

Use of ultrasound technology in the genetic improvement of U.S. lamb composition

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ABSTRACT

Ultrasound technology allows *in vivo* estimation of carcass composition. Successful genetic evaluation of ultrasonic measures depends upon technician certification guidelines and a viable common-endpoint adjustment strategy for field data.

Four technicians and three image interpreters ultrasonically evaluated 172 lambs to determine accuracy and repeatability of loin eye area (LEA), backfat thickness (BF), and body wall thickness (BW) estimations. Correlations between ultrasonic and carcass measurements were 0.66, 0.78, and 0.73 for LEA, BF, and BW, respectively.

Performance was similar among technicians and interpreters. Mean bias ranged from -1.30 to -2.66 cm², -0.12 to -0.17 cm, and 0.14 to -0.03 cm, for LEA, BF, and BW, respectively; prediction standard errors ranged from 1.86 to 2.22 cm², 0.12 to 0.14 cm, and 0.35 to 0.38 cm, respectively. Repeatability standard errors ranged from 1.61 to 2.45 cm², 0.07 to 0.11 cm, and 0.36 to 0.42 cm for LEA, BF, and BW, respectively.

Changes in ultrasonic measurements were evaluated using seven serial scans on 24 growing Suffolk ram lambs. All equations had similar goodness of fit. Equations were tested on other populations, including similarly-managed rams across breeds and years and ewe lambs fed for slower gain. Correlations between predicted and actual measures ranged from 0.78 to 0.87 for BF and 0.66 to 0.93 for LEA in winter-born rams, were only slightly lower in fall-born rams, and ranged from 0.72 to 0.74 for BF and 0.54 to 0.76 for LEA in ewe lambs. Of the equations tested, linear and allometric forms appear best for general use.

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GENERAL INTRODUCTION

Consumption of lamb meat has steadily declined over the past 40 years and has reached critically low levels in the United States. Increased concern for the health aspects of red meat has led modern consumers to demand products with a higher ratio of lean:fat. The U.S. lamb industry in particular is failing to meet these demands.

Unfulfilled consumer demand for a leaner product affects all segments of the industry, yet some segments hold more potential than others in offering a real solution. In general, the lean content of a carcass or of its component retail cuts can be improved by decreasing fat and/or increasing muscle. However, fat removal by trimming at the retail level is inefficient and costly. Improvements in portion size of muscle cuts are easily accomplished by increasing carcass weight, but modern feed costs dictate that increasing carcass weight simply by feeding lambs to heavier live weights is no longer as viable a solution. Body composition can be influenced by nutritional regime (as well as genetic makeup), yet livestock nutrition has advanced to the point that most animals can at least approach their genetic potential for lean growth. If genetic potential of the animal is the limiting factor, it follows logically that consumer demand for leaner meat should be met by genetic selection for improved carcass composition.

Prediction of post-fabrication lean yield using measurements taken on whole carcasses is well-documented in the meat science literature. Predictive equations developed in the meats area can assist the preceding livestock sector in identifying indicator traits that are best measured and selected upon for genetic improvement of composition. However, there is presently no large-scale genetic evaluation of lamb carcass traits in the U.S.

Limitations exist for genetic evaluation and improvement of carcass traits. Collecting actual postmortem carcass measurements on animals intended for reproduction presents an obvious biological incongruity. Collection of carcass data on progeny and relatives of breeding animals is expensive, and it is difficult for the packer to incorporate such record-keeping into modern high-speed production lines. The use of ultrasound technology that allows carcass traits to be estimated in live animals holds promise to overcome these limitations. However, at present, the accuracy and consistency

of ultrasonic measures in predicting carcass measures and eventual carcass yield is not well-established for U.S. lambs. Also, not all carcass measures used in lean yield equations are commonly estimated by *in vivo* ultrasound, whether limited physically or by tradition.

In order for ultrasonic scan data to be useful for genetic evaluation, the data must be adjusted to a common endpoint. Adjustment of ultrasonic measures requires knowledge of animal growth and development, which is generally considered across either age or weight. Within the U.S. sheep population, little research has been done to describe the growth patterns of scan measures or to develop strategies for their adjustment. Identification of *in vivo* measures and the general descriptions of growth that have been developed for sheep in other countries provide valuable information, but it should not be assumed that this research will automatically apply to U.S. lambs because of considerable differences in body size and management systems.

Finally, genetic evaluation of carcass traits in the form of ultrasound EPDs requires estimates of the phenotypic and genetic parameters for the traits of interest. These parameters also are not well-studied in U.S. sheep, partly because current population size and structure would limit their reliability.

Therefore, the objectives of this research were to: 1) Assess both the accuracy and consistency of *in vivo* ultrasonic measures in predicting the analogous carcass measurements, 2) describe the longitudinal changes in ultrasonic measures of body composition during lamb growth and develop common-endpoint adjustment strategies for lamb scan data, and 3) using estimates of the phenotypic and genetic parameters from the global literature, develop and introduce to the U.S. National Sheep Improvement Program EPDs for ultrasonically-derived indicators of carcass composition in sheep.

LITERATURE REVIEW

Industry trends and consumer demand

The United States lamb industry faces a fundamental problem: consumption of lamb meat is declining (Schroeder et al., 2001; Stanford et al., 1998). This is not recent news; decreased consumer demand for lamb meat has been a continual theme in the literature for decades (Waldron, 2002; Bradford, 1967). Purcell (1998) describes demand as a complex interaction of consumption and price that is often misunderstood, and he cautions against drawing inferences from only one of the two. However, the industry has also experienced dramatic decreases in live price simultaneous with decreased consumption (Beermann et al., 1995). Meanwhile, production costs are sharply increasing, creating new challenges for all industry sectors. The problem is real.

Any logical solution to the problem of decreased demand begins with a concerted effort on the part of the U.S. lamb industry to better meet consumers' needs. Today's consumer is increasingly health-conscious and is concerned with the dietary aspects of red meat. In addition to requiring products with more lean and less fat, the modern consumer desires acceptable palatability, consistent quality, and high relative value for money spent (Ward et al., 1995). Per capita lamb consumption is responsive to lamb price; increases in price are likely to cause per capita consumption to decrease by a comparable percentage (Schroeder et al., 2001). In short, consumer buying decisions are influenced both by product quality and price.

Increased portion size of muscle cuts and decreased fatness are two factors that could increase consumer acceptance of lamb (Jeremiah et al., 1993). By definition, both factors would likely be addressed by an improvement in lamb composition. The financial waste from market animals with excess fat causes significant losses to allied industries (Wilson, 1992), and economic inefficiencies in production add to the price of the end product. Thus, an improvement of composition holds potential to increase demand both by improving product quality and decreasing price.

