99	
	FAT365LQ	FAT36534	FAT36524	FAT36514
FAT365LQ		.99	.98	.97
FAT36534	.95		.98	.98
FAT36524	.97	.94		.99
FAT36514	.94	.95	.98	
	LMA365LQ	LMA36534	LMA36524	LMA36514
LMA365LQ		.97	.96	.91
LMA36534	.96		.92	.91
LMA36524	.96	.96		.98
LMA36514	.93	.96	.99	

[a]Angus above the diagonal Simmental below.

[b]Variable abbreviations are explained in the Materials and Methods.

greater indicate that animals can be very accurately adjusted to 365 days of age using the slope between two measurements taken 30 to 60 days apart.

The second data collection and adjustment option was to evaluate adjusting an animal to 365 days of age using the slope of the line between a single measurement and a breed constant intercept at birth. These breed constant intercepts are the mean intercepts of individual animal linear regressions on age presented in Paper II of this Dissertation. The slope of the line between the breed constant at birth and each of the four measurements taken on an animal were evaluated to assess the effect of taking a single measurement farther away from when the CG averaged a year of age.

Table 2 presents the rank correlations comparing the results of these adjustments with the basis of comparison, which is again adjusting an animal to 365 days of age along the best fitting linear and quadratic regression curve on an individual animal basis. These results clearly indicate the potential ranking problems possible as we move the average age at the time of measurement away from 365 days. In all traits of both breeds for every 30 days farther away, the measurements are taken from when the CG average is close to 365 days there is a significant decrease in rank correlation, especially in the two carcass traits. It should be noted that when the average age of the CG is near 365 days and the age variation within the CG is fairly small this crude but simple adjustment procedure does a pretty good job of ranking the animals like our basis of comparison.

Table 2. Rank correlations between the individual animal linear and quadratic adjustment and each of the single measurement adjustment procedures

	WT365LQ	WT365B4	WT365B3	WT365B2	WT365B1
WT365LQ		.97	.94	.94	.89
WT365B4	.99		.96	.95	.91
WT365B3	.97	.97		.96	.91
WT365B2	.92	.94	.93		.93
WT365B1	.82	.82	.80	.91	
	HT365LQ	HT365B4	HT365B3	HT365B2	HT365B1
HT365LQ		.90	.77	.60	.65
HT365B4	.95		.81	.70	.70
HT365B3	.76	.83		.76	.72
HT365B2	.64	.77	.86		.69
HT365B1	.66	.72	.75	.75	
	FAT365LQ	FAT365B4	FAT365B3	FAT365B2	FAT365B1
FAT365LQ		.97	.90	.83	.71
FAT365B4	.94		.90	.86	.73
FAT365B3	.67	.67		.86	.72
FAT365B2	.54	.61	.62		.78
FAT365B1	.48	.47	.45	.54	
	LMA365LQ	LMA365B4	LMA365B3	LMA365B2	LMA365B1
LMA365LQ		.88	.65	.42	.45
LMA365B4	.94		.58	.30	.32
LMA365B3	.73	.79		.49	.49
LMA365B2	.61	.71	.61		.72
LMA365B1	.62	.64	.54	.86	

[a]Angus above the diagonal, Simmental below.

[b]Variable abbreviations are explained in Materials and Methods.

Table 3 contains a summary of rank correlations between values adjusted to 365 days of age using procedures 1, 2, 3a, and 4a. Procedures 3a and 4a are the best adjustment options previously presented in Tables 1 and 2. Comparing these two adjustment procedures with procedure 1 (adjusting to 365 days of age along the individual animal linear and quadratic curve) and procedure 2 (adjusting to 365 days of age along the individual animal linear regression line through the four measurements) suggests that procedure 3a ranks the animals most like the basis of comparison (procedure 1). In Simmentals, adjustment procedures 3a and 4a yield similar results with 3a having a slight advantage. The same is true for WT and UFAT in Angus but in HT and ULMA the rank correlations clearly suggest the two measurement adjustment procedures have an advantage.

