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Prediction of retail product and trimmable fat in beef cattle using ultrasound or carcass data

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Prediction of retail product and trimmable fat in beef cattle using ultrasound or carcass data

by

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ABSTRACT

The most widely used system to predict percent retail product from the four primals in beef cattle is USDA yield grade. The purpose of this study was to determine if routine ultrasound measurements and additional rump measurements could be used to more accurately predict the percent lean from the four primals than the carcass measurements going into the USDA yield grade equation. This study utilized market cattle (n = 471) consisting of Angus bulls, Angus steers, and crossbred steers. The right side of each carcass was fabricated into retail cuts, lean trim, fat, and bone; weights of each component were recorded. Percent retail product from the four primals was then expressed as a percentage of side weight. Traditional carcass measures collected were: 1) hot carcass weight (HCW), 2) 12-13th rib fat thickness (CFAT), 3) 12-13th rib ribeye area (CREA), and 4) percent kidney, pelvic, and heart fat (KPH). Live animal ultrasound measures collected within seven days prior to harvest were: 1) scan weight (SCANWT), 2) 12-13th rib fat thickness (UFAT), 3) 12-13th rib ribeye area (UREA), 4) subcutaneous fat thickness over the termination of the *biceps femoris* in the rump(reference point) (URFAT), 5) depth of *gluteus medius* under the reference point (URDEPTH), and 6) area of *gluteus medius* anterior to the reference point (URAREA). A stepwise regression was performed to develop models to predict percent retail product from the four primals based on carcass measures or ultrasound measures, and comparisons were made between the models. Significant measures ($P < 0.001$) for the carcass data were CFAT, KPH, and CREA with a model $R^2 = 0.297$. Significant measures ($P < 0.001$) for the ultrasound data were UFAT, UREA, SCANWT, URDEPTH with a model $R^2 = 0.448$. This study also validated 10 equations which had been either previously reported (n = 8), or modified (n = 2) from a previously reported equation to predict percent retail product in beef cattle. Validation of these equations included reporting R^2, root mean squared error, and P-value for each equation.

GENERAL INTRODUCTION

Introduction

The beef cattle industry has been in a marketing methodology transition for several years now. The move has been away from paying producers on "averages" and to start paying producers for meeting the desired marketing windows. Part of this change has meant placing more emphasis on selection of breeding stock for desirable carcass characteristics. Collection of carcass data by the American Angus Association (AAA) and Angus breeders has been a long term commitment, and through structured sire evaluation programs over 64,000 records have been collected since the 1970's (AAA, 2002). However, an evolution in data collection procedures has recently taken place among Angus breeders. Since 1998, more than 168,000 head of Angus cattle have been evaluated through centralized ultrasound processing for body composition traits (AAA, 2002).

Many studies have been conducted to evaluate retail product prediction based on carcass measurements (Murphey et al., 1960; Abraham et al., 1968; Crouse and Dikeman, 1976; Abraham et al., 1980; Dikeman et al., 1998). Meanwhile live animal prediction of percent retail product through the use of real-time ultrasound has been more recent (Herring et al., 1994b; Greiner, 1997; Williams et al., 1997; Realini et al., 2001). Many of these ultrasound studies (Greiner, 1997; Williams et al., 1997; Realini et al., 2001) have also been interested in incorporating some new measure of lean or fat (body wall thickness below the ribeye, depth of *biceps femoris* in the rump, and depth of the *gluteus medius* in the rump, respectively) to augment the measures which correspond to the proven carcass traits for predicting percent retail product, and have had mixed results with novel traits. Responsible use of prediction equations to percent retail product would necessitate validation of previously reported equations, especially the one being used in genetic evaluation (AAA, 2002).

The objectives of this study involved: 1) developing ultrasound and carcass derived prediction equations for percent retail product, 2) investigating new measures for ultrasound which have not been previously investigated, 3) validating equations which are being used by the beef cattle industry to evaluate seedstock and carcasses for percent retail product.

Thesis Organization

This thesis is comprised of an abstract, general introduction, a review of the literature, an individual paper, a general summary, literature cited throughout the thesis, and an appendix. The paper also has references listed within it, followed by tables, and then figures. The paper is written for submission to Journal of Animal Science, and follows the Journal of Animal Science Style and Form. The appendix evaluates differences in data collection between years.

LITERATURE REVIEW

Carcass Traits Used to Predict Retail Product Yield in Beef Cattle

Retail product yield determination in beef cattle has been a trait of significant importance for quite some time. Researchers have spent a considerable amount of time, money, and effort working on methods of quantifying and predicting the retail product yield of individual animals. Today there are several methods in use for defining retail product from a beef carcass. There are methods to define retail product as completely boneless product yield, or some proportion of bone-in product and differing levels of fat trim. The primary methods of defining retail yield from a beef carcass are retail product coming from the four major wholesale cuts of the beef carcass or retail product from the whole side of beef. Abraham et al. (1980) found that retail sales value was highly correlated to both measures of retail yield from the four primals ($r = 0.97$), and retail yield from the whole side ($r = 0.99$), with 25% fat in the retail trim. Many retail product studies use the measures of yield in terms of weight of retail product, however, this is highly dependent upon the weight of the animal or carcass at harvest (Abraham et al., 1968; Epley et al., 1970; Williams et al., 1997; Greiner, 1997; Realini et al., 2001). Therefore, retail product yield is also expressed as a percentage of the carcass weight, and then a determination is made about which traits are significant predictors of percent retail product. Herring et al. (1994b) suggested that another alternative for reducing excess fat production may be through the prediction of trimmable waste fat.

There are two times in particular when determination of retail product yield is of economic importance in the beef cattle industry. The first, and most traditional, is in the carcass. This is important because the beef retailer is interested in having an estimate of the retail yield that is to come from a particular carcass before it is purchased and/or fabricated. Some of the earliest work trying to accomplish this task was reported by Murphey et al. (1960). Murphey et al. (1960) developed the equation for predicting percent retail product from the round, loin, rib, and chuck as: 51.34% – (2.277 * fat thickness over ribeye, cm) – (0.0205 * carcass weight, kg) – (0.462 * kidney fat, percent of carcass) + (0.115 * area of ribeye, cm^2). This work was part of the basis for the United States Department of Agriculture (USDA) yield grading equation which is the evaluation system beef carcasses are legally traded under today (USDA, 1997). Today, the USDA yield grading equation is: 2.5 + (0.984 * adjusted fat thickness, cm) + (0.20 * kidney, pelvic, and heart fat, %) + (0.0084 * hot carcass weight, kg) – (0.0496 * ribeye area, cm^2). Cross et al. (1973) suggested that when the USDA yield grade equation is applied to populations of more homogeneous carcasses than the population it was developed from, it is unlikely that the same relationship between estimated and actual yields would be obtained. The relationships between carcass attributes and the retail yield of the carcass are of utmost importance in predicting the profitability of the retailer or packer. Packers have moved to capture more processing revenues with specific boxed beef programs or lines. Dikeman et al. (1998) found that the “close-trimmed” (to 0.64 cm surface fat) lines of boxed beef produced by three major U.S. beef processors for retailers and purveyors account for approximately 45% of total boxed beef production.

Carcass evaluation requires equations which accurately estimate the percent of preferred retail cuts because it is not always feasible (time, labor, equipment, etc.) to actually fabricate carcasses into retail cuts (Cross et al., 1973). Cross et al. (1973) proposed that errors or variations in splitting, cutting, and trimming the beef carcass are greatly enhanced when carcass cut-out data are obtained under packing house conditions.

The other logical time period for determination of retail yield or body composition is at time of selection for replacement breeding stock. This time period for evaluation may not have the direct economic impacts that assessment of the carcass has in today’s market, however, in the future those seedstock producers who have the retailer and consumer in mind when selecting breeding stock should have a competitive advantage. The dominant technology being used to determine retail product percentage on potential breeding stock is real-time ultrasound. Determination of retail product yield at this point in the beef production chain is much more difficult. There are several factors which occur between taking these measurements on seedstock and producing harvest progeny. These factors impact the ability to evaluate the true changes in retail product yield, or body composition in prospective seedstock replacements.

Carcass 12-13th Rib Fat Thickness

Abraham et al. (1980) put forth the recognition that researchers probably would agree unanimously that a measure of external fat thickness is the most important single factor affecting the yield of retail cuts from beef carcasses. This statement was made knowing that fat thickness at the ¾ position over the ribeye betweeen the 12-13th rib has been the measurement most often used. Average fat thickness (avg of ¼, ½, and ¾ positions) resulted in higher coefficients of multiple regression than a single fat thickness measurement (R^2 = 0.58 and 0.63 for equations using single fat thickness measure and average fat thickness measure, respectively) (Abraham et al., 1968). Miller et al. (1988) agreed that subcutaneous fat thickness is the single most important indicator ($R^2 = 0.59$) of fed beef cattle carcass composition.

Crouse and Dikeman (1976) found that the correlation within a breed of sire between percent retail product and fat thickness at the 12-13th rib interface was -0.64. Epley et al. (1970) found that as a single trait for predicting percent total retail cuts, 12-13th rib fat thickness was the most important, and accounted for 50% of the variation. Fat thickness was the most important variable in equations predicting percent of boneless steak and roast meat (Abraham et al., 1968). Crouse et al. (1975) found the individual trait most highly correlated with percentage cutability was fat thickness ($r = -0.76$) at the12-13th rib. This relationship was approximately the same whether considered over all sire breed groups or pooled within groups (Crouse et al., 1975).

Abraham et al. (1980) found that the actual thickness of fat over the ribeye is a good measure of the amount of external fat trim, although the external fat may be irregularly distributed on the carcass and some fat over the ribeye may be removed during removal of the hide. Some researchers have suggested that a subjective adjustment be made to the actual measurement of fat thickness over the 12-13th rib to account for differences in overall finish of the animal (Murphey et al., 1960; Crouse and Dikeman, 1976; Abraham et al., 1980). Crouse and Dikeman (1976) found that when they used an adjusted 12-13th rib fat thickness the correlation was -0.77 to percent retail product (compared to -0.64 for unadjusted fat thickness). This is in agreement with Herring et al. (1994b), who also found a higher relationship between adjusted 12-13th rib fat thickness and cutability percentage than actual 12-13th rib fat thickness, regardless of how percentage cutability was defined (0.32 cm fat trim or 1.27 cm fat trim). Adjusted fat thickness alone accounted for a large portion of the variation ($R^2 = 0.67$) in cutability (Abraham et al., 1980). This is somewhat better than Shackelford et al. (1995) who found that adjusted 12-13th rib fat thickness was the best trait for predicting percent retail yield ($R^2 = 0.58$). May et al. (1992) found the carcass trait that was most highly correlated with boneless subprimal yield and percentage of trimmable fat was adjusted fat thickness, with simple correlations of -0.69 and 0.84, respectively. May et al. (2000) found that more often than not carcass fat measures were adjusted upward. May et al. (2000) found that adjusted fat thickness had a higher association with boneless subprimal yield than unadjusted fat thickness ($r = -0.69$ vs. -0.53, respectively). Greiner (1997) also found a stronger correlation for adjusted rib fat thickness than for unadjusted rib fat thickness to percent retail product ($r = -0.73$ and -0.68, respectively). Additionally, Miller et al. (1988) found that adjusted fat thickness alone accounted for 69% of the variation in carcass percent fat.

Reiling et al. (1992) found that 12-13th rib fat thickness accounted for 28.6% of the variation in percent retail product. Greiner (1997) found a correlation between unadjusted carcass fat thickness and retail product to be -0.68 ($P < 0.001$) and -0.08 ($P < 0.10$) for percent and weight, respectively.

Fat thickness over the ribeye is such a significant predictor of percent retail product, that the USDA may not yield grade some cattle if fat is altered. This change was introduced in the October 1980 changes to the USDA official standards for grades of steer, heifer, cow, and bullock beef (USDA, 1997). “Carcasses that have had more than minor amounts of external fat removed shall not be eligible for a yield grade determination, although carcasses with only minor amounts of external fat removed may be yield graded if the official grader determines that an accurate yield grade determination can be made” (USDA, 1997).

Dikeman et al. (1998) found that given any particular USDA yield grade, the percentage of subcutaneous fat removed during fabrication cannot be predicted with high accuracy ($R^2 = 0.25$). It was also found that the percentage of intermuscular fat for a USDA 3.0 yield grade carcass was approximately 1.5 times as much as subcutaneous fat (Dikeman et al., 1998). The proportion of intermuscular fat was higher than the proportion of subcutaneous fat for all yield grades (Dikeman et al., 1998). However, the percentage of subcutaneous fat increased as USDA yield grade number increased (Dikeman et al., 1998). This would lead to the assumption that 12-13th rib fat thickness would probably predict percent fat better in cattle that were excessively fat (USDA yield grades 4 and 5). Additionally, May et al. (1992) found a significant decrease in the percentage of lean in primal round and chuck with increased fatness.

Crouse et al. (1975) suggested that the magnitude of the correlation between 12-13th rib fat thickness and percentage cutability, and the homogeneity of the relationships over all and within breed groups, indicated that fat thickness would be a valuable predictor of cutability in a population of carcasses regardless of genetic origin.

Carcass 12-13th Rib Ribeye Area

Abraham et al. (1968) found that 12-13th rib ribeye area had a low but significant ($P < 0.05$) correlation ($r = -0.18$) with cutability expressed as a percentage of carcass weight. Cross et al. (1973) also found that 12-13th rib ribeye area was significantly ($P < 0.01$) related to percent of retail cuts. Herring et al. (1994b) found the correlation between 12-13th rib ribeye area and percent retail product from the four primals trimmed to 0.32 cm fat thickness to be 0.324 ($P < 0.05$). However, Herring et al. (1994b) indicated this was one of the weaker relationships, and the 12-13th rib ribeye area was not included ($P > 0.10$) in the final regression equations to predict percent retail product from the four primals trimmed to 0.32 cm fat thickness. Greiner (1997) found the correlation between retail product and carcass ribeye area to be 0.31 and 0.68 for percent and weight of, respectively.

Crouse et al. (1975) found the correlation between cutability and 12-13th rib ribeye area was much larger ($r = 0.47$) over all sire breed groups, than it was within sire breed groups ($r = 0.18$). Crouse and Dikeman (1976) found the correlation between carcass ribeye area at the 12-13th rib and percent retail product was 0.15 within breeds of sire. This indicates that 12-13th rib ribeye area may be particularly useful in prediction equations to partly account for variability in cutability that is associated with breed group differences (Crouse et al., 1975). Cross et al. (1973) found that regardless of the genetic background, identification of carcasses which have a high ratio of valuable cuts is facilitated by the use of prediction equations which include 12-13th rib ribeye area (rather than wholesale round weight, trimmed or untrimmed) as the index of muscling in the carcass.

Partial correlation between 12-13th rib ribeye area and cutability, holding carcass weight constant was 0.52 (Crouse et al., 1975). Crouse et al. (1975) concluded that this correlation indicates that the 12-13th rib ribeye area is more important as a predictor of cutability in cattle of similar weight, than in the cattle varying widely in weight. Furthermore, Abraham et al. (1968) found that when carcass weight, fat thickness and kidney fat were held constant, 12-13th rib ribeye area had a highly significant ($P < 0.01$) partial correlation of 0.24 with percent of boneless steak and roast meat. Cross et al. (1973) also proposed that the relative importance of 12-13th rib ribeye area within a specific group of carcasses (e.g. in a given research study) depends largely on the variability in fatness and retail cut yields compared to that of 12-13th rib ribeye area.

Abraham et al. (1980) found 12-13th rib ribeye area to be the third most important variable to be added to regression equations for predicting percent retail product, and 12-13th rib ribeye area increased the R^2 from 0.76 to 0.82. Reiling et al. (1992) found that ribeye area accounted for 25.7% of the variation in percent retail product.

However, Epley et al. (1970) found that when used alone 12-13th rib ribeye area only accounted for 1% of the variation in percent total retail cuts. Epley et al. (1970) also found that when 12-13th rib ribeye area was deleted from the equation which predicted percent retail cuts of the four primals, the standard error of estimate only increased 0.07 and R^2 decreased 0.04. Hence, Epley et al. (1970) concluded that 12-13th rib ribeye area contributed little predictive value in estimating percent retail cuts. Wallace et al. (1977) found carcass ribeye area to be of little value in predicting primal or whole side percent retail yield. Cross et al. (1973) indicated that *longissimus* muscle area may be more predictive in a given group of carcasses that have small variability in fatness.

Abraham et al. (1980) indicated that an equation which includes muscle to bone ratio ($R^2 = .85$) instead of ribeye area ($R^2 = .83$) could improve the prediction of cutability if a better measure of muscling was available.

Measurement of carcass ribeye area does possess error. There was an overall difference between carcass ribeye area tracers of about 1.3 cm^2 in several clinics to evaluate ultrasound technicians (Robinson et al., 1992). Because any suspect or wayward tracings were omitted, this report of carcass measurement error actually underestimates the true variability (Robinson et al., 1992).