The importance of composition on lamb demand is likewise long-documented and is presented in several reviews (Bradford, 1967; Stanford et al., 1998). Unfortunately, despite the volume of literature, the U.S. lamb industry has made relatively little progress toward improving the composition of the slaughter lamb population (Beermann et al., 1995). For the better part of the past decade, the U.S. literature has been devoid of a comprehensive review of lamb composition, indicating the issue has either fallen from academic favor or shifted to more specific focuses. The U.S. lamb industry must more efficiently address the concerns of the modern consumer if it wishes to remain competitive with imported lamb and other protein sources (Beermann et al., 1995). Failure to do so could well result in the total demise of the industry.

There is no guarantee that improvement in composition will immediately, if ever, remedy the problem of decreased lamb demand. Other factors that clearly influence demand, including consumer income and lifestyles, are difficult for the industry to control (Schroeder et al., 2001). Secondly, a widespread initiative on part of industry breeders to improve composition must be preceded or at least be closely followed by an economic incentive to do so, which, to date, has not been strong enough to effect change (Waldron, 2002; Wilson, 1992).

Lamb Carcass Indicators and Attributes

Introduction

Lambs that can satisfy consumer preferences and also be profitable for the packer must yield a high percentage of closely-trimmed retail cuts. To estimate this attribute, U.S. lamb carcasses are assigned a USDA yield grade, which is calculated based on the amount of external fat present on the carcass (USDA, 1992). Increased fatness corresponds with a greater numeric yield grade and is indicative of a lesser percentage of product expected to be derived from the carcass. Yield defined as such is synonymous with “lean content” and “cutability,” and is driven by live body composition. Chemical composition of meat (extractable lipid and/or protein) is the most precise measure of composition and, as such, is most valuable for research investigating consumer health

aspects of meat. Composition can also be defined by the amounts or proportions of lean and/or fat tissue as determined by carcass dissection. However, composition is most commonly studied in terms of the amount of wholesale or retail product yielded from uniform fabrication procedures, due to its lower measurement cost and its economic implications for a wider range of industry sectors.

In meat science literature, carcass “quality” is evaluated separately from yield and refers to the characteristics of lean that influence palatability (USDA, 1992), specifically in the form of tenderness, juiciness, and flavor. However, most reports that seek to stimulate demand for lamb by improving “product quality” are actually focused on improving the lean composition of lamb meat. In a fundamental paper titled: “Genetic and economic aspects of selecting for lamb carcass quality,” Bradford (1967) defines quality as “percent of lean meat, especially in the preferred cuts, and having desirable eating quality.” Despite conflicting nomenclature, improving composition of lambs is one strategy to provide products that are of a quality more acceptable to the consumer.

Although consumer demand calls for cuts with less fat, extremes in leanness are associated with decreased palatability (Ward et al., 1995), which could even further decrease consumer acceptance of lamb. The objective of improving carcass composition must therefore not focus solely on increasing muscle or decreasing fat but rather on changing the two simultaneously, maintaining the minimal amount of fat necessary to retain juiciness and flavor. This approach may be implied but has not always been explicitly stated in literature calling for leaner composition.

The improvement of any trait is largely dependent on its ability to be measured. Records of actual carcass cutability are objective and measurable, but because they require complete carcass fabrication and detailed record-keeping, they are difficult to obtain under current industry infrastructure, especially in any substantial quantity. Meat scientists have therefore sought to identify measurements that can be taken on whole, non-fabricated carcasses and that are indicative of the eventual carcass yield of uniform, closely-trimmed retail cuts. Predicted yield equations using relatively easily-obtained whole carcass measures have been commonplace in the literature and meat industry for over a half century.

Literature Overview

Lamb carcass composition saw particularly heavy research focus from U.S scientists in the 1960s (Hoke, 1961; Field et al., 1963; Judge and Martin, 1963; Carpenter et al., 1964; Spurlock & Bradford, 1965; Judge et al., 1966; Johnston et al., 1967; Cunningham et al., 1967; Oliver et al., 1967; Oliver et al., 1968; Field and Riley, 1968; Carpenter et al., 1969; USDA, 1969). During this time, emphasis was mostly on the relationship between carcass traits. The need for cutability estimates that were measurable in live animals was frequently suggested (Bradford, 1967).

Since that time, few studies have focused on identifying indicator traits for lamb carcass cutability. Instead, current meat science literature explores the various technologies available to measure these known indicators more efficiently. Electromagnetic scanning (Berg et al., 1994), video image analysis (Stanford et al., 1998; Horgan et al., 1995), bioelectrical impedance (Berg and Marchello, 1994; Slinger et al., 1994; Jenkins et al., 1988; Cosgrove et al., 1988), and optical grading probes (Hopkins et al., 1995; Garrett et al., 1992; Jones et al., 1992; Cabassi, 1990) have been investigated most commonly. The primary objective of such technology is to allow non-invasive carcass evaluation at the rapid chain speed of modern packing plants (Stanford et al., 1998). While further study is merited on available technology allowing greater efficiency in production lines, this report will instead focus on traditionally-obtained carcass measures and the predicted yield equations derived from them, particularly as they relate to live animal measures.

Indicators of Carcass Lean Yield

A wide variety of lean yield indicator traits have been investigated in a substantially diverse range of lamb populations. Carcass traits differ considerably in their ability to predict lean yield. Intuitively, the indicator trait exhibiting the greatest degree of variability among carcasses should have the most profound effect on variation in cutability (Smith et al., 1969). Variation in indicator traits is often confounded within other differences between lambs, however. Factors including breed (Snowder et al., 1994; Leymaster and Jenkins, 1993; Makarechian et al., 1978), sex (Carpenter et al., 1969), and nutrition (Cassard et al., 1969) have been clearly shown to affect composition, and, in

diverse populations, often have greater influence on cutability than any carcass measurement. The practical value of predictive yield equations using carcass indicator traits is thus somewhat dependent on their applicability to animals or carcasses that differ in breed, sex, or nutrition (Hedrick, 1983).

Because of implications for the producer and packer, the relationship of carcass indicator traits with USDA carcass grades may be as economically important as their effect on cutability. Carcass grades are an effort to standardize evaluation of carcasses and facilitate marketing of uniform product; if pricing for U.S. lamb carcasses becomes more value-based, it is likely price grids will utilize USDA yield and quality grades as is common in the beef industry (Berg et al., 1997). Such value-based marketing approaches have already been proposed (Umberger, 1994), but have not yet become commonplace in the U.S. lamb industry.