In general, the rank correlations between procedure 1 and procedures 2 and 4a yield similar results. Paper II of this Dissertation concluded that the quadratic effect of age was essential to describe the compositional changes taking place. Although the two measurement adjustment procedure (3a) presented here is a linear adjustment the slope of this line over the measurement period suggested (30-60 days apart when the CG averages 365 days of age) better adjusts for compositional changes during this time period than procedures 2 and 4a. This is especially true for the traits that displayed large quadratic effects in Paper II of this Dissertation.

Genetic parameters were estimated with a REML algorithm (VanRaden, 1986) that included sire and maternal grandsire genetic relationships

Table 3. Rank correlations between different ways of adjusting growth and carcass data to 365 days of age[a,b]

	WT365LQ	WT365L	WT36534	WT365B4
WT365LQ		.97	1.0	.97
WT365L	.98		.98	.99
WT36534	.99	.98		.98
WT365B4	.99	.99	.99	
	HT365LQ	HT365L	HT36534	HT365B4
HT365LQ		.88	.95	.90
HT365L	.90		.93	.96
HT36534	.97	.93		.94
HT365B4	.95	.96	.97	
	FAT365LQ	FAT365L	FAT36534	FAT365B4
FAT365LQ		.97	.99	.97
FAT365L	.90		.97	.98
FAT36534	.95	.89		.98
FAT365B4	.94	.93	.94	
	LMA365LQ	LMA365L	LMA36534	LMA365B4
LMA365LQ		.91	.97	.88
LMA365L	.87		.90	.92
LMA36534	.96	.90		.88
LMA365B4	.94	.94	.96	

[a]Angus above the diagonal Simmental below.

[b]Variable abbreviations are explained in the Materials and Methods.

(Boldman, 1989). Age-constant data obtained from adjustment procedure 1 were used in this analysis. Table 4 contains single trait estimates of sire variance, error variance and h^2 for Angus bulls. The parameter estimates for FAT365LQ could not be solved for Angus because the sire variance was zero. The h^2 of LMA365LQ in this study (.64) was much higher than the h^2 reported by Wilson et al. (1993) for LMA from Angus field data (.32). Table 5 contains the results of the same analysis of Simmental data. Woodward et al. (1992) reported h^2 estimates from Simmental field data of .28 and .18 for retail cuts per day (RC) and percent cutability (CU), respectively. Although these are not exactly the same traits they certainly are indications of muscle and fatness. Lamb et al. (1990), Arnold et al. (1991) and McDonald (1991) reported h^2 of UFAT to be .24, .26, and .25, respectively, while Turner et al. (1990) and Johnson (1992) found this h^2 to be only .04 and .14, respectively. The h^2 for FAT365LQ (.21) for Simmental bulls in Table 5 agrees more closely with the first three studies. The h^2 estimates for LMA365LQ for both breeds are much higher than those reported by Turner et al. (1990), Arnold et al. (1991), McDonald (1991), and Johnson (1992) of .11, .28, .25, and .40, respectively. These estimates are also generally higher than age constant estimates of carcass measured LMA in the literature (Benyshek, 1981; Brakelsburg et al., 1971; Cundiff et al., 1971; Dinkel and Busch, 1973; Koch, 1978; Koch et al., 1982). These studies report h^2 of LMA to be from .25 to .56 and h^2 of carcass fat to be from .40 to .68. The h^2 of HT365LQ in Table 5 is also much lower than the h^2 of frame score reported by Johnson (1992) (.42). This is perhaps partly due to

Table 4. Single trait variance component and heritability estimates for Angus growth and ultrasonically measured carcass traits[a]

Trait	Sire Variance	SE	Error Variance	SE	h^2	SE
WT365LQ	498.37	308.88	3322.74	317.53	.52	.28
HT365LQ	.8042	.4747	4.8125	.4600	.57	.29
FAT365LQ[b]						
LMA365LQ	2.2955	1.2826	12.0670	1.1529	.64	.30

[a]Adjusted to a year of age using individual animal linear and quadratic regressions.

[b]Estimates not available, sire variance approaches zero.