Percent Kidney, Pelvic, and Heart Fat

Epley et al. (1970) found that using percent kidney, pelvic, and heart fat alone accounted for 26% of the variation in total retail yield. Abraham et al. (1980) found that adding percentage kidney, pelvic, and heart fat as the second variable in a regression equation raised the R^2 from 0.67 to 0.76. Cross et al. (1973) found that percent of kidney, pelvic, and heart fat was significantly associated ($P < 0.01$) with percent retail cuts ($r = -0.59$). Herring et al. (1994b) found that estimated percentage of kidney, pelvic, and heart fat had the second strongest correlation ($r = -0.634$) (behind USDA yield grade, $r = -0.703$) to percent retail product from the four primals trimmed to 0.32 cm fat thickness. Griffin et al. (1999) found kidney, pelvic, and heart fat to be the first variable to enter the model to predict percent retail product, regardless of trim level (2.54 cm, 1.27 cm, and 0.64 cm). Greiner (1997) found the correlation between percent kidney, pelvic, and heart fat and retail product to be -0.40 ($P < 0.001$) for percent and not correlated ($P > 0.10$) for weight. Crouse et al. (1975) found that although the correlation between cutability and percentage of kidney and pelvic fat is only moderate, this measure of fatness should be a useful predictor of cutability within breeds or over a mixed breed population. Crouse and Dikeman (1976) found that the correlation within breed of sire groups between cutability and estimated percent kidney and pelvic fat and actual percent kidney and pelvic fat was -0.38 and -0.47, respectively. This indicates that the error associated with estimating the percent kidney and pelvic fat is relevant when comparing to actual cutout data.

Abraham et al. (1980) found that cutability of kidney, pelvic, and heart fat-in carcasses can be better estimated than the cutability of carcasses with this fat removed at harvest time. This effect is probably due to a relationship between kidney, pelvic, and heart fat and some portion of total carcass fat which is not closely associated with adjusted fat thickness (Abraham et al., 1980). One possibility may be the relationship between percentage kidney, pelvic, and heart fat and percentage intermuscular (seam) fat ($r = 0.59$) (Abraham et al., 1980).

Reiling et al. (1992) found that percent kidney, pelvic, and heart fat accounted for very little variation in percent retail product ($R^2 = 0.033$). Wallace et al. (1977) found kidney fat percentage accounted for 25% and 30% of the variation in percentage of primal and whole side percent retail product.

Crouse et al. (1986) did some extensive work to determine the impacts of kidney and pelvic fat on the prediction of retail product. This work was conducted to evaluate the impact of removing kidney and pelvic fat on the slaughter floor before chilling of the carcass. Average cutability of carcasses was 2 percentage points higher (44.9% vs. 46.9%) ($P < 0.01$) when kidney and pelvic fat was omitted, as though it had been removed on the slaughterhouse floor (Crouse et al., 1986). Crouse et al. (1986) found the correlation between cutability without kidney and pelvic fat and cutability with kidney and pelvic fat was 0.982. Crouse et al. (1986) found that estimation equations with and without kidney and pelvic fat were about equal in accounting for variation in percentage cutability. The two methods of computing cutability (with and without kidney and pelvic fat) had similar accuracy as measures of yield, therefore, changes in procedures for dressing of carcasses and estimating yield of carcasses should be based on economic considerations (Crouse et al., 1986). It appears that on large populations of cattle, equations can be developed with or without kidney and pelvic fat to similarly account for percent retail product.

Hot Carcass Weight

Hot carcass weight was found to be the most important trait (even better than 12-13th rib fat thickness) to predict percent retail product from the four primals by Epley et al. (1970). When hot carcass weight was used alone to predict percent total retail yield it accounted for 49% of the variation (Epley et al., 1970). Crouse and Dikeman (1976) found the correlation between hot carcass weight and cutablity to be -0.46 within breed of sire groups. Greiner (1997) found the correlation between hot carcass weight and retail product to be -0.26 for percent and 0.83 for weight. Abraham et al. (1968) found that partial correlation (r = -0.21) (holding adjusted 12-13th rib fat thickness, 12-13th rib ribeye area, and kidney fat percent constant) indicated that the effect of carcass weight on percent of boneless steak and roast meat was much less than indicated by the simple correlation coefficient (r = -0.50). Abraham et al. (1980) found that adding hot carcass weight as the fourth variable raised the R^2 from 0.82 to 0.83.

Hot carcass weight alone accounted for 85% of variation in weight of retail cuts (Epley et al., 1970). Epley et al. (1970) found that while hot carcass weight was positively correlated with weight of retail cuts, it was negatively associated with percent retail cuts. Herring et al. (1994b) also found that hot carcass weight was negatively associated ($P < 0.05$) with percent retail product from the four primals trimmed to 0.32 cm fat thickness (r = -0.303).

Crouse et al. (1975) found that the net result of a strong negative relationship within breed groups and a strong positive relationship between breed group means is the low negative overall correlation (-0.07) where breed group was ignored for relating hot carcass weight to percent retail product.

Usefulness of hot carcass weight for a combination of all breed groups is questionable (Crouse and Dikeman, 1976). Abraham et al. (1968) found that carcass weight did not account for a significant amount of the variation in most equations predicting percent of boneless steak and roast meat. Reiling et al. (1992) found that hot carcass weight accounted for very little variation in retail yield ($R^2 < 0.01$).

Marbling

Wallace et al. (1977) found marbling score to explain 56% and 59% of the variation in percentage of primal and whole side percent retail yield, respectively. Crouse and Dikeman (1976) found that marbling was important for predicting percent retail product. Abraham et al. (1980) found that for prediction of whole side retail product marbling is a better fourth trait than hot carcass weight. Abraham et al. (1980) found that replacing hot carcass weight with marbling as the fourth variable in the regression equation, did not increase the explained proportion of yield variability ($R^2 = 0.83$ for either combined equation). Greiner (1997) found the correlation between marbling score and retail product to be -0.52 for percent and not significant ($P > 0.10$) for weight, on a group of cattle which were very diverse in breed makeup. Herring et al. (1994b) observed that there seemed to be an increased relationship between marbling score and percentage of cutability, as percentage of cutability included a larger portion of the carcass. However, when marbling score was included in stepwise regression procedures, it was never selected ($P > 0.10$) for the prediction equation (Herring et al., 1994b). When adjusted 12-13th rib fat thickness was omitted from the model, it was replaced by marbling, implying that both traits account for some of the variation in cutability percentage (Herring et al., 1994b).

Other Carcass Traits

Abraham et al. (1980) found the R^2 values showed that use of percentage fat trim (0.91) instead of adjusted fat thickness (0.83) substantially increased the proportion of the yield variability explained by the independent variables. This difference is an indication of the improvement in predicting cutability that might be realized if a more precise measure of fat trim were available (Abraham et al., 1980). For percentage retail product, the R^2 value and residual standard deviation (RSD) were improved when percentages of subcutaneous fat and intermuscular fat were added as variables to equations that included carcass traits (Dikeman et al., 1998). Dikeman et al. (1998) also found that percentage of retail product partial correlations were 0.05 and 0.102 for percent subcutaneous fat and percent intermuscular fat, respectively. These partial correlations show that intermuscular fat was approximately twice as important as subcutaneous fat in predicting percent retail product (Dikeman et al., 1998). These fat percentages made greater contributions to the equations than carcass weight, 12-13th rib ribeye area, kidney and pelvic fat, and marbling score as determined by partial correlation coefficients (Dikeman et al., 1998).

Wallace et al. (1977) proposed that since the shoulder fat (at the ventral tip of the *trapezius* muscle, between the 5th and 6th ribs, off the posterior edge of the scapula) on the carcass has such a high relationship with yield, this fat measurement could more accurately indicate yield in carcass grading programs, than the conventional rib fat measurement.

Miller et al. (1988) found that percentage chemical fat in the 9-10-11th rib section accounted for a significant portion of the variation in percentage carcass fat (R^2 = 0.85), this was the best single trait for predicting percent carcass fat. The most accurate method of determining the composition of fed steers was utilization of the 9-10-11th rib chemical composition, and should be the method of choice in this age class of cattle (Miller et al., 1988). Crouse and Dikeman (1976) also found percentage ether extract of the soft tissues from the 9-10-11th rib section to be the most highly associated with percent retail product (r = -0.90 over all breed groups, r = -0.84 within breed groups).

Shackelford et al. (1995) found that the wholesale rib muscle yield percentage was a very strong predictor of percent retail yield from the carcass (R^2 = 0.83). Addition of the wholesale rib short rib yield percentage and marbling score to this trait increased the R^2 to 0.87, making this the most accurate prediction equation for percent retail product yield (Shackelford et al., 1995). Shackelford et al. (1995) found that for each dependent variable (lean, fat, and bone) the single best predictor was a wholesale rib measurement of that same trait. Shackelford et al. (1995) suggested that the wholesale rib variables were better predictors of their respective dependent variables than 9-10-11th rib section variables because the wholesale rib represented a higher proportion of the carcass.

Among the strongest relationships found by Crouse and Dikeman (1976) were percent retail product to trimmed lean in the round and round fat trim percent with correlations of 0.76 and -0.76 respectively within sire breed groups. Reiling et al. (1992) found the R^2 to be 0.573 for predicting percent retail product using percent boneless closely trimmed round, this is in contrast to the R^2 of 0.469 for the USDA yield grading equation. A correlation of 0.645 was found between percentage closely trimmed boneless round, and percent retail product, and a correlation of 0.904 was found between the actual weight of the closely trimmed boneless round, and weight of retail product from the side (Williams et al., 1997).

Evaluations or measurements of body wall thickness (measured 10.2 cm from the lateral end of the ribeye), conformation grade, maturity, quality grade, and round muscling grade were statistically significant in some of the equations developed, however, there was no improvement over using the four variables of the USDA yield grade (Abraham et al., 1980). On the other hand, Cross et al. (1973) found that body wall thickness was significantly ($P < 0.01$) related to percent retail cuts ($r = -0.61$).

Crouse and Dikeman (1976) found that measurements of length and thickness of the carcass made no practical contribution to the R^2 when marbling score was already included in the equation. On the other hand, Abraham et al. (1968) found that partial regression coefficients indicated that width of round was significantly ($P < 0.05$) related to yield of boneless steak and roast meat when carcass weight was held constant.

Conformation did not contribute significantly to equations for predicting yield of boneless steak and roast meat in the study by Abraham et al. (1968). However, Cross et al. (1973) found that USDA conformation score was significantly ($P < 0.01$) related to percent retail cuts ($r = -0.25$). Furthermore, May et al. (1992) found that when holding frame size, sex class, and fat thickness constant, there was a higher percentage yield of chuck roll, ribeye roll, and strip loin (high value cuts) for carcasses from thick-muscled cattle than for those from average and thin muscled cattle. Regardless of frame size, fat thickness, or sex class, percentage yield of the round and rib decreased as muscle score changed from thick to thin; however, there was an increase in the percentage of loin and plate (May et al., 1992).

Percentage of hindquarter fat trim was highest for carcasses from thin muscled cattle and lowest for carcasses from thick muscled cattle (May et al., 1992).

General Capabilities of Carcass Derived Equations

Cross et al. (1973) found that equations which include hot carcass weight, 12-13th rib ribeye area, 12-13th rib fat thickness, and percent kidney fat or alternatively, 12-13th rib fat thickness, kidney fat weight, and 12-13th rib ribeye area were satisfactory for predicting percent boneless retail cuts from individual and combined breeds. These equations gave R^2 values of 0.76 and 0.75, respectively, for all breeds combined. Dikeman et al. (1998) found that the USDA yield grade parameters work well to predict percent retail product trimmed to 0.00 cm fat on both the development and the validation groups of cattle ($R^2 = 0.66$ and $R^2 = 0.54$, respectively). USDA yield grade had a significant ($P < 0.0001$) effect on retail yield accounting for 75% and 76% of the variation in percent retail product when trimmed to 0 mm and 8 mm, respectively (Hamlin et al., 1995).

Cross et al. (1973) found that the Murphey equation and the U.S.D.A. cutability equations are useful in predicting percent retail yield, with correlations of 0.86 and 0.83 respectively. Herring et al. (1994b) found the simple correlation between USDA yield grade and percent retail product from the four primals trimmed to 0.32 cm fat thickness to be -0.703 ($P < 0.01$). Miller et al. (1988) concurs that if only one method is available to evaluate composition and cost is the most limiting factor, then USDA yield grade factors should be the method of choice across all age classes of cattle. Realini et al. (2001) found that factors from the USDA yield grading equation were able to account for 87% of the variation in weight of retail product, and 40% of the variation in percent retail product. Shackelford et al.

(1995) found the USDA yield grade equation was able to account for 63% of the variation in percent retail product, however, the best equation ($R^2 = 0.72$) used adjusted 12-13th rib fat thickness, marbling score, 12-13th rib ribeye area, and estimated percent kidney, pelvic, and heart fat.

Percentages of retail product decreased by an average of 3.5% for each full USDA yield grade increase (Dikeman et al., 1998). Trimming to 0.76 cm fat cover vs. 0.00 cm fat cover resulted in about 5.3% more retail product (Dikeman et al., 1998).

Reiling et al. (1992) observed the USDA yield grading equation was able to account for 46.9% of actual retail yield. Furthermore, it was found that the percentage of round accounted for 57.3% of the variation in retail yield, while the four factors in the USDA yield grading equation accounted for 47.7% of the variation, inclusion of all 5 traits accounted for 66.5% of the variation (Reiling et al., 1992). Thus indicating that muscle measures in the round should be beneficial to prediction of percent retail product.

Some data indicate that there are definite differences among breeds and that a given prediction equation may not be applicable to all breeds (Abraham et al., 1968). For Angus and Charolais, hot carcass weight was not a significant predictor, for Herefords 12-13th rib ribeye area was not significant, and for Charolais, fat thickness was not significant (Abraham et al., 1968).

Shackelford et al. (1995) found that carcass prediction equations for cattle ($n = 1160$) accounted for 69 to 78% of the phenotypic variation in cutability, but the prediction equations explained 84 to 96% of the genetic variation in cutability. Heritabilty estimates were higher for actual carcass cutout data ($h^2 = 0.65$ to 0.69) than they were for the predicted cutout values that were developed ($h^2 = 0.51$ to 0.64) (Shackelford et al., 1995).

Relevance of Ultrasound for Beef Cattle Body Composition Evaluation

Unless accurate and practical live cattle measures of carcass merit are developed, carcass expected progeny differences (EPDs) will have to be based on progeny tests (Herring et al., 1994b). Several researchers have indicated that ultrasound seems to be the technology with the greatest chance of success in identifying value of individual live animals or carcasses, for implementation into a value-based marketing system(Cross and Whittaker, 1992; Griffin et al., 1999).

Ultrasound has been a technology that has gone through considerable advancements since 1961. Ultrasound has offered several advantages through time for evaluation of body composition in cattle. It is non-invasive, quickly performed, and exhibits potential accuracy. Stouffer et al. (1961) indicated that the 10-second film developing process was of value in this application because immediate development and evaluation of the picture insured a complete display while the animal was still restrained. Ultrasound equipment is relatively delicate, therefore, the equipment was checked for linear and depth calibration each time after moving, or setting up, and at various intervals during the probing (Stouffer et al., 1961). It is obvious that evaluation of this ultrasonic display requires knowledge of the anatomy of the region being probed (Stouffer et al., 1961). The application of the method described (belt drive & polaroid camera) to cattle and hogs was practical with only minimum animal restraint (Stouffer et al., 1961). The validity of comparing carcass ribeye area and fat with ultrasonic ribeye area and fat is not certain, because the effects of slaughtering, hanging, splitting, and shrouding on the shape and size of the ribeye, as well as the fat are not clear (Stouffer et al., 1961). Stouffer et al. (1961) thought the principal and sensitivity of the method warranted further refinement of the technique, even at that early date. The coefficients relating similar ultrasound and carcass traits were significantly different from zero, and indicated that significant repeatability of the methods could be expected (Stouffer et al., 1961).

Amplitude (A) mode pulse echo scanners have been used to measure fat depth on cattle and pigs since the late 1950’s (M^{c}Laren et al., 1991). Brightness (B) mode ultrasound machines, with multi-element linear array transducers that produce two-dimensional cross-sectional images of the body, are more recent introductions to the animal science industry (M^{c}Laren et al., 1991). B-mode scanners produce a continuously changing or “real-time” image that can be frozen and stored for later use, capturing of images requires judgement and is a potential source of error (M^{c}Laren et al., 1991).

Error between ultrasonic and carcass measurements of fat thickness and *longissimus* muscle area may be influenced by placement of the transducer, cleaning of the area of measurement, setting of near and far gains for image registration, and interpretation of the image produced by the technician (Perkins et al., 1992a). Additionally, harvest techniques (hide pullers vs. air knives vs. hand knives), changes of configuration of the various tissues during onset of rigor mortis, and ribbing of the carcass at the 12-13th rib interface also could affect levels of predictability of ultrasound data (Perkins et al., 1992a). Herring et al. (1994a) found that technicians tend to bring the ultrasound measured traits toward the mean by overestimating ribeye area on light muscled cattle, and underestimating ribeye area on heavier muscled cattle, as well as underestimating fat thickness on fat cattle (n = 44).

Houghton and Turlington (1992) pointed out some of the limitations of reporting accuracies of ultrasound data with simple correlation coefficients. Population variation influences correlation coefficients (i.e. a larger than normal variation will produce high correlation coefficients) (Houghton and Turlington, 1992). Correlation coefficients do not reflect bias (Houghton and Turlington, 1992). Correlation coefficients are not easily understood by most producer groups (Houghton and Turlington, 1992). Another reporting method proposed by Houghton and Turlington (1992) was frequency distribution (where the cumulative percent of ultrasound minus carcass measurements are within some value). Standard errors of differences should be chosen because of their genereal acceptance as a measure of variability and because by squaring differences, a few large errors are properly considered more serious than a greater number of small discrepancies (Robinson et al., 1992). The first certification test of ultrasound technicians was held in January 1989 at Texas A&M University, using standards which had been developed by the Beef Improvement Federation (Cross and Whittaker, 1992). Of particular importance is evaluation of level of variability within technicians, because between technician variance is more easily addressed in analysis of field data through contemporary grouping (Perkins et al., 1992b). Skills in the capture of ultrasonic images and interpretation of the captured image are of paramount importance (Perkins et al., 1992b). Herring et al. (1992) found that technican x machine interaction approached significance ($P < 0.10$) in a model to predict absolute difference between carcass and ultrasound measures of fat thickness and loin muscle area. Significant differences for technicians and breed type x technician interactions were not detected, indicating that technicians were equally accurate, or in error, depending on the perspective, independent of breed type (Perkins et al., 1992b).