Subjective methods

In production lines with emphasis on speed and minimal expense, subjective methods of estimating cutability, and particularly fatness, are common. Subjective evaluation methods are more useful for diverse lamb populations than for uniform ones (Stanford et al., 1998), but even in populations with wide variations in breed, age, and size, subjective measures alone are only marginal predictors of composition.

There is considerable tradition and tendency in the selection of breeding sheep, live slaughter lambs, and lamb carcasses to use subjective visual measures of shape, or conformation, as an indicator of meatiness (Nsoso et al., 2000). Subjective measurements of conformation are of minimal value in predicting cutability (Hopkins et al., 1995), but conformation has important production and marketing implications because aesthetics play a major role in livestock selection and pricing (Hedrick, 1983). Attempts to objectively express conformation in terms of carcass weight relative to length (Tatum et al., 1998; Abdullah et al., 1998; Hopkins et al., 1997; Kempster et al., 1982) have not improved relationship to meat yield over subjective conformation scores (Nsoso et al., 2000). As reviewed by Stanford et al. (1998), Kempster et al. (1976) showed conformation score to be a marginal indicator of lean meat percent yield ($R^2 < 0.20$, $RSD = 3.57$). Jones et al. (1993) showed the best equation for predicting saleable meat yield

($R^2 = 0.61$, RSD = 1.71%) included “grade rule” measurement and a subjective conformation score, but the removal of subjective conformation from the equation had only a negligible effect ($R^2 = 0.55$, RSD = 1.84%).

The paradox of conformation with respect to lean yield is that scoring systems that reward blockiness inadvertently result in selection for greater levels of fatness (Hedrick, 1983; Kempster et al., 1981; Spurlock et al., 1966), as lamb carcasses with desired conformation are generally fatter than those with poor conformation (Stanford et al., 1998). Because of the correlated effect on fatness, Smith, Carpenter, and King (1969) showed conformation scores were positively associated with trimmed retail product weight but negatively associated with trimmed product percentage.

USDA grading standards removed leg conformation score from yield grade specifications and currently carcass conformation score is only included in calculating quality grade (USDA, 1992). The importance of conformation score in predicting lean yield appears limited to light lambs (Smith and Carpenter, 1973), or to groups with multiple breed types represented, especially those including exceptionally heavy-muscled breeds such as the Texel (Hopkins et al., 1995b).

Carcass Weight and related calculations

When carcass lean yield is reported in terms of product weight, carcass weight is its single best predictor (Oliver et al., 1968). Smith et al. (1969) reported no success in predicting product weight if carcass weight was not included as an independent variable. Simple correlation coefficients between carcass weight and lean cut weight are high, at 0.94 (Smith et al., 1969) and 0.92 (Berg et al., 1997). Carcass weights are expected to be heavier for older lambs, and increases in weight are commonly achieved by extending the time on feed. However, because carcass fatness is also expected to increase with age (Beermann et al., 1995), heavier carcasses are often substantially fatter (Southam and Field, 1969) and thus the correlation of weight to percentage lean is usually negative and less strong, ranging from -0.42 (Smith et al., 1969) to -0.17 (Berg et al., 1997).

Because of the relative importance of carcass weight, one strategy to assess the importance of other measures is to adjust these measures to a common carcass weight, but few studies have reported partial correlation coefficients (after removing the effect of

carcass weight) between carcass measures and carcass yield. This strategy also has limitations. When carcass yield attributes are recorded in percentages rather than weights, carcass weight is expectedly less important. One such study by Hodge and Oddie (1984) showed that the carcass traits with the highest simple correlations to percentage fat trim (fat depth) and percentage boneless meat (kidney and channel fat) also remained the most important when reported in terms of partial correlations.

Carcass weights are easily obtained and play a major role in current lamb pricing (Stanford et al., 1998). Equations including carcass weight as the sole predictor of either percentage lean yield (RSD = 4.72%; Harrington and Kempster, 1989) or percentage carcass fat (RSD = 3.53%; Kirton et al., 1984) were significantly improved by the addition of a single fatness measure (RSD = 2.75% and 2.16 to 2.78%, respectively). Although carcass weight is seldom used by itself to predict composition, it plays an important role in most two-parameter prediction equations.

Dressing percentage (DP), a calculation relating carcass weight to live weight, has been the focus of some research attention due to its high economic importance under current U.S. lamb pricing structures. Because lamb carcass value is generally a simple function of carcass weight, a producer concerned with the efficiency of producing heavy carcasses, or a packer buying live fat lambs, benefits from increased dressing percentages. In the absence of an effort to reduce carcass fatness or, at least, delay its onset, it is thus only logical that a system rewarding additional weight without discounts for the correlated decrease in lean composition will, over time, result in larger, heavier, and, correspondingly, fatter lamb carcasses being marketed. Such appears to be the case with the current U.S. lamb industry (Waldron, 2002; Beermann et al., 1995).

With respect to composition, DP has been investigated to some degree as a predictor, but has been shown to have little effect on lean content (Hedrick, 1983). Although an increase in fat content is certainly expected from increased DP, this effect is more accurately predicted with mere carcass weight due to the influence of rumen fill on DP (Stanford et al., 1998). The additional record keeping required to calculate DP further limits its accuracy as a predictor and its applicability to the industry.

Other simply-calculated measurements related to carcass weight, such as specific gravity (Adams et al., 1970; Rouse et al., 1970) have mostly been abandoned due to the

difficulty in obtainment, the lack of improved predictive ability over mere carcass weight, and the advent of better technology to estimate composition.

Backfat

Fatness is the single most important factor in determining carcass percentage yield (Smith and Carpenter, 1973), largely because it is the most variable (Hedrick, 1983). From a research perspective, subcutaneous backfat thickness (BF) is the most practically-obtained carcass fatness measurement. In the U.S., BF is generally measured between the 12th and 13th ribs in lambs at the interface of the wholesale rack and loin. Strong negative correlations of -0.84 to -0.86 between subcutaneous fat and percentage lean cuts were reported by Smith et al. (1969) and reinforced by more recent studies (Garrett et al., 1992; Berg et al., 1997). Backfat thickness is more highly correlated with percentage lean yield than with product weight (Berg et al., 1997; Leeds et al., 2007). At the high chain speeds of commercial packing plants, if modern automated technology is not available, BF is generally estimated in intact carcasses rather than measured in ribbed carcasses. Although the methods used to measure BF for research studies are different than for industry applications, it is an important predictive measure in either case.