Table 5. Single trait variance component and heritability estimates for Simmental growth and ultrasonically measured carcass traits[a]

Trait	Sire Variance	SE	Error Variance	SE	h^2	SE
WT365LQ	335.98	310.54	3293.51	377.79	.37	.31
HT365LQ	.4503	.5535	7.3998	.8489	.23	.27
FAT365LQ	.0003	.0005	.0061	.0008	.21	.26
LMA365LQ	2.8206	1.7374	10.0813	1.1561	.87	.43

[a]Adjusted to a year of age using individual animal linear and quadratic regressions.

the small amount of variation in frame size in the Simmental bulls and partly due to the error involved in HT measurement. It should be noted that the estimates of sire and error variance for FAT365LQ in Table 5 are extremely small. It is also important to remember that the h^2 estimates in this study are from a limited amount of data and consequently the standard errors are quite large.

Table 6 contains sire EPD and accuracy means and ranges for each trait by breed. In the Angus breed, the 26 sires evaluated had a mean effective progeny number (EPN) of 8.17 and the range in EPN was from 1.93 to 19.55. The 14 Simmental sires evaluated had EPNs ranging from 3.58 to 21.36 and the mean EPN was 9.67. The narrow range in FAT365LQ EPDs for Simmentals indicates that it would be difficult to make much change in FAT with selection based on these EPDs. The range in LMA365LQ EPDs for Angus bulls is reasonably close to the range in LMA EPDs (-4.2 to 4.2 cm^2) in the Angus sire summary (Wilson et al., 1993). The range in accuracies suggest that these results are subject to some possible change but certainly have merit as preliminary indications.

When multiple trait analysis of the data were performed there were convergence problems in both breeds when all four traits were involved. In Angus, when FAT365LQ was removed from the analysis convergence criteria were met and the resulting variance component and heritability estimates are presented in Table 7. These h^2 estimates are very close to those of the single trait analysis in Table 4. Woodward et al. (1992) also found that single versus multiple trait analysis of carcass and growth traits in Simmental field data had very little effect on h^2

Table 6. Sire EPDs and accuracies of growth and ultrasonically measured carcass traits adjusted to a year of age with individual animal linear and quadratic regressions[a]

		Sire EPDs		Accuracy	
Breed	Trait	Mean	Range	Mean	Range
Angus	WT365LQ,kg	-.22	-22.62 to 19.10	.55	.29 to .76
	HT365LQ,cm	.01	-.84 to 2.67	.57	.30 to .78
	FAT356LQ[b],cm				
	LMA365LQ,cm^2	-.05	-6.19 to 4.73	.59	.32 to .80
Simmental	WT365LQ,kg	-.57	-17.22 to 9.29	.52	.27 to .73
	HT365LQ,cm	0	-1.07 to 1.14	.42	.18 to .64
	FAT365LQ,cm	0	-.02 to .04	.41	.17 to .63
	LMA365LQ,cm^2	.03	-4.84 to 5.81	.71	.50 to .87

[a]From single trait analysis.

[b]FAT365LQ did not converge for Angus, sire variance approaches zero.

Table 7. Multiple trait variance component and heritability estimates for Angus growth and ultrasonically measured carcass traits[a]

Trait	Sire Variance	SE	Error Variance	SE	h^2	SE
WT365LQ	482.51	303.81	3328.89	318.12	.51	.28
HT365LQ	.7948	.4719	4.8156	.4602	.57	.29
LMA365LQ	2.2626	1.2723	12.0787	1.1542	.63	.30

[a]Adjusted to a year of age using individual animal linear and quadratic regressions.

estimates. In Simmentals when HT365LQ was removed from the analysis convergence criteria were met and the resulting variance component and h^2 estimates are shown in Table 8. Multiple trait analysis in this case yielded higher h^2 estimates than single trait analysis for WT365LQ and FAT365LQ. The h^2 estimates for LMA365LQ were identical in the two analyses.

Table 9 presents the genetic (r_g) and phenotypic (r_p) correlations between the three traits evaluated with the multiple trait analysis for Angus. This table indicates that in Angus bulls yearling weight and muscling are positively associated (r_g = .67) and that the genetic relationship between LMA365LQ and HT365LQ is small (r_g = .13). This suggests that selection for age constant-ULMA should allow animals to increase in muscling and weight without great increases in height, which should allow breeders to moderate height and mature size while improving growth and carcass traits.