Limited data suggest that the positional variation of ribeye area and fat thickness at the 12th and 13th ribs, changes of shape and size of the ribeye due to slaughtering, hanging, and variability in pressure of the transducer against the hide during probing are probable factors accounting for low relationships between ultrasonic and carcass measurements (Stouffer et al., 1961). M^{c}Laren et al. (1991) found that obtaining an ultrasonic cross-sectional image of subcutaneous fat and the *longissimus* muscle required only seconds. Several advances have been made over time in the ultrasound hardware available for beef cattle carcass evaluation. This equipment enhancement was thought to provide opportunity to reduce error variation in *longissimus* muscle area prediction (Perkins et al., 1992a). Duello (1993) used a 17.5 cm transducer on the Aloka 500V (Aloka, USA, Wallingford, CT) as early as 1990. Perkins et al. (1992a) used an Aloka 210 equipped with a 12.5 cm transducer, however, they reported on the availability of an Aloka 500, which could be equipped with a 17.2 cm transducer. Herring et al. (1994b) were able to use a 17.2 cm linear transducer, which enables imaging of the entire 12-13th rib ribeye area on most cattle.

Herring et al. (1994a) found that there was no trend for magnitude of ultrasound repeatability error as ribeye area or fat thickness at the 12-13th rib increase. Furthermore, based on repeatability correlations, Herring et al. (1994a) found that ultrasound loin muscle area (as high as r = 0.90) can be at least as repeatable as hip height (r = 0.88). Herring et al. (1994a) also determined that ultrasound measurements can be reliable sources of information for obtaining carcass trait information on live cattle, although not all technicians are qualified to do so. More information regarding the effect of the technician on the accuracy of ultrasonic estimates of final carcass composition in the live animal could be important in developing breeding values (EPDs) for carcass traits for use by seedstock producers (Perkins et al., 1992b).

The independent variables (predictors based on instrument grading technologies) in new equations to predict yield of lean may or may not likely change, but the intercept and the coefficients in the best equations almost certainly would change from the current USDA yield grade standards (Cross and Whittaker, 1992). Wilson (1992) indicates that ultrasound measurements may or may not be useful depending on two things: 1) whether measurements can be made on the carcass that are useful in predicting percentage fat and percentage lean; 2) whether ultrasound can be used to measure the same traits on the live animal. Ultrasonics, or other technologies used for live animal measurement, must provide significant improvement in the accuracy of predicting lean and fat weight and(or) body composition (i.e. percentage of lean and percentage of fat) over that which live weight and other easily measured traits or scoring systems provide (Wilson, 1992). Wilson (1992) observed that much of the scanning research taking place was emulating carcass measures historically collected in the cooler. It was suggested that ultrasound research in beef cattle needed to investigate alternative scanning sites (Wilson, 1992) and the round of the beef animal was identified as a potential candidate for new scanning sites.

The appropriate endpoint to evaluate cattle for retail product determination was investigated by Hassen et al. (1999) and it was found that variables to predict composition traits performed better with 365-day adjusted data than the data at an average harvest age of 448 days. Hassen et al. (1999) suggested that if equations are to be developed for prediction of percent retail product, retail product weight or hot carcass weight from these earlier measurements, selection of independent variables and development of regression equations need to be done based on measurements made or adjusted to the corresponding age ranges. Therefore, Hassen et al. (1999) suggested that observations adjusted to earlier dates made by certified technicians, together with other live measures, could be used to predict end products as well as similar measures made just before harvest.

Ultrasound 12-13th Rib Fat Thickness

The underestimation of fat depth by ultrasound may be partially due to the amount of pressure against the hide with the transducer (Stouffer et al., 1961). Wallace et al. (1977) found that ultrasonic fat thickness at the shoulder, rib, lumbar, and rump positions were highly correlated with their corresponding carcass measurements (r = 0.70, 0.77, 0.74, and 0.89, respectively). Griffin et al. (1999) also found a simple correlation coefficient of 0.81 between ultrasound measured 12-13th rib fat thickness (before hide removal on the kill floor) and ribbed carcass measures of 12-13th rib fat thickness. Perkins et al. (1992a) observed a correlation of 0.75 between carcass fat thickness and ultrasound fat thickness (collected approximately 24 hours before harvest). Realini et al. (2001) found a correlation between adjusted carcass fat thickness and ultrasound fat thickness of 0.79. Greiner (1997) found a correlation of 0.89 between carcass fat thickness and ultrasound fat thickness. Robinson et al. (1992) found the correlation between carcass rib fat and ultrasound rib fat to be 0.90. May et al. (2000), in a study comparing scanning techniques on live animals and hanging carcasses, found the correlation between carcass fat thickness measures and ultrasound measures to be higher on the live animal than on the hanging carcass (r = 0.81 and 0.73, respectively for unadjusted carcass fat measures, and r = 0.85 and 0.74, respectively for the adjusted carcass fat measures). On 832 head of cattle, Duello (1993) found a correlation between carcass fat thickness and ultrasound fat thickness of 0.84, and ultrasound underpredicted fat thickness by 0.051 cm. Greiner (1997) found that ultrasound underpredicted the carcass fat thickness by 0.06 cm. It is important to note that ultrasound machines are calibrated to calculate distances within a standard media, and beef cattle hide, fat, and muscle tissues, each have a unique variation from that standard media.

Miller et al. (1988) found that 12-13th rib fat thickness measures and ultrasound measures were not always close within each age class and showed the difficulty in making accurate live measurements. Analysis revealed important machine (both A-mode and B-mode) x operator interactions ($P < 0.001$) for scanned fat depth measurements of cattle (M^{c}Laren et al., 1991). M^{c}Laren et al. (1991) found that total variance of fat depth in cattle was greater for B-mode than for A-mode ultrasonic measures. B-mode means were also 2 times as great as A-mode means for cattle (making B-mode measures much closer to carcass measures) (M^{c}Laren et al., 1991).

Perkins et al. (1992a) found that ultrasound was more precise in estimating carcass fat thickness in cattle with a lesser degree of 12th rib fat thickness. Perkins et al. (1992b) found differences between ultrasonic and carcass measures for 12th rib fat thickness were not statistically different. Pooled simple correlations between carcass fat thickness and ultrasonic fat thickness was 0.86, while the pooled rank correlation was 0.73 (Perkins et al., 1992b). Repeatabilities for ultrasonic fat thickness over 2 days were 0.88 and 0.93 for technicians 1 and 2, respectively (Perkins et al., 1992b). Hamlin et al. (1995) found that when percentage trimmable fat and ultrasound measures of 12-13th rib fat thickness were compared through time of feeding, all correlations were significant ($P < 0.001$) and positive. Not surprisingly there was an increase of coefficients across time from the first measure to the last measure (Hamlin et al., 1995).

Little to no improvement in accuracy of measuring fat thickness was observed with the longer transducer (Error percentage rates of 20.7% and 20.6% were observed with the long transducer (17.2 cm) and short transducer (12.5 cm), respectively) (Perkins et al., 1992b). Herring et al. (1994a) found that there was no advantage for the Aloka 500 (17.2 cm transducer) over the Aloka 210 (10.7 cm transducer) when measuring 12-13th rib fat thickness.

Faulkner et al. (1990) found the intercept of carcass fat thickness measurement vs. ultrasound fat thickness measurement to not be different from 0, and the regression coefficient of ultrasound fat was not different from 1. Hence, breed, weight, and sex did not significantly ($P > 0.15$) influence accuracy of ultrasound estimation of fat thickness (Faulkner et al., 1990). In cattle, operator variance was significant only when operators measured fat depth from their own recordings, indicating that the recording process involved less operator error than the interpretation of an image from video tape (M^{c}Laren et al., 1991). Faulkner et al. (1990) found that seventy-two percent of the cattle had ultrasound to carcass fat differences of ± 0.2 cm or less. It was proposed (Faulkner et al., 1990) that calculations to within 0.2 cm may be as accurate as is possible due to measurement errors associated with both ultrasound and carcass measures. Faulkner et al. (1990) indicated that carcass and ultrasound fat correlations may be related to skinning procedures, as the group skinned with knives had the highest R^2 (0.65), the group skinned with hide puller and air knives had the lowest R^2 (0.19), and the group skinned with a hide puller only had an intermediate R^2 (0.54). Herring et al. (1994a) suggested that the use of hide pullers in most harvest facilities may warrant greater reliance on ultrasound 12-13th rib fat thickness as a truer measure of the steer's 12-13th rib fat thickness. Herring et al. (1994b) found the correlation between ultrasound 12-13th rib fat thickness to be 0.722 for adjusted 12-13th carcass fat thickness, and only 0.676 for actual 12-13th rib fat thickness, indicating that the majority of the difference between adjusted 12-13th rib fat and actual 12-13th rib fat was a result of hide removal. Faulkner et al. (1990) concluded that real-time linear array ultrasound is an accurate and precise method of measuring 12-13th rib fat thickness in live cattle. Robinson et al. (1992) found there was a tendency for ultrasound measures to overestimate carcass values in lean animals, and underestimate values in fatter animals.

M^{c}Laren et al. (1991) found repeatability to be 0.13 for field operator interpreted fat depth. This low value reflects the importance of operator effects. Repeatability of experienced off-site technician interpreted fat depth was .90 (M^{c}Laren et al., 1991).

Regression analysis relating percent carcass fat to live 12-13th rib fat thickness gave a R^2 value of 0.72 (Miller et al., 1988). When weight was added as a covariate for percent carcass fat that R^2 value dropped to 0.56 (Miller et al., 1988). Wallace et al. (1977) found ultrasound rib fat thickness to have R^2 values of 0.60 and 0.51 for predicting percent primal retail cuts, and percent whole side retail cuts, respectively. Ultrasonic measurements of rib and lumbar fat were the most highly correlated fat measurements with percentages of primal retail percent yield and whole side percent retail yield (Wallace et al., 1977). Johns et al. (1993) found that fat thickness at the 12-13th rib was significantly ($P < 0.05$) correlated to weights of carcass lean and fat ($r = -0.17$ and 0.72, respectively), but the correlation was higher when lean and fat were expressed as percentages ($r = -0.57$ and 0.72, respectively). Herring et al. (1994b) found the simple correlation to be -0.52 ($P < 0.01$) between ultrasound 12-13th rib fat thickness and retail product from the four primals trimmed to 0.32 cm of fat thickness. Griffin et al. (1999) found that hide-on ultrasound measured 12-13th rib fat thickness on the kill floor was the only other variable besides percent kidney, pelvic, and heart fat which entered the model ($P < 0.50$) for predicting percentage retail product. Greiner (1997) found the correlation between ultrasound 12-13th rib fat thickness and retail product to be -0.74 ($P < 0.001$) for percent and -0.10 ($P < 0.05$) for weight.

The best variable for use in prediction of retail yield was fat thickness ($R^2 = 0.58$ to 0.64) when regressed on percentage of retail product (Hamlin et al., 1995). Final ultrasound 12-13th rib fat thickness is the major trait influencing retail yield components and can be used for the prediction of retail product percentage, as indicated by changes in R^2 values when other ultrasound traits were added to the model (Hamlin et al., 1995). Realini et al. (2001) found that ultrasound rib fat thickness was more closely correlated to percent retail product than adjusted carcass fat thickness ($r = -0.33$ vs. -0.24, respectively). Greiner (1997) found ultrasound rib fat thickness to be the live measurement most highly correlated to percent retail product ($r = -0.74$). Ultrasound fat thickness was also more strongly associated with percent retail product than adjusted carcass fat thickness ($r = -0.74$ and -0.73, respectively) (Greiner 1997).

Ultrasound 12-13th Rib Ribeye Area

Perkins et al. (1992a) found a correlation coefficient of 0.60 between carcass 12-13th rib *longissimus* muscle area and ultrasound 12-13th rib *longissimus* muscle area (collected approximately 24 hours before harvest). Ultrasound estimates were slightly more precise for animals with *longissimus* muscles smaller than 83.9 cm^2 than for those with *longissimus* muscles larger than 83.9 cm^2 (Perkins et al., 1992a). Perkins et al. (1992b) found differences between ultrasonic and carcass measures for 12-13th rib ribeye area were not statistically different. Pooled simple correlation between carcass loin muscle area, and ultrasonic loin muscle area was 0.79, while the pooled rank correlation was 0.78 (Perkins et al., 1992b). Realini et al. (2001) found a correlation between carcass ribeye area and ultrasound ribeye area of 0.69. The average ribeye area measured ultrasonically was smaller than the carcass ribeye area (Stouffer et al., 1961). Regardless of evaluation method (live estimation, live animal ultrasound evaluation, or hanging carcass ultrasound evaluation) accuracy of *longissimus* muscle area was not as high as accuracy of evaluation for fat thickness (May et al., 2000) (using 12.5 cm transducer and split screen imaging technology). Greiner (1997) found a correlation of 0.86 between carcass ribeye area and ultrasound ribeye area. Greiner (1997) also found that ultrasound had a bias relative to carcass ribeye area of + 0.71 cm^2. On 832 head of cattle, Duello (1993) found a correlation between carcass ribeye area and ultrasound ribeye area of 0.77, and ultrasound over predicted ribeye area by 1.81 cm^2. Robinson et al. (1992) found the correlation between carcass ribeye area and ultrasound ribeye area to be 0.87. An experienced sonographer can measure ribeye area only marginally less accurately than it can be measured in the carcass (Robinson et al., 1992).

Effect of equipment operator on the ribeye area was not significant; however, differences were noted among interpreters (Wallace et al., 1977). More experienced interpreters had consistently higher correlations with carcass ribeye area than less experienced interpreters (Wallace et al., 1977). M^cLaren et al. (1991) found that in cattle if a technician interpreted 12-13th rib ribeye area, there was no effect of scanning operator. Correlation coefficients between carcass *longissimus* muscle area and mean of operator interpreted scanned *longissimus* muscle area was 0.31 (M^cLaren et al., 1991). Operators using a B-mode machine obtained correlations for *longissimus* muscle area of cattle as high as 0.35 (M^cLaren et al., 1991). M^cLaren et al. (1991) found that image interpretation causes a larger source of variation than image acquisition does. Frequency distributions indicated no differences between technicians in estimating fat thickness, but revealed technician differences in predicting loin muscle area, this difference in precision was likely due to interpretational errors and not to animal variation or machine settings, because the latter were held constant for both technicians (Perkins et al., 1992b).

Elimination of split screen imaging techniques may have led to improved accuracies of ultrasonic estimates of loin muscle area with the long transducer (Perkins et al., 1992b). Griffin et al. (1999) found that ultrasound measured 12-13th rib ribeye area on the kill floor with the hide on was not well correlated (r = 0.52) with 12-13th rib split surface measures of ribeye area, this could be due to the equipment used (Aloka model 210 only has a 10.7 cm probe), and limited numbers of animals (n = 20). Perkins et al. (1992a) suggested that improvement in imaging of the *longissimus* muscle was necessary before ultrasonic measurements should be used as selection criteria (these data were collected with 12.5 cm transducer). May et al. (2000) indicated that split screen imaging may not be feasible at chain speeds for measuring *longissimus* muscle area on hanging carcasses. Use of a 17 cm transducer resulted in variation between scan and carcass ribeye area measures to be reduced approximately 25%, although fat scans were approximately 25% less accurate (Robinson et al., 1992).

Repeatability was 0.28 for operator interpreted *longissimus* muscle area for cattle; this low value reflects the importance of operator effects (M^cLaren et al., 1991). However, repeatabily of technician interpreted 12-13th rib ribeye area was even lower at 0.19 (M^cLaren et al., 1991). Wallace et al. (1977) found that on repeat measurements, correlations ranged from 0.80 to 0.89. Herring et al. (1994a) found that the Aloka 500 (17.2 cm transducer) was a more repeatable ultrasound unit than the Aloka 210 (10.7 cm transducer) for measuring 12-13th rib ribeye area, especially for technicians with limited ability or experience. Repeatabilities for ultrasonic loin muscle area over 2 days were 0.81 for two different technicians (Perkins et al., 1992b). Repeatability estimates of loin muscle area interpretation from videotape were 0.87 and 0.84 within technicians, and 0.81 and 0.71 between technicians, thus interpretation from videotaped images is also repeatable (Perkins et al., 1992b).

Herring et al. (1994b) proposed that ultrasound 12-13th rib ribeye area may be a more accurate estimate of actual *longissimus* muscle area than carcass 12-13th rib ribeye area, which may be distorted by angle of ribbing and different body pressures.

Herring et al. (1994b) found that ultrasound 12-13th rib ribeye area entered prediction equations second, and accounted for an additional 10 to 11 percent of the variation in percent retail cuts from the four primals. Correlations ranging from 0.53 to 0.58 and 0.33 to 0.45 existed between ultrasound 12-13th rib ribeye area and carcass 12-13th rib ribeye area, respectively, with total retail yield (Herring et al., 1994b).

Ultrasonic ribeye area did not improve the precision of any of the equations for retail yield (Wallace et al., 1977). Hamlin et al. (1995) also found that models using ultrasound 12-13th rib ribeye area as the independent variable were not accurate ($R^2 < 0.15$) in predicting percentage of retail yield, and suggested that there may be another muscle characteristic measure which should be used to predict retail product percentage.