External fat can be removed during fabrication to enhance consumer acceptance of resulting retail cuts. However, external fat is also associated with internal seam fat, particularly between muscles of the shoulder and rack. Added intermuscular fat requires innovative fabrication beyond typical wholesale and/or retail cuts, a process that produces costly waste and invokes added labor time and expense (Garrett et al., 1992). Even after carcasses are trimmed to uniform external fat thickness, differences in seam fat remain visible to the consumer, and excesses in seam fat are only accentuated by the removal of subcutaneous fat. Garrett et al. (1992) reported 15.26% seam fat in rib chops fabricated from boneless racks from yield grade 4 carcasses, compared to 10.59% for yield grade 2.

Currently, backfat thickness is the sole factor for current USDA lamb carcass yield grades, after kidney and pelvic fat is removed so as to not exceed 1.0 % (USDA, 1992). When cutability is estimated in lambs within narrow ranges of subcutaneous fatness, other factors become important for accurate prediction of yield, including *longissimus* muscle area, carcass weight, and KPH fat (Smith and Carpenter, 1973).

Internal fat

Internal fat content is a significant component of overall fatness, and, as such, is another important determinant of carcass cutability. Garrett et al. (1992) showed kidney and pelvic fat to be more strongly correlated to percent lean ($r = -0.69$) than adjusted backfat thickness ($r = -0.54$), loin eye area ($r = 0.27$), or leg conformation score ($r = 0.27$). As reported by Ramsey et al. (1991), kidney and pelvic fat weight and percentage were more highly correlated with percentage carcass fat ($r = 0.81$ and 0.78) and protein ($r = -0.76$ and -0.74) than backfat thickness ($r = .72$ with fat and -0.67 with protein). Hodge and Oddie (1984) found that an equation including carcass weight and percent kidney and channel fat was more accurate than one containing carcass weight and fat depth in predicting lean cut yield (RSD 2.87 vs. 2.96) or boneless meat (RSD 3.17 vs. 3.33), and accordingly recommended that Australian lamb be classified for pricing based on carcass weight and internal fat. The authors asserted that objective measurement of internal fat would require lamb carcasses to be weighed twice, before and after its removal, but would be less difficult and expensive than obtaining objective measures of backfat thickness with minimal technology (Hodge and Oddie, 1984).

While these studies have shown internal fat to be as or more important than backfat in predicting cutability, the relative importance of internal fat is substantially less for USDA-graded lamb carcasses because, as per current USDA specifications, “carcasses cannot have more than 1.0 percent of their weight in kidney and pelvic fat to be eligible for grading” (USDA, 1992). The removal of excess internal fat prior to grading greatly reduces the variation in internal fat content among chilled carcasses, thus exaggerating the relative importance of backfat for predicting percentage yield of lean retail cuts from graded carcasses. To some degree, current U.S. lamb industry practices negate the findings on internal fat from studies done prior to 1992; however, excess internal fat still creates waste and economic losses for allied industries, and these effects on the price of the end product should not be overlooked.

In the context of this report, the most critical limitation for internal fat as an indicator of lean yield is its difficulty to be estimated *in vivo*.

Body wall thickness

A measure of fatness at a point 2 inches lateral to the outer edge of the *longissimus dorsi* was proposed by Carpenter et al. (1964) and later termed body wall thickness. Body wall thickness (BWT) was shown to have similar relationship to percentage fat trim as compared to traditional 12th rib fat thickness ($r = 0.78$ vs. 0.81). A subsequent study, in which Carpenter was co-author (Oliver et al., 1968), found BWT to explain a greater proportion of variation in weight of consumer cuts than average fat thickness ($R^2 = 3.51\%$ vs. 0.73%), and, more strikingly, found BWT (coupled with cold carcass weight) produced the best two-parameter model for predicting retail cut weight ($R^2 = 92.75\%$). Smith et al. (1969) reviewed and tested 18 best predictive equations from the 1960s, three of which included a body wall measure. Although inclusion of BWT neither affected the correlation to percentage primal cuts nor was it included in the best equation predicting either product percentage or weight, body wall thickness was part of a predicted equation that was nearly as accurate and did not require ribbing of the carcass. Body wall thickness had high ($r = -0.72$ to -0.86) and significant correlations to percent bone-in primal cuts evaluated within narrow ranges of carcass by Smith and Carpenter (1973) and these correlations were similar to those for total fat ($r = -0.80$ to -0.92) and fat probe ($r = -0.79$ to -0.85), particularly for heavier carcasses more typical to those today. More recently, Tschirhart et al. (2002) showed body wall thickness to be more highly correlated ($r = 0.31$) to percentage primal cuts than adjusted fat thickness ($r = 0.09$), ribeye area ($r = 0.11$), or hot carcass weight ($r = 0.13$). Body wall thickness and ribeye area were included as variables in the two-parameter equation deemed by that study to be optimal for predicting percentage yield.

A measurement very similar to body wall thickness as defined by U.S. scientists is often reported in studies from Australia (Hopkins et al., 1995a; Hopkins et al., 1995b) and New Zealand (Ramsey et al., 1991). A “grade rule” (GR) measurement taken 11 cm from the dorsal midline and reflecting total tissue thickness (both fat and muscle) between the surface of the carcass and the 12th rib (Kirton and Johnson, 1979), was shown by Hopkins et al. (1995a; 1995b) to be the single best predictor of percentage yield. In the best predictive equations relating carcass measures to carcass yield attributes, a GR measurement was included with carcass weight in all but two equations

for estimating weight of carcass components (Hopkins et al., 1995a) and in all models predicting percentage components (Hopkins et al., 1995b). Jones et al. (1993), as cited by Stanford et al. (1998) likewise showed the best equation for predicting saleable meat yield ($R^2 = 0.61$, $RSD = 1.71\%$) included GR and a subjective conformation score, but the removal of subjective conformation from the equation had only a negligible effect ($R^2 = 0.55$, $RSD = 1.84\%$). The GR measurement has been shown to be as (Kirton and Johnson, 1979) or more accurate (Ramsey et al., 1991; Kemp et al., 1970) than backfat thickness for prediction of carcass composition, and GR plays a critical role in determining lamb carcass grades in New Zealand (Stanford et al., 1998).

Current USDA yield grading specifications describe body wall thickness as measured “5 inches (12.7 cm) laterally from the middle of the backbone between the 12th and 13th ribs” (USDA, 1992). Body wall is not used directly in calculation of USDA yield grade, but expected body wall thickness ranges for each yield grade are given as a guide for the adjustment of backfat thickness (USDA, 1992). Because of the vagueness in these guidelines, it is doubtful that body wall thickness is or will be used frequently, and certainly not objectively, in the routine assignment of USDA yield grades.