Table 8. Multiple trait variance component and heritability estimates for Simmental growth and ultrasonically measured carcass traits[a]

Trait	Sire Variance	SE	Error Variance	SE	h^2	SE
WT365LQ	472.10	370.21	3249.76	372.77	.51	.35
FAT365LQ	.0005	.0005	.0061	.0008	.32	.30
LMA365LQ	2.8039	1.7303	10.0864	1.1568	.87	.43

[a]Adjusted to a year of age using individual animal linear and quadratic regressions.

Table 9. Angus growth and ultrasonically measured carcass trait phenotypic and genetic correlations[a,b]

	WT365LQ	HT365LQ	LMA365LQ
WT365LQ		.40	.67
HT365LQ	.44		.13
LMA365LQ	.39	.03	

[a]Adjusted to a year of age using individual animal linear and quadratic regressions.

[b]Genetic correlations above the diagonal, phenotypic correlations below.

Table 10 contains the r_g and r_p between the three traits in the Simmental multiple trait analysis. Similar to Angus the Simmental r_g between WT365LQ and LMA365LQ is quite large (.80). This table also indicates virtually no genetic association between LMA365LQ and FAT365LQ (r_g = -.03). Phenotypically, FAT365LQ is only moderately correlated with yearling weight and LMA365LQ (r_g = .26 and .25, respectively). The r_g between WT365LQ and FAT365LQ in this study (-.29) is in reasonable agreement with Johnson (1992) who found it to be -.55. Other researchers (Lamb et al., 1990; Turner et al., 1990; Arnold et al., 1991) have reported a positive genetic relationship between ultrasonically measured fat and weight traits.

Arnold et al. (1991) and Johnson (1992) reported that the r_g between yearling weight and yearling LMA was .57 and .38, respectively. Turner et al. (1990) on the other hand reported this r_g to be -.07 and suggested the two traits had independent genetic determination. Table 9 suggests a moderate r_g (.40) between yearling weight and height in Angus bulls while Johnson (1992) reports the r_g between frame score and yearling weight to be high (.67). Johnson (1992) also reports r_g of frame score with ULMA and UFAT of .01 and .14, respectively, and suggest that the genetic relationship between skeletal size and carcass traits in Brangus bulls is small if even existent.

Although the parameter estimates and sire EPDs are not reported here they were also estimated for age constant variables adjusted via procedures 2, 3a, and 4a. The main reason for performing these analyses was to allow comparison of sire EPDs from four of the previously

Table 10. Simmental growth and ultrasonically measured carcass trait phenotypic and genetic correlations[a,b]

	WT365LQ	FAT365LQ	LMA365LQ
WT365LQ		-.29	.80
FAT365LQ	.26		-.03
LMA365LQ	.59	.25	

[a]Adjusted to a year of age using individual animal linear and quadratic regressions.

[b]Genetic correlations above the diagonal, phenotypic correlations below.

evaluated adjustment procedures (1, 2, 3a, and 4a). Table 11 presents the rank correlations between sire EPDs from each of these adjustment procedures by trait. Again, remember that there was no convergence for adjusted UFAT in Angus bulls and consequently the solutions are not available. As one might expect, this table generally yields the same results as Table 3. However, the advantage of the two measurement adjustment procedure (3a) is even clearer in Table 11.

In conclusion, this study suggests that producers can scan bulls twice, 30-60 days apart and do a very accurate job of adjusting UFAT and ULMA to a year of age. One of these two scans (preferably the second) needs to be taken when the CG average age is near 365 days. The age variation within the contemporary group needs to be as small as possible (SD < 20 days). This data collection and adjustment procedure seems the

Table 11. Rank correlations between sire solutions from four different adjustment strategies[a,b]

	WT365LQ	WT365L	WT36534	WT365B4
WT365LQ		.88	.97	.92
WT365L	1.0		.91	.97
WT36534	.97	.96		.94
WT365B4	.98	.97	.99	
	HT365LQ	**HT365L**	**HT36534**	**HT365B4**
HT365LQ		.77	.91	.86
HT365L	.99		.89	.92
HT36534	.98	.98		.97
HT365B4	.96	.97	.96	
	FAT365LQ	**FAT365L**	**FAT36534**	**FAT365B4**
FAT365LQ				
FAT365L	.83			
FAT36534	.98	.80		
FAT365B4	.92	.84	.92	
	LMA365LQ	**LMA365L**	**LMA36534**	**LMA365B4**
LMA365LQ		.83	.98	.81
LMA365L	.82		.85	.93
LMA36534	.96	.87		.83
LMA365B4	.93	.93	.98	

[a]Angus above the diagonal Simmental below.