Hamlin et al. (1995) suggested that the relationship between ultrasound 12-13th rib ribeye area and retail product percentage might be expected to be higher in cattle with less external fatness. In a small sample (n = 32) of cattle which were fatter than industry average, Realini et al. (2001) found that ultrasound ribeye area was the live animal measure with the strongest influence on percent retail product. Williams et al. (1997) found that ultrasound ribeye area, was consistently a significant variable for predicting percent retail product, as well as weight of retail product. Greiner (1997) found the correlation between ultrasound ribeye area and retail product to be 0.17 ($P < 0.001$) for percent and 0.61 ($P < 0.001$) for weight.

Ultrasound Rump Fat Thickness

In Australia, carcass measures of rump fat are available, and Robinson et al. (1992) found the correlation between carcass and ultrasound (at the P8 site) measures of rump fat to be 0.92. Ultrasound rump fat thickness had the highest correlation to the corresponding carcass measurement ($r = 0.89$) (Wallace et al., 1977).

Johns et al. (1993) found that rump fat thickness was significantly ($P < 0.05$) correlated to weights of carcass lean and fat ($r = -0.26$ and 0.34, respectively), but the correlation was higher when lean and fat were expressed as percentages ($r = -0.58$ and 0.42, respectively). Regression analysis relating percent carcass fat to rump fat thickness gave an R^2 value of 0.72, when weight was added as a covariate for percent carcass fat that R^2 value dropped to 0.43 (Miller et al., 1988).

Williams et al. (1997) found that ultrasound rump fat was the live measure which accounted for the most variation in percent retail product, when each of the single variables were fit alone. Wallace et al. (1977) found ultrasound rump fat thickness to have R^2 values of 0.27 and 0.28 for predicting percent primal retail cuts, and percent whole side retail cuts, respectively. Realini et al. (2001) found that ultrasound rump fat thickness was more closely correlated to percent retail product than adjusted carcass fat thickness ($r = -0.39$ vs. -0.24, respectively). However, the inclusion of rump fat thickness (beyond live weight, ultrasound rib fat thickness, and ultrasound ribeye area) explained little additional variation in percent retail product (R^2 increased from 0.37 to 0.39) (Realini et al., 2001). When Williams et al. (1997) included ultrasound rump fat in prediction equations for weight of retail product, ultrasound rib fat became nonsignificant. An additional 14% of the variation in percent retail product was accounted for adding ultrasound rump fat to live weight, ultrasound rib fat thickness, and ultrasound ribeye area ($R^2 = 0.318$ vs $R^2 = 0.175$, respectively) (Williams et al., 1997). As single predictors of percent retail product, ultrasound rump fat thickness, and ultrasound rib fat thickness were the two most significant variables of all live animal measurements with R^2 values of 0.24 and 0.13, respectively (Williams et al., 1997). Greiner (1997) found the correlation between ultrasound rump fat thickness and retail product to be -0.66 ($P < 0.001$) for percent and not significant ($P > 0.10$) for weight.

Reverter et al. (2000) observed that in lean cattle (8 distinct breed-sex groups, all with average 12-13th rib fat thickness less than 11 mm) the rump fat thickness was greater, and showed more variation than 12-13th rib fat thickness. This observation is also consistent with the work of Wallace et al. (1977), and Williams et al. (1997). Greiner (1997) observed a higher mean level of fat in the rump than at the 12-13th rib (10.9 mm vs. 10.2 mm, respectively), however, there was less variation in the rump fat measure than 12-13th rib fat measure (standard deviation of 3.2 mm vs. 3.5 mm, respectively).

Live Weight

Wallace et al. (1977) found that live weight did not contribute significantly to predicting percent primal or total retail cuts. Greiner (1997) found the correlation between live weight and retail product to be -0.26 ($P < 0.001$) for percent and 0.81 ($P < 0.001$) for weight. Williams et al. (1997) found the correlation of final weight to be 0.913 ($P < 0.01$) for weight of retail product, but not significantly correlated ($P > 0.05$) to percent retail product.

Ultrasound Rump Lean Measurements

Johns et al. (1993) found that depth of the *biceps femoris* in the rump was significantly ($P < 0.05$) correlated to both weight and percentage of carcass lean ($r = 0.10$ and 0.59, respectively). Depth of the *biceps femoris* had a stronger relationship with weight of retail product than any other live animal or carcass variable, with the exception of weight (Williams et al., 1997). Additionally, Williams et al. (1997) found that depth of the *biceps femoris* generally had the strongest correlation with percent retail product, weight of trimmable fat, and percent trimmable fat, of the other measures of muscle observed (ultrasound ribeye area or carcass ribeye area). When included with other variables, ultrasound ribeye area consistently entered models before ultrasound *biceps femoris* depth for both weight of retail product, and percent retail product (Williams et al., 1997). Williams et al. (1997) observed that ultrasound measurement of the *biceps femoris* is rather difficult to obtain on the live animal, and suggested further study into the repeatability and measurement technique.

It was also found by Johns et al. (1993) that the depth of the *gluteus medius* in the rump was significantly ($P < 0.05$) correlated to both weight ($r = 0.17$) and percentage of carcass lean (r = 0.42). Realini et al. (2001) found the depth of *gluteus medius* to be correlated to weight of retail product (r = 0.53, $P < 0.01$). However, Realini et al. (2001) found that depth of *gluteus medius* was not correlated to percent retail product ($P > 0.10$). The inclusion of *gluteus medius* depth (beyond live weight, ultrasound rib fat thickness, and ultrasound ribeye area) explained little additional variation in percent retail product (R^2 increased from 0.37 to 0.38) (Realini et al., 2001).

Other Ultrasound Measured Traits

Wallace et al. (1977) indicated that shoulder fat thickness was the most important fat measurement from the carcass, whereas rib fat had been when measured ultrasonically. This difference was partly due to the low precision in making shoulder fat measurements on the live animal, as observed by the correlation between live and carcass shoulder fat thickness (r = 0.70) and high residual standard deviation (RSD = 0.48 cm) (Wallace et al., 1977). However, Miller et al. (1988) found that ultrasound shoulder fat measurements could increase the R^2 value from 0.72 to 0.78 for predicting percent carcass fat, when added to ultrasound rump fat thickness. Alternatively, ultrasound shoulder fat thickness could increase the R^2 value from 0.72 to 0.76 for predicting percent carcass fat, when added to ultrasound 12-13th rib fat thickness (Miller et al., 1988).

Greiner (1997) found the correlation between ultrasound body wall thickness and retail product to be -0.48 ($P < 0.001$) for percent and -0.10 ($P < 0.05$) for weight.

May et al. (1992) indicated that with muscle score and fat thickness constant, frame size had little influence on the percentage yields of untrimmed subprimals, except for the percentage yield of rib, which increased as frame size decreased from large to small. The most notable difference between frame sizes of cattle was the slight increase in percentage of fat trim that occurred as frame size decreased (May et al., 1992).

General Capabilities of Live Animal Derived Retail Product equations

Measurements of fat, compared to measures of muscle, had higher correlations to percent retail product, and percent trimmable fat (Williams et al., 1997). Hamlin et al. (1995) found that a model which used final 12-13th rib fat thickness, final 12-13th rib ribeye area, and final live weight only increased R^2 values from 0 to 3% over models containing only final 12-13th rib fat thickness (depending on level of fat trim in retail product).

Johns et al. (1993) found that an equation using hip height and depth of the *biceps femoris* in the rump ($P < 0.10$) could account for 51% of the variation in percent lean in the carcass, when using cattle that varied greatly in frame size.

Johns et al. (1993) determined that a combination of live fat measurements (12-13th rib fat, and two different measures in the rump) could be combined with percent kidney, pelvic, and heart fat in the carcass ($P < 0.10$), to account for 77% of the variation in carcass percent fat. Miller et al. (1988) found that ultrasound shoulder fat thickness, ultrasound 12-13th rib fat thickness, ultrasound rump fat thickness, and ultrasound 12-13th rib ribeye area were all significant ($P < 0.05$) to predicting percent carcass fat with reasonable accuracy ($R^2 = 0.83$ and RSD = 2.61).

Hamlin et al. (1995) found ultrasound measures to account for about 10% less of the variation in retail product percentage than carcass measures were able to do. Miller et al. (1988) found that ultrasound measures were neither accurate nor precise when evaluating percentage fat in feeder cattle ($n = 10$) ($R^2 = 0.18$). However, in fed cattle ($n = 10$) Miller et al. (1988) found that ultrasound traits were moderately accurate (R^2 = 0.71) in predicting percent carcass fat.

Models using the same variables, except exchanging ultrasound derived and carcass derived measures of fat were similar in their ability to account for differences in percent retail product (Griffin et al., 1999). Williams et al. (1997) found that the best models using live animal measures had R^2 values slightly greater than models using the carcass measures found in USDA equations for predicting weight of retail product (R^2 = 0.865 vs. 0.840, respectively) and percent retail product (R^2 = 0.322 vs. 0.312, respectively). Realini et al. (2001) found that models based on live animal measures had similar R^2 values to models using carcass measures (0.81 vs. 0.87, for weight of retail product, and 0.41 vs. 0.40, for percent retail product, respectively). Greiner (1997) found on a large set (n = 534) of biologically diverse cattle that live measures of weight, ultrasound 12-13th rib fat, ultrasound rump fat, and ultrasound ribeye area accounted for 60% of the variation in percent retail product, while USDA yield grade factors collected on the carcass accounted for 65% of the variation in percent retail product. When evaluating prediction equations for weight of retail product, USDA yield grade factors accounted for 86% of the variation, and live measures of weight, ultrasound 12-13th rib fat, and ultrasound ribeye area accounted for 83% of the variation (Greiner, 1997). Herring et al. (1994b) found that live animal equations ranked steers equally as well as carcass and the USDA cutability equations for percentage of lean product.

There may be some interesting interactions among class of cattle being classified and usefulness of ultrasound in predicting carcass composition. For example, Miller et al. (1988)

found differences when comparing the merits of ultrasound in calves, feeder cattle, yearlings, fed cattle, and cows for predicting percentage carcass fat.

May et al. (2000) found that an equation using live ultrasound fat thickness, *longissimus* muscle area, and carcass weight explained the highest amount of variation (R^2 = 0.57) for predicting percentage yield of boneless subprimals trimmed to 0.64 cm. This equation was followed by an equation using live weight and subjective estimates of fat thickness, and ribeye area (R^2 = 0.49), then hanging carcass ultrasound measures (R^2 = 0.31) (May et al., 2000). When live ultrasound fat thickness replaced carcass fat thickness in the four variable equation developed from the yield grade factors , there was a small decrease in the R^2 (0.72 vs. 0.57) (May et al., 2000).

Greiner (1997) found that the best live animal model was as accurate as carcass variable models for predicting percent retail product (based on means for bias and absolute residual of predicted and actual percent retail product). Williams et al. (1997) found that ultrasound measures were as predictive of retail yield and trimmable fat as carcass measures currently found in the USDA retail yield equation.

Sex Comparisons

Reiling et al. (1992) found the percentage of internal fat was nearly identical for bulls and steers but was less ($P < 0.01$) than that of heifers. Bulls yielded 4.3% more total boxed beef than steers (Reiling et al., 1992), this may have been related to the heavier finish on the steers (1.01 cm adj. fat thickness on steers, vs. 0.64 cm adj. fat thickness on bulls). Abraham et al. (1980) found that the in cooler adjustments to fat thickness may have needed to be of larger magnitude for heifers than the ones that were used in that study.

Use of Information

MacNeil (1983) provided two criteria for identification of a “best” prediction equation: 1) the equation must be unbiased or without descernible trends in the errors of prediction; and 2) the accumulated squared errors of prediction should be minimized. MacNeil (1983) suggested that the C_p statistic and residual variance ($\sigma^2_{y\bullet x}$) statistics are more informative than R^2 for selection between equations derived in the same study. Minimal residual variance is a more appropriate general criterion for selection of the prediction equation than is maximum R^2 (MacNeil, 1983). The selected prediction equation would have $C_p \cong p$ with p a minimum (where p is the number of parameters, including intercept, in the prediction equation) (MacNeil, 1983). A fundamental requirement to the intended application of the chosen prediction equation is that the equation was derived from and will be applied to samples of the same populations (MacNeil, 1983). Standard error of prediction is thought to be the primary measure of the ability to correctly rank or predict differences between animals (Robinson et al., 1992).

Implications

Shackelford et al. (1995) indicated that the high genetic correlations between heritability estimates derived from actual carcass cutout data and predicted estimates indicate that selection would be very effective in changing actual yields of retail product, fat trim, and bone. Acceptance by cattle producers of ultrasound as a tool for genetic improvement and carcass merit prediction is dependent on the use of only qualified technicians and proper equipment (Herring et al., 1994a). Hassen et al. (1999) claimed that from a genetic evaluation standpoint, carcass merit of potential sires could be predicted as early as a year of age using live animal real-time ultrasound measures. Ultrasound is a promising avenue for describing differences between animals and could be used on an industry-wide basis if developed correctly (Hamlin et al., 1995). The possibility is also present for ultrasound to be used for prediction of retail yield on the live animal (Hamlin et al., 1995). Ultrasonic measures of fat thickness and loin muscle area are repeatable between days of measure and technicians (Perkins et al., 1992b). Houghton and Turlington (1992) determined that ultrasound rib fat measurements were accurate, and could be used to enable harvest of cattle at a predetermined body compositional end point.

Ultrasound technicians should: 1) understand the principals of ultrasound scanning technology and be familiar with the basic principals of performance recording and genetic evaluation; and 2) be able to produce repeatable scans bearing a clear and consistent relationship to carcass data (Robinson et al., 1992). High repeatability requirement should be set for ultrasound accreditation (Robinson et al., 1992). Evaluation of level of variability within a technician is of particular importance, because between technician variance is more easily addressed in analysis of field data for genetic evaluations through contemporary grouping (Perkins et al., 1992b). Experience improved repeatability and accuracy for fat scanning but had little effect on standard errors of prediction for ribeye area, far and away the most difficult trait to assess (Robinson et al., 1992). Considerable skill and expertise are required to produce accurate results and an effective training and accreditation system is necessary (Robinson et al., 1992). Development and maintenance of ultrasound scanning technique is critical (Robinson et al., 1992). These are all important considerations as ultrasound is implemented for genetic evaluation programs to evaluate body composition in beef cattle.

One of the questions still remaining, however, is whether these ultrasound measurements can be effectively used with breeding cattle to predict harvest progeny body composition (Hamlin et al., 1995; Duello, 1993). Reverter et al. (2000) found that ultrasound fat measurements on replacement heifers were moderately to highly correlated with abbatoir data from steer carcasses. These relationships were not as pronounced in the bull data (Reverter et al., 2000), probably due to generally lower mean levels of fat, and less variation exhibited by bulls. The work of Wilson et al. (1999) would indicate that there is a strong relationship between ultrasound measures collected on yearling bulls, and steers fed for harvest, with genetic correlations of 0.77, 0.71, and 0.75 for intramuscular fat, 12-13th rib ribeye area, and 12-13th rib fat thickness, respectively.

Carcass evaluation programs must be on a national scale to be effective, with measurements coming from a large proportion of the species population (Wilson, 1992). Thus, the use of ultrasonics requires a capability that can be practically implemented in the field at an affordable cost (Wilson, 1992). Measurements of depth and areas at anatomical reference points must exist that can be practically and accurately measured in the live animal and, in turn, be used to significantly improve prediction of body composition over other easily measured traits (Wilson, 1992). Wilson (1992) suggested four areas for ultrasound research in beef cattle: 1) identification of measurements that can be made on the carcass and consequently with ultrasound on live animals that are predictive of carcass composition; 2) development of appropriate procedures for dealing with differences in mean levels of fatness and differences in variation in cattle in diverse contemporary groups; 3) development of growth models, within breed and sex, from serial scanning that will allow proper adjustment of scan records to a common end point; and 4) estimation of heritabilities and genetic correlations for ultrasound measurements at specific reference points for use in genetic evaluation programs for carcass merit.

It is important to realize that percent retail product is a composite trait composed of several contributing factors. It combines the traits which have been shown to have a significant relationship to percent retail product. With the tremendous discounts often associated with USDA yield grade 4 and 5 cattle in today's market place, it may seem that producer's should attempt to select for cattle which have increased percent retail product. However, percent retail product is not a selection index, and there have been no economic weights put with the traits of importance in predicting percent retail product. This equation is simply a prediction of observed changes in percent retail product from changes in related traits. In fact, there is some evidence (MacNeil et al., 1984) that females from sires selected for reduced fat trim of steer progeny are expected to reach puberty later and at a heavier weight, have reduced fertility, and be larger at 7 yr of age. Therefore, producers should know what traits are contributing to the changes in percent retail product (fat thickness, ribeye area, or weight), and what, if any, antagonistic changes may come with this selection decision, which focuses on increasing the percent retail product trait only. Afterall, beef production needs to be approached in a total system manner.