However, the body wall thickness measure continues to be promising as an indicator of composition. A main advantage of BWT as compared to backfat thickness is its greater magnitude, which should allow BWT to be more accurately measured than BF using tools with similar, limited precision (e.g. interpolating between tenths of an inch on a backfat probe). The comparative value of any carcass trait for predicting composition is described by several well-established principles: 1) The most important factor in the accuracy of any prediction equation is the degree of variation within the traits (Smith and Carpenter, 1973), i.e., the component exhibiting the greatest amount of variability among carcasses should have the most profound effect on cutability (Smith et al., 1969); and 2) Measures of fatness are the most variable carcass measure (Hedrick, 1983), and, as such, are generally the most important factor in determining carcass percentage yield (Smith and Carpenter, 1973).

Therefore, between the two most commonly reported measures of external fatness, the predictive value of body wall thickness as compared to that of the more traditional backfat thickness measure is ultimately dependent on the relative variation in

BWT as compared to BF within the subset of lambs to be evaluated. In the more uniform populations expected to be found at livestock shows (Tschirhart et al., 2002) or when experimental populations are stratified into narrow ranges of fatness or carcass weight (Smith and Carpenter, 1973), body wall thickness appears to be a similarly (Smith and Carpenter, 1973) or more predictive (Tschirhart et al., 2002) measure of composition than backfat. Further analysis of variance for BWT as compared to BF, particularly in lambs with exceptionally heavy carcass weights, would be particularly interesting.

Loin Eye Area

Longissimus dorsi or loin eye area (LEA) is generally a strong indicator of retail product weight ($r = 0.81$) but a weaker indicator of retail product percentage ($r = -0.17$) (Smith et al., 1969) due to its correlation to fatness. Methods of measuring LEA include using a dot grid on ribbed carcasses and tracing the outline of the *longissimus* for determination of its area with a planimeter. Differences between methods of measuring LEA have been shown to be small compared to the effect of cutting error or of bilateral asymmetry (Hedrick, 1983). Smith et al. (1969) report adjustment of LEA to carcass weight improves its ability as a predictor of lean primal cut percentage ($r = 0.42$ vs. -0.17). Smith and Carpenter (1973) showed LEA to be a better indicator of muscling than leg conformation score in carcasses heavier than 50 lb, which are more representative of today's slaughter weights.

Predictive Equations

Carcass composition is a chemical attribute, more feasibly studied as a function of tissue weights and proportions. While total dissection of carcasses gives measurements of its component tissues including muscle, fat, and bone, most studies instead choose to report the yield of saleable wholesale and/or retail cuts due to the more standard fabrication procedures and the additional economic implications. Yield of saleable cuts certainly reflects composition, but discrepancy exists in the literature as to how product yield is reported. Most studies express product yield as a percentage of carcass weight, but some simply report weight of wholesale or retail product (Oliver et al., 1968). Although product weight and percentage lean are related, they are clearly not

synonymous, with simple correlations between the two reported by Smith et al. (1969) being only -0.11. Coefficients of determination (Smith et al., 1969) and correlations (Hedrick, 1983) are reportedly higher for equations predicting lean cut weight than for those predicting percent lean yield, but their applicability to additional populations is often questioned.

The review of ovine carcass cutability by Smith, Carpenter, and King (1969) compared 19 predictive equations derived from the substantial volume of lamb cutability literature of the 1960s. The reported range of correlations for calculated variables to actual percentage of lean primal cuts ranged in magnitude from $r = 0.582$ to 0.902 . The most accurate equations for predicting either weight or percent yield of product weight included carcass weight, internal fat, “total” fat (an average of four fat thickness measurements), and *longissimus dorsi* (LD) area. Equations substituting body wall thickness and visual fat cover score for “total fat” and LD area were nearly as accurate ($R^2 = 0.97$ vs. 0.98) and did not require ribbing of the carcass. In general, all equations using carcass weight plus either measurements or estimates of internal fat and fat thickness to predict product weight or percent had predictive accuracy (R^2) in excess of 80%. The USDA yield grade equation (USDA, 1969) at the time, which included leg conformation score, percentage kidney pelvic and heart fat, and adjusted fat thickness, was upheld as a reliable predictor of the percentage of retail product for the population studied (Smith et al., 1969).

Some concern exists to rely heavily on predictive equations from the 1960s due to changes in animal size and physiological type since that time, but the notion that carcass muscle size is highly predictive of lean weight and that carcass fat thickness is highly predictive of percentage yield remains generally understood. The most comprehensive, recent U.S. work relating lamb carcass measures to composition was published by Berg et al. (1997). Reported correlations for LEA and BF with weight of boneless, closely-trimmed primal cuts were 0.79 and 0.39, respectively. These same predictors had correlations to percentage carcass yield of 0.29 and -0.50, respectively.

Correlation coefficients for predictive equations are expectedly higher when those equations are obtained from populations of greater variability (Hedrick, 1983). Early studies sought diverse populations to establish general principles in growth and

development. More current research has focused on more specific contemporary groups with respect to breed, sex, physiological maturity, and nutritional regime. It is certainly necessary, but with caution, that predictive equations are applied outside the populations from which they were derived (Hedrick, 1983).

Even with established indicator traits and predictive equations of the utmost reliability, use of actual carcass data for genetic evaluation is limited by the number of animals on which information is available, i.e. only those harvested. At best, this includes only progeny and siblings of the breeding animals actually responsible for genetic improvement. This limitation provides a solid and obvious case for the need of predictors of carcass composition that can be measured in live animals, which has been recognized for decades (Bradford, 1967).

Validation of *in vivo* Predictors of Lamb Carcass Composition

Modern technological advances mean more options now exist for measurement of indicators of carcass composition, with varying degrees of accuracy and cost. Not all methods currently available, however, are practical for use in the current U.S. lamb industry. Methods that offer the most precision and accuracy and are ideal for research purposes often have unjustifiable costs or labor requirements for application to breeding stock selection or evaluation of market readiness (Stanford et al., 1998). Incorporation of more precise but yet more expensive technology in the evaluation of elite breeding stock, such as the use of CT scanning in UK Suffolks (Simm et al., 2002) requires a more organized infrastructure and a higher premium paid for superior seedstock than is currently available in the U.S.