[b]Variable abbreviations are explained in the Materials and Methods.

most accurate and practical. The results of this study indicate that if single measurement data collection and adjustment procedures are used, producers are going to sacrifice some accuracy as it relates to correctly ranking both individual animals and sire EPDs. However, whether or not the expense and difficulty of taking the second measurement is worth the increase in accuracy of taking two measurements is not known.

With the exception of adjusted fat thickness in Angus bulls all evaluated traits were heritable. Although some of these h^2 estimates are not in real close agreement with those of other researchers they are based on limited numbers. As the number of sires represented and the number of animals evaluated increases these estimates will stabilize. This study and others cited within certainly suggest that selection based on genetic evaluations of ultrasonically measured LMA could be effective. The use of this type of UFAT evaluation on the other hand is a bit less certain. It appears that, at the energy levels fed in many performance bull tests, these young bulls are not fully expressing their genetics to fatten. For this reason it is extremely important that the ultrasound technician accurately evaluate the differences that are present. It also seems important that the sire groups and contemporary groups are fairly large to aid in determining differences. Finally, one again needs to remember that these results are based on fairly limited numbers. Consequently, these results are only preliminary and more information must be collected before any major programs are initiated.

IMPLICATIONS

The data collection and adjustment procedures presented in this paper suggest that there are practical and accurate ways to use ultrasonically evaluated carcass data in a carcass evaluation program. Preliminary analysis involving limited numbers certainly suggest that improvement in LMA is possible via this system. The amount of variation in fat thickness causes these evaluations to appear less appealing from a genetic improvement standpoint. However, with more animals evaluated and improving technology, valid genetic evaluations of sires for UFAT is still possible. The small amount of variability in UFAT measurements makes it unlikely to ever be a tool to make individual animal selections, however, its use to evaluate sire group differences and create genetic evaluation data bases is still promising. More investigation is also needed to determine the relationships between composition differences in breeding and market animals. Along with this, research is certainly needed to determine how ultrasound measurements of breeding and market animals and carcass data, both current and future, are going to be combined in genetic evaluation programs. More importantly perhaps is how are the differences in carcass EPDs of sires, as determined by ultrasonic evaluation of yearling breeding animals, expressed in their offspring fed as market animals.

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GENERAL CONCLUSION

The results presented suggest that, when operated by an experienced, competent technician, real-time ultrasound technology has the potential to accurately measure fat thickness and longissimus muscle area in live beef cattle. Accurate and practical data adjustment procedures are presented that allow animals to be compared at a constant endpoint. Preliminary analysis indicated that yearling longissimus muscle area in both breeds and fat thickness in Simmentals, as determined by ultrasound measurements, are heritable traits on which selection should be effective. These estimates are based on limited numbers and consequently the standard errors are large. As additional data is collected the accuracy of these evaluations will increase and hopefully genetic analysis of fat thickness in Angus will be successful. Also, as the technology continues to improve so should the accuracy and usefulness of this information.

Genetic evaluation and improvement of carcass traits is a must if the beef industry is to stay competitive. Results of these studies and those referenced within certainly indicate that real-time ultrasound technology has the potential to play a key role in this process. Certainly one of the limiting factors to the widespread use of this technology to evaluate carcass merit will be its ability to measure intramuscular fat or marbling in the live animal. Current research results look promising.

Although the results from the genetic analysis portion of this report look very promising more data is needed before any major industry moves take place. More investigation is needed to determine the relationships between compositional differences in breeding and market animals. Also, how data collected on carcasses and ultrasound information are going to be used together must be determined. The real question yet to be answered is how are the differences in carcass EPDs, developed from ultrasound data collected on yearling breeding animals, expressed in the market offspring they are intended to represent.

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