PREDICTION OF RETAIL PRODUCT AND TRIMMABLE FAT IN BEEF CATTLE USING ULTRASOUND OR CARCASS DATA

A paper to be submitted to the Journal of Animal Science

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Abstract

The most widely used system to predict percent retail product from the four primals in beef cattle is USDA yield grade. The purpose of this study was to determine if routine ultrasound measurements and additional rump measurements could be used to more accurately predict the percent lean from the four primals than the carcass measurements going into the USDA yield grade equation. This study utilized market cattle (n = 471) consisting of Angus bulls, Angus steers, and crossbred steers. The right side of each carcass was fabricated into retail cuts, lean trim, fat, and bone; weights of each component were recorded. Percent retail product from the four primals was then expressed as a percentage of side weight. Traditional carcass measures collected were: 1) hot carcass weight (HCW), 2) 12-13th rib fat thickness (CFAT), 3) 12-13th rib ribeye area (CREA), and 4) percent kidney, pelvic, and heart fat (CKPH). Live animal ultrasound measures collected within seven days prior to harvest were: 1) scan weight (SCANWT), 2) 12-13th rib fat thickness (UFAT), 3) 12-13th rib ribeye area (UREA), 4) subcutaneous fat thickness over the termination of the *biceps femoris* in the rump(reference point) (URFAT), 5) depth of *gluteus medius* under the reference point (URDEPTH), and 6) area of *gluteus medius* anterior to the reference point

(URAREA). A stepwise regression was performed to develop models to predict percent retail product from the four primals based on carcass measures or ultrasound measures, and comparisons were made between the models. Significant measures ($P < 0.001$) for the carcass data were CFAT, CKPH, and CREA with a model $R^2 = 0.297$. Significant measures ($P < 0.001$) for the ultrasound data were UFAT, UREA, SCANWT, URDEPTH with a model $R^2 = 0.448$. This study also validated 10 equations which had been either previously reported ($n = 8$), or modified ($n = 2$) from a previously reported equation to predict percent retail product in beef cattle. Validation of these equations included reporting R^2, root mean squared error, and P-value for each equation.

Introduction

Retail product yield from the four primals is a very economically important trait for the beef industry. Abraham et al. (1980) found that retail sales value was highly correlated to both measures of retail yield from the four primals ($r = 0.97$), and retail yield from the whole side ($r = 0.99$), with 25% fat in the retail trim. Several studies have evaluated the ability of carcass measured traits to predict retail product yield from beef cattle (Abraham et al.1968; Epley et al. 1970; Crouse and Dikeman, 1976; Abraham et al., 1980). More recently, ultrasound has also been used to evaluate retail product yield in beef cattle and has been compared to the well established carcass measures used to predict retail product yield (Herring et al. 1994; Greiner 1997; Williams et al. 1997; Realini et al. 2001). Also, researchers using ultrasound technology have investigated novel sites to be measured, and investigated these new measurements for significance in predicting percent retail product (Greiner 1997; Williams et al. 1997; Realini et al. 2001). The objective of this study was to investigate the relative capabilities of ultrasound and carcass measurements to predict percent retail product from the four primals. A second objective was to determine the capabilities of measures of depth of *gluteus medius* and/or area of *gluteus medius* in the rump of fed cattle to predict percent retail product from the four primals. A final objective was to validate prediction equations published by other researchers in their abilities to predict percent retail product from the four primals.

Materials and Methods

Data for this study were obtained from four-hundred seventy-one calf-fed bulls and steers over two summers (2000 and 2001). All bulls were Angus bulls, while steers were either Angus or crossbred (Angus, Simmental, Red Angus, or Limousin sires represented). Cattle were managed and harvest dates selected based on marketability into a grid marketing environment. Cattle were harvested according to standard industry protocol.

Real-time ultrasound images were collected by a centralized ultrasound processing (CUP) qualified technician within one week of harvest. These images were collected using one of two ultrasound technologies: 1) Classic Scanner 200 (Classic Medical Co., Tequesta, FL) equipped with a 3.5 Mhz 18 cm linear array transducer (n = 387), or 2) Aloka 500V (Aloka USA, Wallingford, CT) equipped with a 3.5 Mhz 17.2 cm linear array transducer (n = 84). Live animal ultrasound measurements taken were: 1) live weight (held off feed overnight until after scanning had taken place on the scan date) (SCANWT), 2) subcutaneous fat thickness at the ¾ position between the 12th and 13th ribs (UFAT), 3) *longissimus dorsi* area between the 12th and 13th ribs (UREA), 4) subcutaneous fat thickness over the termination point of the *biceps femoris* in the rump (reference point) (URFAT), 5) depth of the *gluteus medius* beneath the reference point (URDEPTH), and 6) area of the *gluteus medius* anterior to the reference point (URAREA), 7) percent intramuscular fat within the *longissimus dorsi* between the 12th and 13th ribs (UPFAT). There were three types of images collected to acquire these measures: 1) a cross-sectional image between the 12th and 13th ribs (Figure 1), 2) a longitudinal image collected slightly above a line from the hooks to the pins in line with the *shaft of the ileum* (Figure 2), and four independent longitudinal images collected over the 12th and 13th ribs, approximately ½ to ¾ the distance laterally across the *longissimus dorsi* (Figure3).

Our protocol for location of image collection in the rump was investigated in a previous study (Tait et al., 2000). CUP qualified interpretation technicians evaluated and measured all images in a laboratory situation. A weighted average fat thickness (COMBOFAT) of 12-13th rib fat thickness (60%) and rump fat thickness (40%) was calculated for each animal, as this measurement is used by the American Angus Association (AAA) for genetic evaluations of fat cover (AAA, 2002). The weighting of 12-13th rib fat thickness and rump fat thickness was investigated for the AAA to determine appropriate weightings of each of these traits in calculation of a single fat thickness to perform genetic evaluations. The weighting was determined by evaluating relative abilities of UFAT and URFAT to predict both percent retail product and percent trimmable fat from the four primals from the year 2000 data collected in this study.

Routine carcass measurements were collected by experienced individuals at approximately 24 to 48 hours post mortem. Carcass measurements collected were: 1) hot carcass weight (HCW), 2) subcutaneous fat thickness at the ¾ position between the 12-13th ribs (CFAT), 3) *longissimus dorsi* area between the 12-13th ribs (CREA), and 4) percent kidney, pelvic, and heart fat (CKPH). Fat thickness over the 12th rib was only adjusted if there was an obvious disruption of the fat thickness at the location of measurement, overall fat distribution of the carcass was not used as an adjustment criteria for fat thickness over the 12-13th rib. USDA yield grade (USDAYG) was then calculated from these carcass measurements (USDA, 1997).

Carcasses were transported from commercial harvesting facilities to a fabrication site (Jim's Wholesale Meats, Harlan, IA). This facility was chosen because of the high levels of experience exhibited by the work force, and their commitment to quality and consistency of data collection over time. Many of the same employees were present during all of the fabrication dates, and the same employee fabricated the same cut across fabrication dates whenever feasible.

The right side of each carcass was fabricated into retail ready cuts, with weights recorded for retail cuts, lean trim, fat, and bone. The cuts were trimmed to 0.64 cm of external fat, except for the knuckle and tenderloin, which were trimmed completely. The four primals were fabricated following commercial procedures. The following cuts were produced according to NAMP (1997): #114 shoulder clod; #112A lip-on ribeye; #116 chuck roll; #167A peeled knuckle; #168 top round; #170 gooseneck round; #189A full tenderloin, side muscle on, defatted; #180 boneless strip loin; #184 boneless top sirloin butt; #185C tri-tip bottom sirloin butt; #185B ball-tip bottom sirloin butt. Trim was visually determined to be either: 85% lean and 15% fat, or 50% lean and 50% fat by experienced meat cutting staff at the processing facility. These two versions of trim were marketed as such by the processing facility. Weight of the 85% lean trim was included in the calculation of retail product weight. Weight of the 50-50 trim was mathematically adjusted to represent 85% lean trim as retail product, and the remainder as trimmable fat. Weight of retail product (KGRP) from the four primals was calculated as the sum of the NAMP identified cuts earlier, and 85% lean trim (including mathematically adjusted 50-50 trim) coming from the four primals, this measure was then doubled in order to be expressed on a whole carcass basis. Percentage retail product from the four primals (PRP4P), was determined as the weight of retail product from the four primals divided by the sum of the primal weights (chuck, rib, loin, round, brisket, plate, and flank) of the cold carcass side, immediately prior to dissection. Weight of fat trim (KGFT) was determined as weight of all fat removed from the four primals plus the non-retail trim portion of the 50-50 trim. This weight of fat was also expressed as a percentage (PFT4P) of the cold side weight in the same manner that retail product was expressed on a percentage basis. Calculation of these fat measures has been included to help others evaluate the suggestion of Herring et al. (1994) of reducing excess fat production by predicting excess waste fat (rather than predicting lean retail product).

All data were analyzed using procedures MEANS, CORR, STEPWISE, and GLM of version 8.1 of SAS (SAS Institute, Cary, NC). Correlations were calculated between several sets of traits (carcass measures and related ultrasound measures; all of the collected data and the cutout determined traits). All stepwise regression equations had SCANWT, UFAT, UREA, URFAT, URDEPTH, URAREA, COMBOFAT, and sometimes UPFAT as candidate traits from live animal measures. All stepwise regression equations had HCW, CFAT, CREA, CKPH, and sometimes MARB as candidate traits from carcass measures. Procedure GLM was used to develop various prediction equations for various applications where data availability may determine which equation is best suited to the situation.

Results and Discussion

Table 1 gives abbreviations for the measurements collected in this study. Means, standard deviations, and ranges for live animal and carcass traits are presented in Table 2.

While these cattle were selected for their ability to fit into grid marketing situations, there was still large variation in some traits. In comparison, Greiner (1997) worked with a set of very genetically diverse cattle, and observed similar standard deviations in ultrasound 12-13th rib fat thickness, ultrasound rump fat thickness, adjusted carcass 12-13th rib fat thickness, carcass ribeye area, and USDAYG (0.35 cm, 0.32 cm, 0.42 cm, 8.7 cm^2, and 0.73, respectively). Surprisingly, these cattle showed a larger standard deviation in ultrasound 12-13th rib ribeye area than Greiner's (1997) data (8.1 cm^2 vs. 7.6 cm^2, respectively). Correlations between ultrasound measured traits and carcass measured traits are given in Table 3.

Simple correlations of live animal and carcass traits to cutout observed traits are presented in Table 4. Weight variables (SCANWT and HCW) had the strongest correlations to KGRP (r = 0.78 and r = 0.90, respectively). The relationships between weight of the live animal or hot carcass, and KGRP are consistent with the work of Greiner (1997) and Williams et al. (1997) (r = 0.81 to 0.91). The next strongest relationships to KGRP was observed in measures of ribeye muscle, and was stronger in the ultrasound (r = 0.62) than in the carcass measurements(r = 0.49). The work of Greiner (1997) and Williams et al. (1997) both showed strong correlations between KGRP and measures of ribeye area, they also both observed a stronger correlation between carcass measures of ribeye area to KGRP than ultrasound measures of ribeye area to KGRP (r = 0.68 vs r = 0.61, for Greiner (1997), and r = 0.51 vs. r = 0.48, for Williams et al. (1997)).

PRP4P was most stongly associated with fat measurements, both ultrasound and in the carcass (r = -0.40 to -0.55). This is in agreement with the work of many researchers (Abraham et al., 1968; Epley et al., 1970; Crouse et al., 1975; Crouse and Dikeman, 1976;

Abraham et al. 1980; Greiner, 1997; and Williams et al., 1997). The composite trait of USDAYG was also quite strongly correlated with PRP4P (r = -0.50). This is a smaller correlation than Herring et al. (1994) (r = -0.703) and Greiner (1997) (r = -0.79) observed, but still larger than the r = -0.461, reported by Williams et al. (1997). In our data, CREA and UREA are similar (r = 0.33 and 0.32, respectively) in their relationships to PRP4P. Herring et al. (1994) and Greiner (1997) found similar correlations for CREA (r = 0.324 and r = 0.31, respectively), while live measures of ribeye area had a smaller correlation with PRP4P in both of these studies (Herring et al. (1994) r = 0.096 (P > 0.05) and Greiner (1997) r = 0.17). Williams et al. (1997) found no significant (P > 0.05) relationship between either measure of ribeye area and PRP4P. CKPH is also associated (r = -0.34) with PRP4P. This relationship between PRP4P and CKPH is consistent with the work of Greiner (1997) and Williams et al. (1997) (r = -0.40 and r = -0.357, respectively), but weaker than values observed by Epley et al. (1970) (r = -0.56) and Herring et al. (1994) (r = -0.634). UPFAT was more strongly associated with PRP4P than MARB (r = -0.41 and -0.35, respectively). Because UPFAT has only recently been obtainable with reasonable accuracy (the first Beef Improvement Federation certification for UPFAT was in 1996), there are no studies available to compare our observed relationship to. Other studies have also looked at the relationship between MARB and PRP4P, and found generally stronger correlations (Crouse and Dikeman (1976) r = -0.48; Herring et al. (1994) r = -0.493; and Greiner (1997) r = -0.52).

CKPH was the carcass trait with the strongest relationship (r = 0.48) with PFT4P. This is within the range of correlations for CKPH to trimmable fat observed by Herring et al. (1994) (r = 0.576) and Williams et al. (1997) (r = 0.435). UFAT was the ultrasound trait with the strongest relationship (r = 0.49) to PFT4P. URFAT was almost as strongly associated to PFT4P as CFAT (r = 0.28 and 0.32, respectively). Williams et al. (1997) also found UFAT to be the live animal measurement with the strongest correlation to percent trimmable fat (r = 0.491) and URFAT to be a close second (r = 0.408). COMBOFAT has a correlation of 0.44 to PFT4P. Miller et al. (1988) found ultrasound measured fat over the shoulder to have the strongest relationship to percent fat ($R^2 = 0.40$).

When considering body composition as consisting of bone, lean, and fat in the carcass, it is not surprising that PRP4P was strongly correlated to PFT4P (r = -0.75). While both Herring et al. (1994) and Williams et al. (1997) calculated percent retail product, and percent trimmable fat, neither of these studies reported the correlation between these traits for us to be able to compare our value. USDAYG is also a prediction of percent retail product coming from the four primals, the strong correlation of USDA yield grade to PFT4P (r = 0.38) is good. However, others have found stronger relationships between USDAYG and percent trimmable fat (Herring et al. (1994) r = 0.653; and Williams et al. (1997) r = 0.550).

Single trait predictors of PRP4P and KGRP are included in Table 5, with R-squared, root mean square error (RMSE), and P-values included for each trait. Table 6 lists R-squared, root mean square error (RMSE), and P-values for single traits as predictors of PFT4P and KGFT. Data reported in Table 5 and Table 6 are consistent with the correlations reported in Table 4.

Stepwise regression was used to develop prediction equations for PRP4P from either live animal measures (Table 7) or carcass measures (Table 8). Significance level for variables to stay in stepwise regression prediction equations was set at $P < 0.10$. Ultrasound collected traits that were eligible for inclusion into stepwise developed regression equations included SCANWT, UFAT, UREA, URFAT, URDEPTH, URAREA, COMBOFAT, and

(UPFAT) (Tables 7, 9, 11, and 13). Carcass traits which were eligible for inclusion into stepwise developed regression equations included HCW, CFAT, CREA, CKPH, and (MARB) (Tables 8, 10, 12, and 14). Environmental and genetic factors were not included in the modeling process so that these results can be utilized by others. UFAT was the first variable to enter the equation among ultrasound measurements, and accounted for 29.9% of the variation in PRP4P. Addition of UREA, SCANWT, and URDEPTH accounted for an additional 14.9 % of the variation in PRP4P. Realini et al. (2001) also investigated these same ultrasound measures of fat and depth of the *gluteus medius* in the rump, but found them to be not significant ($P > 0.10$) in predicting percent retail product. However, the Realini et al. (2001) study was limited in size ($n = 32$) and scope (Hereford sired steers only). Williams et al. (1997) obtained significant variables of UREA, UFAT, and URFAT, and was able to account for 31.8% of the variation in percent retail product. Greiner (1997) was able to account for 60% of the variation in percent retail product by using UFAT, URFAT, UREA, and SCANWT. In the carcass data, CFAT was the first variable to enter the prediction equation, but only accounted for 16.4% of the variation in PRP4P. Other significant ($P < 0.10$) carcass variables to enter the prediction equation were CKPH, and CREA, and these traits accounted for an additional 13.3% of the variation in PRP4P. This decrease in prediction capability of the carcass traits to predict percent retail product is in contrast to the work of Greiner (1997) who observed higher R^2 values for carcass measurement derived prediction equations for percent retail product in comparison to ultrasound measurement derived prediction equations, and Williams et al. (1997) who observed nearly identical R^2 values for carcass and ultrasound derived equations. The USDA yield grade equation trait of HCW was not a significant ($P = 0.171$) predictor of PRP4P in these data. Abraham et al.

(1968) and Crouse and Dikeman (1976) also both found HCW to be a questionable predictor of percent retail product. Our stronger relationships between UFAT and PRP4P, than CFAT and PRP4P have been addressed by Abraham et al. (1980) and Herring et al. (1994) as likely being due to irregularities in the fat cover due to hydraulic hide pulling systems.

These PRP4P equations did not include ultrasound or carcass measures of percent intramuscular fat as possible predictors of cutability. When percent intramuscular fat measures are included in the stepwise analysis (data also included in Tables 7 and 8), UPFAT is the third trait to come into the live animal equation (after UREA, and before URDEPTH), and MARB is the second trait to come into the carcass equation (after CFAT, and before CKPH). Incorporation of percent intramuscular fat measures does increase the accuracy of percent retail product prediction equations for carcass ($R^2 = 0.364$ vs. $R^2 = 0.297$) and ultrasound ($R^2 = 0.487$ vs. $R^2 = 0.448$) measures. Crouse and Dikeman (1976) also found MARB to be a useful predictor of percent retail product, where it's incorporation made the contribution of muscling score minimal. There is a trend in the beef industry today to increase intramuscular fat, while at the same time increasing percent retail product from the same animal. The negative correlation of MARB and UPFAT to PRP4P ($r = -0.35$ and $r = -0.41$, respectively), would be very antagonistic to this current industry trend.