In order for any *in vivo* estimate of carcass composition to be widely useful for the industry, it must also improve significantly upon the predictive ability that is easily achieved using merely live weights (Houghton and Turlington, 1992; Wilson, 1992), linear measurements (Edwards et al., 1989), or subjective visual measures (Houghton and Turlington, 1992; Stanford et al., 1998). Analogous to carcass weight in the context of carcass predictors, live weight is often the standard to which other *in vivo* predictors of

body composition are compared (Simm, 1992). Generally, live weight is highly predictive of lean weight. In literature reviewed by Stanford et al. (1998), live weight accounted for 73% to 83% of the variation in lean weight (kg). Ability of live weight to predict lean weight was improved only marginally by the addition of other *in vivo* predictors, measured by ultrasound ($R^2 = 0.74$ vs. 0.73 ; Jones et al., 1982) or x-ray CT ($R^2 = 0.92$ vs. 0.83 ; Sehested, 1984). However, live weight was a poorer predictor of percent lean meat yield ($R^2 = 0.14$ to 0.15), and its usefulness in predicting body composition was greatly affected by the lambs' stage of maturity. Generally, live weight is limited in its ability to predict body composition because of the wide range of variables that influence the rate of fattening in animals (Wilson, 1992). When estimating percent carcass lean in lambs of similar age and breed, predictive values for live weight improved from $R^2 = 0.14$ to 0.15 to $R^2 = 0.51$ to 0.76 (Stanford et al., 1998), but true slaughter lamb populations are seldom so homogenous.

Ultrasound

The use of ultrasonics as a nondestructive and humane means of measuring fat and muscle in live animals was first described by Wild in 1950 (Hedrick, 1983; Houghton and Turlington, 1992). Ultrasound equipment generates high-frequency sound waves which travel into the body and are reflected from boundaries between tissues of differing densities (Houghton and Turlington, 1992). Quantities of muscle and fat are determined by measuring the echoes rebounding from these tissues. Among the most common ultrasonically measured carcass traits are backfat thickness and *longissimus* muscle (loin eye) size. These measurements are typically taken at the 12th and 13th rib interface, which is the point where carcasses are ribbed to separate the wholesale rack and loin in accordance with USDA specifications.

Two forms of ultrasound equipment exist: amplitude (A-mode) machines, which measure echo amplitude against time and determine differences in tissues by the distance between echoes, and brightness (B-mode) or real-time ultrasound, in which differing tissues densities are determined by echo intensities that are reported as gray scales on a two-dimensional screen (Stanford et al., 1998). A-mode ultrasound has been available

since the 1950s; B-mode machines were developed in the early 1980s (Stanford et al., 1998), and most studies done since that time have utilized B-mode ultrasound.

Although other technologies such as x-ray computed tomography (Jopson et al., 1995), nuclear magnetic resonance (Simm, 1992), velocity of ultrasound (Fisher, 1997), and electromagnetic scanning (Wishmeyer et al., 1996) are now available with greater measurement precision and accuracy, real-time ultrasound appears most feasible from a standpoint of cost and portability (Macfarlane et al., 2006; Stanford et al., 1998) for immediate use by the U.S. lamb industry to improve composition.

Relationship between ultrasound and carcass indicator traits

The number of successful early studies using carcass measures to predict composition (Smith, et al., 1969) and the identified strong need for *in vivo* estimates of composition for genetic improvement purposes (Bradford, 1967) formed the basis from which a stepwise study of *in vivo* prediction of composition could proceed. Accordingly, a majority of studies investigating ultrasound as a means of predicting composition in live lambs have focused on the correlations between ultrasound measurements and their analogous carcass measures.

The review of early studies by Houghton and Turlington (1992) reports the range of published correlations between ultrasound measures and their equivalent carcass measure to be 0.42 to 0.95 for fat measures and 0.36 to 0.79 for muscle measures. More recently reported correlations are generally higher and less variable. Reported correlations between ultrasound fat thickness and carcass backfat include: 0.72 (Sahin et al., 2008), 0.74 (Fernández et al., 1997), 0.77 (Notter et al., 2004; Hiemke et al., 2004), 0.81 (Leeds et al., 2007), and 0.97 (Silva et al., 2006), although some studies still report correlations as low as 0.31 when lambs are not shorn prior to ultrasound (Teixeira et al., 2006). Fewer studies reported correlations between ultrasound loin muscle area and carcass loin eye area. Those reported included: 0.51 (Notter et al., 2004), 0.70 (Hiemke et al., 2004), 0.75 (Leeds et al., 2007), 0.82 (Sahin et al., 2008), 0.88 (Fernández et al., 1997), and 0.95 (Silva et al., 2006). Studies reporting lower correlations between ultrasound and carcass measures of muscling either measured loin eye depth or did not

use a standoff pad (wave guide) on the ultrasound probe, which matches the contours of the body and minimizes tissue distortion in the dorsal and lateral edges of the image.

Generally, it can be concluded that B-mode ultrasound scans of backfat thickness and loin eye area taken between the 12th and 13th ribs in lambs are a reliable means of estimating the analogous carcass measures. However, in the context of ultrasonic estimates, it is the relationship between live animal measures and end composition that is of true significance; scanning to assess carcass traits such as backfat thickness and loin eye area is merely a “prediction of predictors” (Houghton and Turlington, 1992). In order for ultrasound to be truly reliable as an estimator of composition, its direct relationship with carcass yield data must be studied. It is therefore in the context of their relationship with carcass cut-out data that any additional *in vivo* ultrasonic measures (alternative to BF and LEA) are best evaluated.

Ultrasonic Prediction of Composition

Early studies reported that ultrasound was of little to no use in predicting composition in sheep (Stanford et al., 1998). This conclusion was commonly attributed to the fact that measures of fat and muscle in sheep were less variable and of smaller magnitude than in cattle or hogs (Houghton and Turlington, 1992). However, if limited magnitude and variability are in fact the cause of low predictability, these characteristics are not unique to live sheep and would also apply to carcass measurements. Other explanations given for the discouraging reports from early ultrasound studies included the presence of wool and the characteristically soft, mobile external fat layer of lambs compared to other species (Purchas and Beach, 1981). The decreased pelt value resulting of shearing the scan site (Teixeira et al., 2006), as well as the tissue distortion that may result from excessive pressure placed on the transducer (Sahin et al., 2008) have been discussed in many subsequent lamb ultrasound studies.

Despite being of little value in some early studies (Edwards et al., 1989, Leymaster et al., 1985), measurements of fat thickness and *longissimus* muscle area determined ultrasonically in live lambs should have potential to at least approach the analogous carcass measures in their ability to predict carcass lean yield, and studies

reporting similar predictive ability for both methods have existed for nearly as long as B-mode ultrasound (Hedrick, 1983).

Analogous to *ex vivo* predictors of lean yield, the value of ultrasound measures of fatness and muscle size depend upon the way in which the composition is expressed, i.e. whether lean content is reported as a weight or as a percentage of carcass weight. Generally, muscle scans are indicative of tissue weights, and fat scans are indicative of tissue proportions. Some studies, particularly those measuring tissue weights, report partial correlations after adjusting scans to a constant body or carcass weight. Again, the majority of early studies using ultrasound to predict composition showed that the prediction of percentage lean and/or fat after adjustment for body weight was significantly improved by fat scans but not by muscle scans (Wilson, 1992).

Berg et al. (1997) reported that ultrasonic measures of fat thickness and muscle depth had simple correlations with lean tissue percentage of -0.33 and -0.08 (NS), and with lean mass of 0.23 and 0.52, respectively. The same authors in an earlier study (Berg et al., 1996) showed that ultrasonic fat depth was significantly correlated ($P < .01$) to carcass composition when reported in percentages (% boneless, closely trimmed retail cuts, $r = -0.32$; % total dissected lean, $r = -0.50$; and % fat free lean, $r = -0.50$) but not when reported in weights. The same study showed ultrasonic loin eye depth to be significantly correlated ($P < .01$) to carcass composition when reported in weights (total dissected lean weight, $r = 0.40$; fat free lean weight, $r = 0.36$) but not when reported in percentages. Junkuszew and Ringdorfer (2005) showed higher correlations to total % cuts (adjusted for live weight) for ultrasonic fat ($r = 0.72$) than for ultrasonic muscle depth ($r = 0.48$). Coefficients of determination after regression on live weight were higher for ultrasound measurements of both fat and muscle in equations predicting carcass composition when expressed in terms of weight (kg) rather than percentage. Ultrasonic fat depth was superior to muscle depth for predicting composition in percentage ($R^2 = 0.58$ vs. 0.50) whereas ultrasound muscle depth was superior for predicting product weight ($R^2 = 0.67$ vs. 0.62). Generally, much like the analogous carcass measures, ultrasonic fat thickness measures are more useful for predicting percentages of lean or fat, whereas ultrasonic estimates of *longissimus* size are better for predicting lean weights.

In addition to its value in predicting lean yield percentages, ultrasound measurement of 13th rib fat depth has been shown to account for a large part of the total variation in carcass fat weight ($R^2 = 0.82$; Macfarlane et al., 2006), empty body fat weight ($R^2 = 0.904$; Silva et al., 2005), carcass protein ($R^2 = 0.822$; Silva et al., 2005), and carcass energy value ($R^2 = 0.912$; Silva et al., 2005).

In equations predicting weight of wholesale or retail product, live or carcass weight is expected to be the most important and is sometimes (Berg et al., 1996) the only significant variable. However, ultrasonic measurements of fat and muscle have more frequently been shown to add to the predictive ability of live weight. A comprehensive study of U.S. lambs of multiple sire groups (Leeds et al., 2007) reported that body weight alone accounted for 72.9, 70.3, and 69.9% of the variation in roast-ready rack, trimmed loin, and boneless leg weight, respectively, and ultrasound estimates explained an additional 2.3, 4.1 and 5.6 % of variation in these subprimal weights. Both loin muscle area and backfat estimates were included in the best prediction models for loin and leg weights; only ultrasound backfat was added to live weight in best prediction model for rack weight. In a study using ultrasound to predict carcass composition in live Akkaraman lambs in Turkey (Sahin et al., 2008), the addition of ultrasound loin eye area to live weight in a multiple regression equation predicting total carcass muscle (kg) improved the R^2 value by 2% (0.78 to 0.80) and decreased RSD by 4% (0.67 to 0.63). The addition of ultrasound fat depth to live weight in a multiple regression equation predicting total carcass fat (kg) also improved the R^2 value by 2% (0.82 to 0.84) and decreased RSD by 1% (0.25 to 0.24). The addition of ultrasound measures to live weight in equations predicting subcutaneous fat, intermuscular fat, non-carcass fat, and tail fat was not useful. Panting et al. (2000) showed ultrasound ribeye area to be nearly as highly correlated to retail product weight as live weight ($R = 0.82$ vs. 0.88) and the best predictive equation ($R^2 = 0.86$) developed for retail product weight included live weight and ultrasound ribeye area as variables. Neither ultrasound fat thickness nor either carcass measure met the significance level in this study.

Especially because of the volume of literature showing measurements of fatness and muscling to be highly predictive of composition in carcasses (Smith et al., 1969), the low predictive ability of ultrasound reported in early studies, which was most often

attributed to small magnitude and variation of fat and muscle traits in sheep, could instead be the result of unimproved technology or inexperienced technicians. In more recent reports, ultrasound has nearly equaled or even surpassed (Panting et al., 2000) carcass measures in correlation to lean yield. Given the relative lack of precision in tools used for carcass measures, particularly when backfat in hundredths of an inch is interpolated between tenths on a probe or when loin eye area is measured using a dot grid, it is not particularly surprising that ultrasound technology should in time prove to be more accurate. If recent results are in fact due to advanced technology that causes less measurement error, the use of live animal ultrasound measurements, specifically fat depth and loin eye area at the 12th and 13th rib interface, is promising for genetic evaluation of carcass composition.

Alternative ultrasound measurements

Some international discrepancy exists in how *longissimus* muscle size is measured via ultrasound. In carcass studies, loin eye size is generally recorded in terms of area, but when measured ultrasonically, most countries, including the U.K., Australia and New Zealand, report loin eye depth. In contrast to the U.S., these countries quickly adopted ultrasound measurements into selection for improved composition, and ultrasound is now commonplace in their respective genetic evaluation schemes. Although it is more geometrically intuitive that a two-dimensional measure should explain more variation in composition than a one-dimensional measure, early studies reported the opposite. Recently, Leeds et al. (2007) reported that two-dimensional ultrasound loin eye area explained more variation in weight of subprimal cuts than a one-dimensional measurement of loin eye depth ($R^2 = 0.46$ versus 0.39 for trimmed loin and $R^2 = 0.46$ versus 0.40 for roast ready rack) when a transducer of high frequency was used by an experienced technician. It is thus possible that the findings of early studies, which formed the basis for the traditional use of ultrasonic loin eye depth rather than area, may simply have been the result of measurement error associated with earlier technology or technician inexperience. Sahin et al., (2008) reported ultrasonic loin eye area to be more correlated to its analogous carcass measure than ultrasonic loin eye depth ($r = 0.82$ versus 0.60). Hiemke et al., (2004) showed loin width and three loin depths measured with

ultrasound were correlated ($r = 0.25$ to 0.58) to carcass ribeye area, but less so than ultrasonic REA ($r = 0.72$). Silva et al. (2006) compared ultrasound probes of different frequencies and concluded that 7.5 MHz probes were superior to 5 MHz probes in measuring depths of both fat and muscle, but that the opposite was true when comparing estimates of loin eye area. Clearly, more studies are warranted on this discrepancy.