Stepwise regression was also used to develop regression equations to predict KGRP, based on either ultrasound measures (Table 9) or carcass measures (Table 10). In equations based on live animal measures, SCANWT was the first trait to come into the prediction equation, and accounted for 60.3% of the variation in KGRP. Additional significant ($P < 0.10$) traits were COMBOFAT, UREA, UFAT, URDEPTH, and URAREA, and these traits accounted for an additional 18.4% of the variation in KGRP. These results are consistent with Herring et al. (1994) who included SCANWT, UREA, and visual trimness to get R^2 = 0.775. Williams et al. (1997) were able to account for 86.5% of the variation in weight of retail product using the live animal measures of SCANWT, UREA, UFAT, URFAT, and depth of the *biceps femoris,* even though UFAT and depth of *biceps femoris* were not significant ($P > 0.10$). Using traits of SCANWT, UFAT, UREA, and URFAT Greiner (1997) demonstrated an R^2 = 0.84 when predicting weight of retail product. In the equation based on carcass traits, HCW was the first variable to enter prediction equations for KGRP, and accounted for 81.0% of the variation. Other significant ($P < 0.10$) traits added to this equation were CFAT, CREA, and CKPH and accounted for an additional 6.4% of the variation in KGRP. The higher proportion of variation accounted for by HCW than SCANWT in predicting KGRP can be explained by the observation of HCW being an intermediary step from the live animal to weight of retail product, and thus should be more predictive. Herring et al. (1994) and Greiner (1997) both demonstrated weight of retail product was predicted more accurately with carcass measurements than ultrasound measurements (R^2 = 0.898 vs. R^2 = 0.775, for Herring et al. (1994), and R^2 = 0.87 vs. R^2 = 0.84, for Greiner (1997), respectively). Williams et al. (1997) found nearly equal capabilities whether using carcass measures (R^2 = 0.840) or ultrasound measures (R^2 = 0.865).

These KGRP equations did not include ultrasound or carcass measures of percent intramuscular fat as possible predictors of retail product weight. When the percent intramuscular fat measurement is included in the stepwise analysis, UPFAT is the fourth trait to come into the live animal equation (after UREA, and before UFAT) (Table 9). MARB is the third trait to come into the carcass equation to predict KGRP (after CFAT, and before CKPH) (Table 10). Incorporation of percent intramuscular fat measurement only increases the accuracy of weight of retail product prediction equations slightly for carcass (R^2 = 0.889 vs. R^2 = 0.874) and ultrasound (R^2 = 0.804 vs. R^2 = 0.787).

Table 11 shows the equations developed to predict PFT4P from live animal measurements, using stepwise regression. Stepwise regression developed equations to predict PFT4P from carcass measures are shown in Table 12. UPFAT was not a significant trait ($P > 0.50$) in live animal prediction of PFT4P, whereas, MARB replaced both CREA and HCW in the prediction of PFT4P and increased the R^2 by 0.021. Interestingly, the equations developed to predict PFT4P have similar accuracies for ultrasound and carcass traits (R^2 = 0.282 to 0.319). When predicting chemical percent fat in fed cattle, Miller et al. (1988), found the best live animal equation to include UFAT, URFAT, and UREA (R^2 = 0.71), and the best carcass equation to include CFAT, HCW, CKPH, and CREA (R^2 = 0.77). Williams et al. (1997) found a small advantage for carcass measures over ultrasound measures to predict trimmable fat (R^2 = 0.455 and R^2 = 0.360, respectively). Herring et al. (1994) found carcass traits were much better able to predict percent trimmable fat (R^2 = 0.678 to R^2 = 0.679) than live animal measures were able to (R^2 = 0.452 to R^2 = 0.473), however, this work only included UFAT, SCANWT, and a subjective visual appraisal of trimness as the live traits collected.

Stepwise regression was used to develop equations to predict KGFT from ultrasound data (Table 13) as well as carcass data (Table 14). These data indicate carcass measures are better able to predict KGFT than ultrasound measures can (R^2 = 0.461 to 0.479 vs. R^2 = 0.377, respectively). In ultrasound data UFAT was the first trait to predict KGFT, rather than SCANWT. In carcass data equations, HCW was the most significant predictor of KGFT, followed by CKPH. When MARB was included in the carcass data model, it was the third trait to enter the equation and increased R^2 by 0.018, while in ultrasound data UPFAT was not a significant ($P > 0.50$) predictor of KGFT.

After looking at all of these stepwise regression prediction equations to predict PRP4P, KGRP, PFT4P, or KGFT from ultrasound measurements, it is interesting that COMBOFAT was a significant predictor in only one instance (KGRP). Even in this case, UFAT was also included as a separate trait in the prediction of KGRP. For this reason, Table 20 includes prediction equations which have UFAT and URFAT as uniquely separate traits, where the coefficients are different than reported in Table 9, but the overall abilities of the equations to account for KGRP are similar ($R^2 = 0.787$ without UPFAT and $R^2 = 0.804$ with UPFAT).

Since Dikeman et al. (1998) observed that an average carcass will have about 1.5 times as much percent intermuscular fat as subcutaneous fat, it is quite probable that we missed a large portion of the variation in KGFT by not evaluating the fat and lean trim from the brisket, plate, and flank, which have several muscle systems and seams of fat in them.

Another interest in this study was the validation of previously reported percent retail product equations. The percent retail product equations we were interested in validating are given in Table 15. The Murphey et al. (1960) equation is the classic study looking into prediction of percent retail product from carcass measured traits, and was the original basis for the USDA yield grading system. Crouse et al. (1986) studied equation capabilities to predict percent retail product with and without including CKPH, as a proposed change to the USDA yield grading equation, and is thus scaled according to USDAYG. The Crouse et al. (1986) equation without CKPH was then modified to represent the COMBOFAT proportioning between UFAT (60%) and URFAT (40%), as well as a standardized dressing percentage (61.5%), and then this equation was validated using our ultrasound measurements. The Dikeman et al. (1998) equation was developed with whole side cutout data and 0.00 cm trim level on retail product. The Dikeman et al. (1998) equation was also modified to utilize ultrasound data with 60% weighting on UFAT, 40% weighting on URFAT, a 61.5% dressing percentage, and a standardized 2.0% CKPH. The Greiner (1997) and Williams et al. (1997) studies were both comparative between ultrasound measured traits, and carcass measured traits. We validated the equations published by both of these studies for the traits which we collected data on. Interestingly, the Williams et al. (1997) equation is the only instance of an increase in weight being associated with a more favorable percent retail product measurement.

Data in Table 16 indicate ultrasound based prediction equations (c,d, and e superscripts) for predicting PRP4P are more accurate (R^2 = 0.343 to 0.400; RMSE = 1.50 to 1.56) than carcass based prediction equations (a and b superscripts) (R^2 = 0.228 to 0.265; RMSE = 1.66 to 1.70). This work also supports the approach of using a carcass derived percent retail product prediction equation which has been modified to use ultrasound data (using a standard dressing percentage to predict HCW and COMBOFAT to replace CFAT). This is much like the protocol used by the American Angus Association (AAA) in genetic evaluation procedures (AAA, 2002).

The capabilities of these percent retail product equations to predict weight of retail product are included in Table 16 to show one interesting phenomenon in particular. The Williams et al. (1997) carcass derived equation was more highly related to predicting weight of retail product than any of the other equations evaluated (R^2 = 0.482 vs 0.120 and lower).

This is most likely the result of the favorable coefficient for HCW in predicting percent retail product as previously discussed.

The same equations given in Table 15 were evaluated for their relationships to trimmable fat yields (both weight and percentage) and the results are presented in Table 17. These relationships are a rather indirect comparison of information, however, it is interesting that there is such a strong relationship between prediction of retail product, and actual cutout determined trimmable fat ($P < 0.001$ for most equations). The accuracy of predicting PFT4P from previously reported percent retail product equations ($R^2 = 0.080$ to $R^2 = 0.225$) is somewhat lower than accuracy of our developed equations to predict PFT4P ($R^2 = 0.283$ for ultrasound data and $R^2 = 0.298$ to $R^2 = 0.319$ for carcass data). The poorer comparison of previously reported percent retail product equations to predict KGFT ($R^2 = <0.001$ to $R^2 = .165$) than our equations to predict KGFT ($R^2 = 0.377$ for ultrasound data and $R^2 = 0.461$ to $R^2 = 0.479$ for carcass data) is not surprising because we are making a comparison between a percentage equation and a weight trait.

Tables 18 and 19 show various equations to predict PRP4P from ultrasound measures and carcass measures, respectively. Tables 20 and 21 show various equations to predict KGRP from ultrasound measures and carcass measures, respectively. These various equations are reported as a reference for other individuals to determine the best prediction equation available to them for the costs of obtaining these data. For instance, feedlot situations can determine whether an equation with only ultrasound fat thickness is accurate enough for them, or whether they would benefit from also including ultrasound ribeye area into the prediction equations. While some researchers may want to include as many traits as possible and get as high of an accuracy as possible to determine effects of a dietary treatment. P-values for each coefficient are also included so that each individual can determine the level of significance they choose to incorporate traits into prediction equations, whether it be $P < 0.01$, $P < 0.05$, or $P < 0.10$, rather than us just simply reporting all equations as having a P < some value.

Implications

These data confirm that ultrasound measures can accurately estimate percent retail product in beef cattle. In fact, this study found an advantage for ultrasound measures over carcass measures in the prediction of percent retail product. This is most likely a result of continuing efforts to refine image collection protocol and interpretation methods of ultrasound data. The results of these data, and other research, indicate that measurements of fat in the rump are certainly valuable in prediction of retail product measures in beef cattle. We view this multiple location evaluation of subcutaneous fat cover in live cattle as similar to the adjustments made to preliminary yield grade by USDA graders. Certainly, the strong relationships between previously reported prediction equations to predict percent retail product, and actual cutout data collected in this study is encouraging, and further validation of published equations needs to be ongoing.

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Table 1. Abbreviations used for traits

Trait	Definition
Live animal measurements	
SCANWT, kg	Live weight of the animal (held off feed overnight until after scanning)
UFAT, cm	Ultrasound 12-13th rib fat thickness
UREA, cm^2	Ultrasound 12-13th rib ribeye area
UPFAT, %	Ultrasound predicted percent intrmuscular fat
URFAT, cm	Ultrasound rump fat over the reference point
URDEPTH, cm	Ultrasound depth of the *gluteus medius* below the reference point
URAREA, cm^2	Ultrasound area of the *gluteus medius* anterior to the reference point
COMBOFAT, cm	60% of 12-13th rib fat thickness plus 40% of ultrasound rump fat
Carcass measurements	
HCW, kg	Hot carcass weight
CFAT, cm	Carcass 12-13th rib fat thickness
CREA, cm^2	Carcass 12-13th rib ribeye area
CKPH, %	Carcass percent kidney, pelvic, and heart fat
MARB[a]	USDA grader called marbling score
USDAYG	Calculated USDA yield grade based on carcass measurements
PRP4P, %	Percent retail product from the four primals
KGRP, kg	Weight of retail product from the four primals (whole side basis)
PFT4P, %	Percent trimmable fat from the four primals
KGFT, kg	Weight of trimmable fat from the four primals (whole side basis)

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

Table 2. Simple statistics for data collected

Trait	Mean	SD	Minimum	Maximum
Live animal measurements				
SCANWT, kg	550.0	43.4	412.8	698.5
UFAT, cm	1.05	0.32	0.28	2.11
UREA, cm^2	83.8	8.1	61.3	111.6
UPFAT, %	4.79	1.19	2.24	8.92
URFAT, cm	0.96	0.33	0.33	2.01
URDEPTH, cm	8.85	0.85	6.58	11.35
URAREA, cm^2	66.1	9.8	39.4	104.5
COMBOFAT, cm	1.01	0.29	0.33	1.87
Carcass measurements				
HCW, kg	336.4	27.3	249.5	434.5
CFAT, cm	1.06	0.40	0.25	3.56
CREA, cm^2	82.1	8.6	60.6	108.4
CKPH, %	1.98	0.34	1.00	3.50
MARB[a]	5.38	1.02	3.00	9.20
USDAYG	2.68	0.67	1.13	5.33
PRP4P, %	52.65	1.93	47.10	59.03
KGRP, kg	174.6	15.6	130.6	230.7
PFT4P, %	6.97	1.26	3.68	11.62
KGFT, kg	23.2	4.9	10.7	38.1

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

Table 3. Simple correlations between live animal and carcass collected traits

Trait	HCW	CFAT	CREA	CKPH	MARB[a]	USDAYG
SCANWT	0.91***	0.20***	0.17***	0.12**	0.18***	0.33***
UFAT	0.14**	0.68***	-0.22***	0.16***	0.32***	0.61***
UREA	0.54***	0.02	0.56***	0.04	-0.00	-0.16***
UPFAT	0.00	0.34***	-0.23***	0.03	0.63***	0.36***
URFAT	0.05	0.54***	-0.28***	0.11*	0.27***	0.52***
URDEPTH	0.20***	0.24***	-0.03	-0.06	0.18***	0.23***
URAREA	0.17***	0.00	0.06	-0.10*	0.04	0.02
COMBOFAT	0.11*	0.69***	-0.27***	0.15**	0.34***	0.63***

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

† $P < 0.10$
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Table 4. Simple correlations of traits to percent and weight of retail product and fat trim

Trait	PRP4P	KGRP	PFT4P	KGFT
Live animal measurements				
SCANWT	-0.12**	0.78***	0.11*	0.44***
UFAT	-0.55***	-0.13**	0.49***	0.44***
UREA	0.32***	0.62***	-0.17***	0.06
UPFAT	-0.41***	-0.20***	0.22***	0.17***
URFAT	-0.40***	-0.17***	0.28***	0.22***
URDEPTH	0.06	0.14**	0.01	0.05
URAREA	0.10*	0.18***	0.00	0.05
COMBOFAT	-0.54***	-0.16***	0.44***	0.39***
Carcass measurements				
HCW	-0.05	0.90***	0.15***	0.52***
CFAT	-0.41***	-0.04	0.32***	0.31***
CREA	0.33***	0.49***	-0.14**	0.02
CKPH	-0.34***	0.02	0.48***	0.48***
MARB[a]	-0.35***	-0.09*	0.24***	0.22***
USDAYG	-0.50***	-0.03	0.38***	0.40***
PRP4P	1.00***	0.36***	-0.75***	-0.66***
KGRP		1.00***	-0.15***	0.22***
PFT4P			1.00***	0.92***

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

†	$P < 0.10$
*	$P < 0.05$
**	$P < 0.01$
***	$P < 0.001$

Table 5. Single trait predictors of retail product yield

	Percent Retail Product			Weight of Retail Product		
Trait	R^2	RMSE(%)	P-Value	R^2	RMSE(kg)	P-Value
Live animal measurements						
UFAT	0.299	1.62	<0.001	0.016	15.51	0.007
COMBOFAT	0.290	1.63	<0.001	0.025	15.44	<0.001
UPFAT	0.172	1.76	<0.001	0.039	15.34	<0.001
URFAT	0.160	1.77	<0.001	0.028	15.41	<0.001
UREA	0.102	1.83	<0.001	0.381	12.30	<0.001
SCANWT	0.015	1.92	0.009	0.603	9.86	<0.001
URAREA	0.010	1.92	0.029	0.032	15.38	<0.001
URDEPTH	0.004	1.93	0.193	0.021	15.47	0.002
Carcass measurements						
USDAYG	0.250	1.67	<0.001	0.001	15.63	0.560
CFAT	0.164	1.76	<0.001	0.002	15.62	0.346
CKPH	0.116	1.81	<0.001	<0.001	15.63	0.669
MARB[a]	0.122	1.81	<0.001	0.009	15.56	0.040
CREA	0.107	1.82	<0.001	0.237	13.66	<0.001
HCW	0.003	1.93	0.259	0.810	6.81	<0.001

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

Table 6. Single trait predictors of trimmable fat yield

	Percent Trimmable Fat			Weight of Trimmable Fat		
Trait	R^2	RMSE(%)	P-Value	R^2	RMSE(kg)	P-Value
Live animal measurements						
UFAT	0.236	1.10	<0.001	0.198	4.37	<0.001
COMBOFAT	0.196	1.13	<0.001	0.153	4.49	<0.001
URFAT	0.076	1.21	<0.001	0.049	4.75	<0.001
UPFAT	0.049	1.23	<0.001	0.028	4.80	<0.001
UREA	0.028	1.25	<0.001	0.004	4.86	0.189
SCANWT	0.013	1.26	0.014	0.194	4.38	<0.001
URAREA	0.001	1.26	0.550	0.001	4.87	0.500
URDEPTH	<0.001	1.26	0.946	0.002	4.87	0.329
Carcass measurements						
CKPH	0.229	1.11	<0.001	0.229	4.28	<0.001
USDAYG	0.147	1.17	<0.001	0.157	4.48	<0.001
CFAT	0.105	1.20	<0.001	0.099	4.63	<0.001
MARB[a]	0.056	1.23	<0.001	0.047	4.76	<0.001
HCW	0.024	1.25	<0.001	0.268	4.17	<0.001
CREA	0.021	1.25	0.002	0.001	4.87	0.616

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

Table 7. Stepwise regression to predict percent retail product

from the four primals from ultrasound data

Order	Trait	Coefficient	P-Value	Partial R^2	Model R^2
Without percent intramuscular fat					
	Intercept	50.760			
1	UFAT	-3.286	<0.001	0.299	0.299
2	UREA	0.0833	<0.001	0.091	0.391
3	SCANWT	-0.00975	<0.001	0.029	0.420
4	URDEPTH	0.422	<0.001	0.028	0.448
With percent intramuscular fat					
	Intercept	51.514			
1	UFAT	-2.792	<0.001	0.300	0.300
2	UREA	0.0774	<0.001	0.092	0.391
3	UPFAT	-0.356	<0.001	0.033	0.424
4	URDEPTH	0.493	<0.001	0.031	0.455
5	SCANWT	-0.00923	<0.001	0.032	0.487

Table 8. Stepwise regression to predict percent retail product from the four primals from carcass data

Order	Trait	Coefficient	P-Value	Partial R^2	Model R^2
Without percent intramuscular fat					
	Intercept	52.447			
1	CFAT	-1.392	<0.001	0.164	0.164
2	CKPH	-1.559	<0.001	0.069	0.233
3	CREA	0.0580	<0.001	0.064	0.297
With percent intramuscular fat					
	Intercept	55.711			
1	CFAT	-1.256	<0.001	0.164	0.164
2	MARB[a]	-0.499	<0.001	0.087	0.251
3	CKPH	-1.548	<0.001	0.069	0.320
4	CREA	0.0489	<0.001	0.044	0.364

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

Table 9. Stepwise regression to predict weight of retail product from the four primals from ultrasound data

Order	Trait	Coefficient	P-Value	Partial R^2	Model R^2
Without percent intramuscular fat					
	Intercept	8.959			
1	SCANWT	0.259	<0.001	0.603	0.603
2	COMBOFAT	-23.013	<0.001	0.112	0.714
3	UREA	0.588	<0.001	0.063	0.777
4	UFAT	8.518	0.006	0.004	0.781
5	URDEPTH	-2.119	0.005	0.004	0.784
6	URAREA	0.110	0.019	0.003	0.787
With percent intramuscular fat					
	Intercept	12.962			
1	SCANWT	0.261	<0.001	0.602	0.602
2	COMBOFAT	-19.639	<0.001	0.112	0.714
3	UREA	0.560	<0.001	0.063	0.777
4	UPFAT	-1.952	<0.001	0.020	0.797
5	UFAT	8.332	0.004	0.004	0.800
6	URDEPTH	-1.647	0.048	0.002	0.802
7	URAREA	0.098	0.029	0.002	0.804

Table 10. Stepwise regression to predict weight of retail product from the four primals from carcass data

Order	Trait	Coefficient	P-Value	Partial R^2	Model R^2
Without percent intramuscular fat					
	Intercept	-3.045			
1	HCW	0.511	<0.001	0.810	0.810
2	CFAT	-5.266	<0.001	0.037	0.847
3	CREA	0.256	<0.001	0.017	0.864
4	CKPH	-4.809	<0.001	0.011	0.874
With percent intramuscular fat					
	Intercept	7.527			
1	HCW	0.521	<0.001	0.810	0.810
2	CFAT	-4.900	<0.001	0.037	0.847
3	MARB[a]	-1.927	<0.001	0.021	0.868
4	CKPH	-4.875	<0.001	0.011	0.879
5	CREA	0.208	<0.001	0.010	0.889

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

Table 11. Stepwise regression to predict percent trimmable fat from the four primals from ultrasound data

Order	Trait	Coefficient	P-Value	Partial R^2	Model R^2
Without percent intramuscular fat					
	Intercept	6.833			
1	UFAT	1.935	<0.001	0.236	0.236
2	UREA	-0.0274	<0.001	0.023	0.259
3	URDEPTH	-0.194	0.009	0.011	0.270
4	SCANWT	0.00384	0.004	0.013	0.283
With percent intramuscular fat					
	Intercept	6.798			
1	UFAT	1.930	<0.001	0.235	0.235
2	UREA	-0.0271	<0.001	0.022	0.258
3	URDEPTH	-0.194	0.009	0.011	0.269
4	SCANWT	0.00386	0.004	0.013	0.282

Table 12. Stepwise regression to predict percent trimmable fat from the four primals from carcass data

Order	Trait	Coefficient	P-Value	Partial R^2	Model R^2
Without percent intramuscular fat					
	Intercept	3.330			
1	CKPH	1.554	<0.001	0.229	0.229
2	CFAT	0.598	<0.001	0.053	0.282
3	CREA	-0.0195	0.021	0.008	0.290
4	HCW	0.00453	0.026	0.008	0.298
With percent intramuscular fat					
	Intercept	1.849			
1	CKPH	1.584	<0.001	0.229	0.229
2	CFAT	0.651	<0.001	0.053	0.282
3	MARB[a]	0.239	<0.001	0.037	0.319

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

Table 13. Stepwise regression to predict weight of trimmable fat from the four primals from ultrasound data

Order	Trait	Coefficient	P-Value	Partial R^2	Model R^2
Without percent intramuscular fat					
	Intercept	2.550			
1	UFAT	7.500	<0.001	0.200	0.200
2	SCANWT	0.0516	<0.001	0.130	0.328
3	URDEPTH	-0.995	<0.001	0.032	0.359
4	URFAT	-2.207	0.005	0.011	0.370
5	UREA	-0.0564	0.030	0.007	0.377
With percent intramuscular fat					
	Intercept	2.439			
1	UFAT	7.474	<0.001	0.197	0.197
2	SCANWT	0.0516	<0.001	0.131	0.328
3	URDEPTH	-0.995	<0.001	0.032	0.360
4	URFAT	-2.195	0.005	0.011	0.371
5	UREA	-0.0552	0.034	0.006	0.377

Table 14. Stepwise regression to predict weight of trimmable fat from the four primals from carcass data

Order	Trait	Coefficient	P-Value	Partial R^2	Model R^2
Without percent intramuscular fat					
	Intercept	-12.103			
1	HCW	0.0837	<0.001	0.268	0.268
2	CKPH	5.222	<0.001	0.156	0.424
3	CFAT	1.698	<0.001	0.028	0.452
4	CREA	-0.0614	0.005	0.009	0.461
With percent intramuscular fat					
	Intercept	-15.718			
1	HCW	0.080	<0.001	0.268	0.268
2	CKPH	5.242	<0.001	0.156	0.424
3	MARB[a]	0.652	<0.001	0.029	0.452
4	CFAT	1.585	<0.001	0.022	0.474
5	CREA	-0.0445	0.042	0.005	0.479

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

Table 15. Percent retail product prediction equations validated

Source	Type	Intercept	12th FT cm	12th REA cm^2	Weight kg	KPH %	Rump FT cm
Murphey et al. (1960)[a,c,g]	Carcass	51.34	-2.277	0.115	-0.0205	-0.462	N.A.
Crouse et al. (1986)[a,d,g]	Carcass	2.5	0.984	-0.05	0.0084	0.2	N.A.
Crouse et al. (1986)[a,d,h]	Carcass	3.0	0.984	-0.03	0.0041	N.A.	N.A.
Crouse et al. (1986)[a,d,j]	Ultrasound	3.0	0.590	-0.03	0.0025	N.A.	0.394
Dikeman et al. (1998)[b,f,g]	Carcass	65.69	-3.91	0.19	-0.029	-1.29	N.A.
Dikeman et al. (1998)[b,f,k]	Ultrasound	63.11	-2.346	0.19	-0.0178	N.A.	-1.564
Williams et al. (1997)[b,e,g]	Carcass	67.932	-3.331	0.047	0.047	-1.684	N.A.
Williams et al. (1997)[b,e,i]	Ultrasound	65.22	-1.288	0.117	-0.007	N.A.	-2.885
Greiner (1997)[b,f,g]	Carcass	68.83	-5.472	0.165	-0.023	-1.417	N.A.
Greiner (1997)[b,f,i]	Ultrasound	70.67	-6.185	0.083	-0.005	N.A.	-3.513

N.A. = Not Applicable

[a] evaluated four primals retail product

[b] evaluated whole side retail product

[c] 1.27 cm trim level

[d] 0.8 cm trim level

[e] 0.32 cm trim level

[f] 0.00 cm trim level

[g] Carcass data w/ KPH

[h] Carcass data w/o KPH

[i] Ultrasound data

[j] Modified using ultrasound data, COMBOFAT, and 61.5% dressing percent

[k] Modified using ultrasound data, COMBOFAT, 61.5% dressing percent, and 2.0 % KPH

Table 16. Previously reported percent retail product prediction equations for retail product yield

	Percent Retail Product			Weight of Retail Product		
Reported by	R^2	RMSE(%)	P-Value	R^2	RMSE(kg)	P-Value
Murphey et al. (1960) [a]	0.249	1.67	<0.001	<0.001	15.63	0.843
Crouse et al. (1986) [a]	0.250	1.67	<0.001	<0.001	15.63	0.535
Crouse et al. (1986) [b]	0.228	1.70	<0.001	0.006	15.58	0.081
Crouse et al. (1986) [d]	0.400	1.50	<0.001	0.080	14.99	<0.001
Dikeman et al. (1998) [a]	0.265	1.66	<0.001	0.003	15.61	0.239
Dikeman et al. (1998) [e]	0.382	1.52	<0.001	0.073	15.05	<0.001
Williams et al. (1997) [a]	0.160	1.77	<0.001	0.482	11.26	<0.001
Williams et al. (1997) [c]	0.343	1.56	<0.001	0.120	14.66	<0.001
Greiner (1997) [a]	0.261	1.66	<0.001	0.005	15.60	0.129
Greiner (1997) [c]	0.356	1.55	<0.001	0.053	15.22	<0.001

[a] Carcass data w/ KPH
[b] Carcass data w/o KPH
[c] Ultrasound data
[d] Modified using ultrasound data, COMBOFAT, and 61.5% dressing percent
[e] Modified using ultrasound data, COMBOFAT, 61.5% dressing percent, and 2.0 % KPH

Table 17. Previously reported percent retail product prediction equations for trimmable fat yield

	Percent Trimmable Fat			Weight of Trimmable Fat		
Reported by	R^2	RMSE(%)	P-Value	R^2	RMSE(kg)	P-Value
Murphey et al. (1960) [a]	0.148	1.17	<0.001	0.163	4.46	<0.001
Crouse et al. (1986) [a]	0.147	1.17	<0.001	0.156	4.48	<0.001
Crouse et al. (1986) [b]	0.120	1.19	<0.001	0.113	4.59	<0.001
Crouse et al. (1986) [d]	0.216	1.12	<0.001	0.141	4.52	<0.001
Dikeman et al. (1998) [a]	0.165	1.15	<0.001	0.165	4.45	<0.001
Dikeman et al. (1998) [e]	0.192	1.14	<0.001	0.128	4.55	<0.001
Williams et al. (1997) [a]	0.080	1.21	<0.001	<0.001	4.87	0.795
Williams et al. (1997) [c]	0.164	1.16	<0.001	0.084	4.66	<0.001
Greiner (1997) [a]	0.167	1.15	<0.001	0.159	4.47	<0.001
Greiner (1997) [c]	0.225	1.11	<0.001	0.159	4.47	<0.001

[a] Carcass data w/ KPH
[b] Carcass data w/o KPH
[c] Ultrasound data
[d] Modified using ultrasound data, COMBOFAT, and 61.5% dressing percent
[e] Modified using ultrasound data, COMBOFAT, 61.5% dressing percent, and 2.0 % KPH

Table 18. Ultrasound derived equations to predict percent retail product[a]

R^2	RMSE %	Intercept	UFAT cm	UREA cm^2	SCANWT kg	UPFAT %	URFAT cm	URDEPTH cm	URAREA cm^2
With UREA as a measure of muscle									
0.102	1.830	46.263	...	0.0762	...	...	...	...	...
		<0.001	...	<0.001	...	...	...	...	...
0.391	1.509	49.993	-3.2308	0.0722	...	...	...	...	...
		<0.001	<0.001	<0.001	...	...	...	...	...
0.420	1.474	52.755	-2.9786	0.0935	-0.008741	...	...	...	...
		<0.001	<0.001	<0.001	<0.001	...	...	...	...
0.448	1.439	50.760	-3.2861	0.0833	-0.009753	...	...	0.4215	...
		<0.001	<0.001	<0.001	<0.001	...	...	<0.001	...
0.449	1.439	50.792	-3.1135	0.0820	-0.009503	...	-0.2858	0.4248	...
		<0.001	<0.001	<0.001	<0.001	...	0.278	<0.001	...
0.449	1.439	53.685	-2.5120	0.0900	-0.008141	-0.3048	...	...	...
		<0.001	<0.001	<0.001	<0.001	<0.001	...	...	...
0.487	1.390	51.514	-2.7923	0.0774	-0.009226	-0.3559	...	0.4928	...
		<0.001	<0.001	<0.001	<0.001	<0.001	...	<0.001	...

Table 18. (continued)

R^2	RMSE %	Intercept	UFAT cm	UREA cm^2	SCANWT kg	UPFAT %	URFAT cm	URDEPTH cm	URAREA cm^2
Without UREA as a measure of muscle									
0.162	1.769	55.966	...	...	-0.002023	...	-2.3050	...	...
		<0.001	...	...	0.2921	...	<0.001	...	...
0.188	1.743	53.731	...	...	-0.003919	...	-2.4622	0.3873	...
		<0.001	...	...	0.0453	...	<0.001	<0.001	...
0.299	1.616	56.101	-3.2875	...	...	...	...	...	...
		<0.001	<0.001	...	...	...	...	...	...
0.300	1.617	56.391	-3.2726	...	-0.0005549	...	...	...	...
		<0.001	<0.001	...	0.7521	...	...	...	...
0.320	1.596	55.236	-3.2942	...	-0.001840	...	...	...	0.0285
		<0.001	<0.001	...	0.2982	...	...	...	<0.001
0.357	1.551	53.053	-3.6564	...	-0.003214	...	...	0.5878	...
		<0.001	<0.001	...	0.0643	...	...	<0.001	...
0.363	1.546	53.049	-3.3061	...	-0.002919	...	-0.5617	0.5891	...
		<0.001	<0.001	...	0.0929	...	0.0461	<0.001	...

[a] Below each coefficient is the P-Value for that trait

Table 19. Carcass data equations to predict percent retail product[a]

R^2	RMSE %	Intercept	CFAT cm	CREA cm^2	HCW kg	MARB [b]	CKPH %
Without MARB							
0.107	1.824	46.638	...	0.0732	...	...	...
		<0.001	...	<0.001	...	...	...
0.116	1.815	56.441	...	...	...	...	-1.9145
		<0.001	...	...	...	...	<0.001
0.164	1.765	54.696	-1.9400	...	...	...	...
		<0.001	<0.001	...	...	...	...
0.223	1.7030	49.8328	-1.6754	0.0559	...	...	...
		<0.001	<0.001	<0.001	...	...	...
0.233	1.692	57.407	-1.6754	...	...	...	-1.5095
		<0.001	<0.001	...	...	...	<0.001
0.297	1.622	52.447	-1.3919	0.0580	...	...	-1.5592
		<0.001	<0.001	<0.001	...	...	<0.001
0.300	1.620	53.266	-1.3276	0.0634	-0.004213	...	-1.5147
		<0.001	<0.001	<0.001	0.1707	...	<0.001
With MARB							
0.122	1.809	56.199	...	...	...	-0.6600	...
		<0.001	...	...	...	<0.001	...
0.251	1.673	57.502	-1.7359	...	...	-0.5617	...
		<0.001	<0.001	...	...	<0.001	...
0.291	1.629	53.143	-1.536	0.0467	...	-0.5028	...
		<0.001	<0.001	<0.001	...	<0.001	...
0.320	1.596	60.199	-1.4725	...	...	-0.5604	-1.5052
		<0.001	<0.001	...	...	<0.001	<0.001
0.364	1.545	55.711	-1.2559	0.0489	...	-0.4987	-1.5476
		<0.001	<0.001	<0.001	...	<0.001	<0.001
0.364	1.546	55.975	-1.2340	0.0509	-0.001525	-0.4938	-1.5316
		<0.001	<0.001	<0.001	0.6063	<0.001	<0.001

[a] Below each coefficient is the P-Value for that trait

[b] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

Table 20. Ultrasound derived equations to predict weight of retail product[a]

R^2	RMSE kg	Intercept	UFAT cm	UREA cm^2	SCANWT kg	UPFAT %	URFAT cm	URDEPTH cm	URAREA cm^2
0.016	15.511	181.022	-6.0958	...	...	...	...	...	...
		<0.001	0.0065	...	...	...	...	...	...
0.603	9.857	20.827	...	...	0.2796	...	...	...	...
		<0.001	...	...	<0.001	...	...	...	...
0.684	8.795	24.208	-14.1943	...	0.3005	...	...	...	...
		<0.001	<0.001	...	<0.001	...	...	...	...
0.695	8.650	-4.199	...	0.6562	0.2252	...	...	...	...
		0.4454	...	<0.001	<0.001	...	...	...	...
0.709	8.450	26.121	...	...	0.3050	...	-15.5764	-0.4967	...
		<0.001	...	...	<0.001	...	<0.001	0.3065	...
0.755	7.749	1.559	-12.3630	0.5825	0.2496	...	...	...	...
		0.7532	<0.001	<0.001	<0.001	...	...	...	...
0.783	7.318	8.981	-8.6683	0.5542	0.2542	-2.4041	...	...	...
		0.0613	<0.001	<0.001	<0.001	<0.001	...	...	...
0.784	7.294	8.972	-5.5333	0.5716	0.2612	...	-9.7006	-1.2226	...
		0.0795	<0.001	<0.001	<0.001	...	<0.001	0.0054	...
0.787	7.259	8.959	-5.2899	0.5879	0.2586	...	-9.2054	-2.1185	0.1102
		0.0784	<0.001	<0.001	<0.001	...	<0.001	<0.001	0.0187
0.804	6.975	12.962	-3.4509	0.5601	0.2605	-1.9521	-7.8554	-1.6470	0.0983
		0.009	0.012	<0.001	<0.001	<0.001	<0.001	0.003	0.029

[a] Below each coefficient is the P-Value for that trait

Table 21. Carcass data equations to predict weight of retail product[a]

R^2	RMSE kg	Intercept	CFAT cm	CREA cm^2	HCW kg	MARB [b]	CKPH %
0.237	13.659	102.190	...	0.8827	...	...	...
		<0.001	...	<0.001	...	...	...
0.810	6.812	1.124	...	...	0.5158	...	...
		0.7729	...	...	<0.001	...	...
0.847	6.114	2.975	-7.5831	...	0.5341	...	...
		0.3953	<0.001	...	<0.001	...	...
0.864	5.778	-9.103	-5.9779	0.2619	0.5011	...	...
		0.0168	<0.001	<0.001	<0.001	...	...
0.868	5.694	12.483	-6.8300	...	0.5390	-2.2208	...
		<0.001	<0.001	...	<0.001	<0.001	...
0.874	5.558	-3.045	-5.2658	0.2562	0.5105	...	-4.8094
		0.4062	<0.001	<0.001	<0.001	...	<0.001
0.879	5.449	18.566	-6.0487	...	0.5481	-2.2308	-5.0111
		<0.001	<0.001	...	<0.001	<0.001	<0.001
0.889	5.224	7.527	-4.9004	0.2076	0.5210	-1.9268	-4.8754
		0.0421	<0.001	<0.001	<0.001	<0.001	<0.001

[a] Below each coefficient is the P-Value for that trait

[b] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

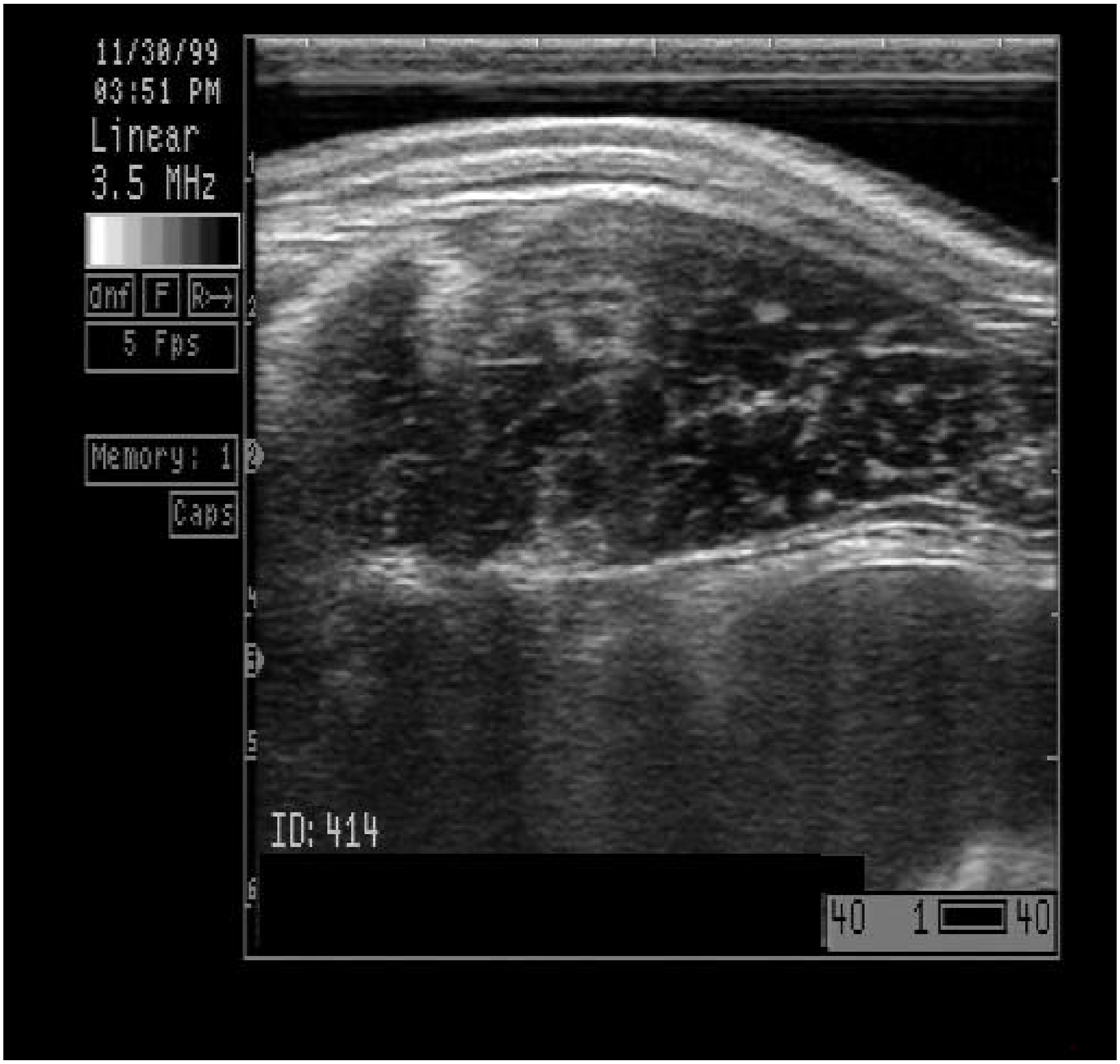

Figure 1. Cross-sectional ultrasound image collected between the 12th and 13th ribs.

Figure 2. Longitudinal ultrasound image collected over the rump of the animal.

Figure 3. Longitudinal image for predicting percent intramuscular fat with ultrasound

GENERAL SUMMARY

Cattle selected for this study were managed with the intent of marketing them into a value-based grid marketing system. As evidenced by the tremendous variation observed in this study, the current methodology of selecting cattle for this scenario based on visual appraisal and having knowledge about the genetic background of the cattle is not sufficient to do an adequate job of selecting cattle to fit a narrow marketing window. These "selected" cattle showed as much or more variation in traits as a study deliberately established to evaluate a wide variation in biological types of cattle (Greiner, 1997).

This study was successful in validating the results of others (Herring et al., 1994; Greiner, 1997; Williams et al., 1997; and Realini et al., 2001) that real-time ultrasound has the ability to evaluate cattle in a consistent manner and give accurate predictions about body composition. In fact, this study showed an advantage (R^2 = 0.448 for ultrasound and R^2 = 0.297 for carcass) in using ultrasound predictions of percent retail product yield over using carcass predictions (which currently is the system beef carcasses are legally traded under in the United States). The results of other researchers (Greiner, (1997); and Williams et al. (1997)) indicates that measurements of fat in the rump are certainly valuable in prediction of percent retail product in beef cattle. This multiple location evaluation of subcutaneous fat cover in live cattle should be viewed as similar to the adjustments made to preliminary yield grade performed by USDA graders in the cooler. Even though the rump fat measurement did not come into the stepwise regression prediction equations developed in this data set, I believe that it is likely an important factor that should be used on large, diverse populations of cattle.

Additionally, this study showed the effectiveness of incorporating an additional measure of lean in the rump (depth of the *gluteus medius* below the apex of the *biceps femoris* in the rump of the animal) in live animal prediction equations for percent retail product. I would speculate that these improvements in prediction capability of ultrasound in body composition work is a direct result of increased interactions among ultrasound technicians who participate in centralized ultrasound processing techniques, and a continual increase in knowledge about the technical aspects of ultrasounding cattle.

Unfortunately, collection of this data did not allow for dissection of the plate, and therefore, brisket, plate, and flank cutabilities were not suitable for incorporation into this analysis. The work of Dikeman et al. (1998) would suggest that we likely missed out on some substantial variability in cutability in these cattle because the brisket, plate, and flank would have a lot of intermuscular fat which contributes 1.5 times as much fat to trimmable fat as subcutaneous fat would.

Carcass data are the traditional means of predicting percent retail product in cattle and works well in a controlled collection situation. However, as there is an increased demand for carcass data from progressive cattle producers, the appendix indicates there is likely more error introduced when carcass data is collected in a commercialized manner at line speed. As more producers are requesting carcass data, there will likely be more pressure to move to an automated carcass data collection method.

When looking at validating previously reported percent retail product prediction equations, ultrasound based prediction equations were more accurate (R^2 = 0.343 to 0.400; RMSE = 1.50 to 1.56) than carcass based prediction equations (R^2 = 0.228 to 0.265; RMSE = 1.66 to 1.70). This work also supports the approach of using a carcass derived percent retail product prediction equation which has been modified to use ultrasound data, much like the American Angus Association (AAA) does in genetic evaluation procedures (AAA, 2002). Certainly, the strong relationships between most of the previously reported prediction equations to predict percent retail product, and actual cutout data collected in this study is encouraging, and further validation of equations developed needs to be ongoing.

Ultrasound data have proven to be effective in predicting percent retail product in cattle which are evaluated (Herring et al., 1994b; Greiner, 1997; Williams et al., 1997; Realini et al., 2001). However, there is still need for further research on how selection of breeding stock, which are developed under a different management scheme, impacts the phenotypes of harvest progeny. This is the arena where application of ultrasound technology to determine percent retail product will be able to make significant progress for the beef industry as a whole. Use of ultrasound in selection of breeding stock could potentially create tremendous decreases in cost of collection of percent retail product data, and could shorten the time lag for this information to be available on potential breeding stock.

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APPENDIX

Comparison of Carcass Data Collection Methods

Because this study was conducted over two years, there was a change in how carcass data were collected between years. In 2000 all carcasses were stationary on a rail while carcass measures of CFAT, CREA, and CKPH were collected. In 2001, CFAT, CREA, and CKPH were collected on the moving line between ribbing of the carcass and USDA grader evaluation. This appendix is intended to address any difference this may have made in accuracy of carcass measures.

Means, standard deviations, and ranges for the data collected in 2000 are presented in Table A.1. Table A.2 shows the means, standard deviations, and ranges for data collected in 2001. While the 2001 cattle had a slightly lower mean PRP4P than 2000 cattle (52.45% vs. 52.81%, respectively), they also had a larger standard deviation for PRP4P (2.06% vs. 1.80%, respectively), which should make the trait more predictable in 2001. Overall the mean of CFAT in 2001 was lower than 2000 (0.98 cm vs. 1.11 cm, respectively) and this is consistent with UFAT. However, the standard deviation of CFAT for the 2001 cattle was less than the 2000 cattle (0.33 cm vs. 0.45 cm, respectively). Whereas, UFAT standard deviation was slightly larger in 2001 cattle than 2000 cattle (0.32 cm vs. 0.30 cm, respectively). Evaluation of CREA and UREA are not as concerning, 2001 data shows a smaller standard deviation for CREA than 2000 data. However, this is consistent with UREA data where 2001 data also has a smaller standard deviation than 2000 data.

Tables A.3 and A.4 report correlations between carcass measures and ultrasound measures in 2000 collected data and 2001 collected data, respectively. Correlations between data collected in 2000 and 2001 are very similar between HCW and SCANWT ($r = 0.91$ and r = 0.96, respectively), CFAT and UFAT (r = 0.69 and r = 0.66, respectively), CREA and UREA (r = 0.56 and r = 0.61, respectively), and MARB and UPFAT (r = 0.54 and r = 0.71, respectively). The only relationship that is weaker in the 2001 data than in 2000 data is fat measurements.

Table A.5 shows prediction equations for PRP4P developed through stepwise regression for ultrasound data from each year of data collection. The 2001 ultrasound data was better able to account for differences in PRP4P than the 2000 ultrasound data was able to do (R^2 = 0.520 vs. R^2 = 0.448, respectively). This is in contrast to the carcass data prediction equations developed through stepwise regression shown in Table A.6. 2001 collected carcass data was considerably poorer at predicting PRP4P than 2000 collected carcass data (R^2 = 0.243 vs. R^2 = 0.404, respectively).

When carcass data is collected in a very controlled manner the capabilities of ultrasound and carcass data to predict PRP4P are very similar (R^2 = 0.448 vs. R^2 = 0.404, respectively). However, when carcass data is collected in a more commercialized manner there is a large discrepancy in ultrasound and carcass data capabilities to predict PRP4P (R^2 = 0.520 vs. R^2 = 0.243, respectively).

Table A.1. Simple statistics for data collected in 2000

Trait	Mean	SD	Minimum	Maximum
Live animal measurements				
SCANWT, kg	551.9	43.3	412.8	657.7
UFAT, cm	1.12	0.30	0.46	2.11
UREA, cm^2	84.8	8.4	67.1	111.6
UPFAT, %	5.08	1.15	2.71	8.29
URFAT, cm	1.08	0.34	0.33	2.00
URDEPTH, cm	9.26	0.77	7.04	11.35
URAREA, cm^2	67.7	10.1	42.6	104.5
COMBOFAT, cm	1.10	0.28	0.47	1.87
Carcass measurements				
HCW, kg	333.3	25.7	249.5	403.3
CFAT, cm	1.11	0.45	0.25	3.56
CREA, cm^2	81.5	9.6	60.6	108.4
CKPH, %	1.95	0.39	1.00	3.50
MARB[a]	5.52	0.99	3.00	8.30
USDAYG	2.74	0.76	1.13	5.33
PRP4P, %	52.81	1.80	48.56	57.65
KGRP, kg	172.1	14.8	133.8	217.9
PFT4P, %	6.76	1.07	3.89	9.00
KGFT, kg	22.0	3.9	10.7	31.0

[a] $Traces^{00}$ = 3.00, $Slight^{00}$ = 4.00, $Small^{00}$ = 5.00, $Modest^{00}$ = 6.00, $Moderate^{00}$ = 7.00

Table A.2. Simple statistics for data collected in 2001

Trait	Mean	SD	Minimum	Maximum
Live animal measurements				
SCANWT, kg	547.9	43.4	430.0	698.5
UFAT, cm	0.96	0.32	0.28	1.96
UREA, cm^2	82.5	7.5	61.3	100.7
UPFAT, %	4.44	1.16	2.24	8.92
URFAT, cm	0.81	0.23	0.33	1.42
URDEPTH, cm	8.36	0.66	6.58	9.91
URAREA, cm^2	64.2	9.0	39.4	90.3
COMBOFAT, cm	0.90	0.26	0.33	1.66
Carcass measurements				
HCW, kg	340.1	28.6	256.7	434.5
CFAT, cm	0.98	0.33	0.25	2.03
CREA, cm^2	82.8	7.2	64.5	102.6
CKPH, %	2.02	0.28	1.50	2.50
MARB[a]	5.21	1.03	3.00	9.20
USDAYG	2.62	0.53	1.20	4.38
PRP4P, %	52.45	2.06	47.10	59.03
KGRP, kg	177.6	16.1	130.6	230.7
PFT4P, %	7.23	1.42	3.68	11.62
KGFT, kg	24.6	5.6	10.9	38.1

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

Table A.3. Simple correlations between live animal and carcass collected traits in 2000

Trait	HCW	CFAT	CREA	CKPH	MARB[a]	USDAYG
SCANWT	0.91***	0.20**	0.03	0.01	0.35***	0.36***
UFAT	0.20**	0.69***	-0.26***	0.18**	0.20**	0.63***
UREA	0.54***	-0.02	0.56***	-0.06	0.02	-0.22***
UPFAT	0.11[†]	0.31***	-0.24***	-0.03	0.54***	0.36***
URFAT	0.07	0.54***	-0.30***	0.14*	0.19**	0.53***
URDEPTH	0.31***	0.21***	-0.13*	-0.12[†]	0.08	0.28***
URAREA	0.19**	-0.08	0.03	-0.15*	-0.00	-0.02
COMBOFAT	0.16*	0.69***	-0.31***	0.18*	0.22***	0.66***

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

[†] $P < 0.10$

* $P < 0.05$

** $P < 0.01$

*** $P < 0.001$

Table A.4. Simple correlations between live animal and carcass collected traits in 2001

Trait	HCW	CFAT	CREA	CKPH	MARB[a]	USDAYG
SCANWT	0.96***	0.21**	0.42***	0.31***	-0.03	0.31***
UFAT	0.16*	0.66***	-0.14*	0.22**	0.40***	0.60***
UREA	0.60***	0.03	0.61***	0.27***	-0.08	-0.09
UPFAT	-0.03	0.33***	-0.21**	0.20**	0.71***	0.35***
URFAT	0.19**	0.48***	-0.21**	0.20**	0.31***	0.54***
URDEPTH	0.32***	0.13†	0.27***	0.20**	0.16*	0.06
URAREA	0.21**	0.07	0.15*	0.03	0.03	0.05
COMBOFAT	0.18**	0.66***	-0.18**	0.23***	0.41***	0.64***

[a] Traces^{00} = 3.00, Slight^{00} = 4.00, Small^{00} = 5.00, Modest^{00} = 6.00, Moderate^{00} = 7.00

† $P < 0.10$
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Table A.5. Stepwise regression to predict percent retail product

from the four primals from ultrasound data

Order	Trait	Coefficient	P-Value	Partial R^2	Model R^2
2000 Ultrasound Data					
	Intercept	50.781			
1	COMBOFAT	-4.045	<0.001	0.302	0.302
2	UREA	0.0818	<0.001	0.099	0.402
3	SCANWT	-0.00868	<0.001	0.022	0.423
4	URDEPTH	0.350	0.004	0.015	0.438
5	URFAT	1.034	0.042	0.009	0.448
2001 Ultrasound Data					
	Intercept	54.919			
1	COMBOFAT	-5.072	<0.001	0.479	0.479
2	UREA	0.0672	<0.001	0.030	0.509
3	SCANWT	-0.00630	0.024	0.012	0.520

Table A.6. Stepwise regression to predict percent retail product from the four primals from carcass data

Order	Trait	Coefficient	P-Value	Partial R^2	Model R^2
2000 Carcass Data					
	Intercept	51.266			
1	CFAT	-1.272	<0.001	0.220	0.220
2	CREA	0.0656	<0.001	0.119	0.339
3	CKPH	-1.223	<0.001	0.065	0.404
2001 Carcass Data					
	Intercept	54.040			
1	CFAT	-1.999	<0.001	0.154	0.154
2	CKPH	-1.981	<0.001	0.056	0.211
3	CREA	0.0529	0.003	0.033	0.243

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