Some measures found to be predictive of composition in carcasses are not commonly measured with ultrasound. Although some measurements such as internal fat or leg conformation are not possible to measure ultrasonically, others, such as body wall thickness, potentially are. No U.S. literature reporting the use of ultrasound-derived body wall thickness to estimate composition in lambs was found, but in New Zealand, ultrasonic estimation of GR, a similar measurement of total tissue thickness over the 12th rib 11cm from the dorsal midline, was shown to account for 64 and 49% of the variation in percentage carcass fat and protein, respectively, and was highly correlated ($r = 0.87$) to its analogous carcass measure (Ramsey et al., 1991). Due to the relatively high predictive value that BWT (Tschirhart et al., 2002) or GR (Hopkins et al., 1995a; Hopkins et al., 1995b; Ramsey et al., 1991) has shown in carcass studies, its measurement *in vivo* using ultrasound may merit further investigation. With respect to genetic improvement of composition, an *in vivo* measure of subcutaneous fat with greater magnitude and/or variability than backfat could potentially allow selection decisions to be made earlier, in younger, leaner lambs (Ramsey et al., 1991).

Silva et al. (2006) reported greater correlations between ultrasound and carcass measures when backfat and loin eye size were estimated between the 3rd and 4th lumbar vertebrae rather than at the more commonly measured location between the 12th and 13th thoracic vertebrae. This measurement site could also be an alternative to ultrasound tradition worthy of consideration.

Accuracy of Prediction

Although widely reported in ultrasound studies, simple correlation coefficients are limited as a true measure of predictive ability because they are influenced by the amount of variation present in the scanned population and they do not reflect bias. In addition to simple correlation estimates already reported, Leeds et al. (2007) evaluated estimates of

carcass measures in lambs using other statistics developed for beef (BIF, 2002) and swine (Bates and Christians, 1994), including prediction standard error, repeatability standard error, and total bias. Estimates were 0.14, 0.08 and 0.07 cm, respectively, for ultrasound backfat, and 1.55, 1.31 and -0.004 cm² for ultrasound loin eye area. These estimates are similar to those of Panting et al. (2000), who reported standard errors of prediction ranging from 0.084 to 0.137 cm, and of repeatability ranging from 0.079 to 0.16 cm for ultrasound fat thickness, and standard errors of prediction ranging from 1.74 to 2.69 cm² and of repeatability ranging from 1.07 to 3.25 cm² for ultrasound ribeye area. The only other study found that reported standard errors of prediction in U.S. lambs (Tait et al., 2005) listed SEPs for 12th rib fat thickness ranging from 0.12 to 0.13 cm, and for ribeye area ranging from 1.92 to 2.18 cm², for 3 technicians. Bias reported in this study ranged from -0.03 to 0.13 cm for backfat and from -1.50 to 0.21 cm² for ribeye area.

If U.S. sheep breeders make a concerted effort to improve composition using ultrasound, the need for some sort of technician certification program is paramount. Certification using statistics assessed by the beef and swine industries is logical. In the only study found to date doing so, Tait et al. (2005) proposed the following certification standards for U.S. sheep scan technicians: SEP, SER, and bias ≤ 0.10 in (0.254 cm) with $r \geq 0.60$ for fat thickness, and SEP, SER, and bias ≤ 0.50 in² (3.23 cm²) with $r \geq 0.50$ for loin eye area. Use of ultrasound in sheep will likely be concentrated in the seedstock sector rather than also used to assess market readiness in feedlot animals (as is common in cattle). Accordingly, the ability of a technician to merely rank sheep correctly within contemporary groups, but to do so with high repeatability, is potentially more important than the ability to exactly predict carcass measures. Otherwise, “acceptable” is difficult to define. Further investigation of certification statistics, with more attention given to the degree of variation in scan measures among different lamb populations, is clearly needed.

Apart from the inherent limitations of ultrasound, other inaccuracy in its ability to predict composition could be due to effects of technician (McLaren, et al., 1991), experience (Hiemke et al., 2004), animal, or machine (Silva et al., 2006; Teixeira et al., 2006). Studies of these effects in sheep are limited and highly necessary. The work done to date in cattle and swine would provide an excellent model for the sheep industry to assess the various effects on accuracy of ultrasound.

Growth and Development of Composition Indicators

It is well-established in all domestic farm animals that the rate of fat deposition increases with age or weight (Beermann et al., 1995). It is likewise well-established that increased age or weight corresponds with increased muscle size, although muscle expressed as a proportion of shorn, empty body weight has been shown to be relatively constant at about 30% in sheep (Thonney et al., 1987), excepting only some unique breeds such as the Texel and Soay (Stanford et al., 1998). Generally, as sheep age, body weight, muscle size and fatness all increase. With respect to retail meat yield, weight of product is expected to increase with age due to increases in carcass weight and muscle size, and percentage of product is expected to decrease due to greater amounts of fat relative to lean content, expressed over larger carcass weights in the denominator. In assessing the changes that occur with growth in carcass tissue traits, it is therefore important to differentiate growth patterns assessed in terms of total deposition versus relative deposition.

The serial measurement of actual carcass traits in the same animals presents obvious biological limitations, but some carefully-designed experiments have attempted to describe the sequence and rate of accretion of different tissues using dissection techniques to assess lamb carcass composition at different stages of development. One such study by Rouse et al. (1970) measured the relative differences in muscle, fat, and bone tissue deposition of lambs between feeder (32kg) and slaughter (50kg) weights and concisely summarized several important principles. Growing lambs accrue bone, muscle, and fat tissue in relative order. Bone development (%) occurs at a slower relative rate than the other tissues later in the growth phase growth, lean deposition (%) decreases as lambs increase in weight, and separable fat has the greatest percentage increase over the growth phase, which is disproportionately greater at heavier weights. Separable lean (%) increases more rapidly in the hindsaddle than in the foresaddle, and percentage fat increases more rapidly in the foresaddle, reinforcing the concept that lambs fatten from anterior to posterior. The weight at which the rate of muscle deposition slows is

dependant on skeletal structure, thus the selection of feeder lambs possessing adequate skeletal frame size is important, particularly in determining the stage of maturity at which lean tissue reaches maximum deposition relative to other tissues and the ratio of muscle to bone is optimal. *Longissimus* muscle area and backfat over the midpoint of the *longissimus* were the single best predictors of percentage muscle and fat in the carcass, respectively, and these indicator traits followed similar growth patterns as the attributes.

In an effort to avoid seasonality of lamb prices (Berg et al., 1997) or to produce larger, more consumer-appealing cuts (Stanford et al., 1998) feeders often keep lambs on feed past their ideal market weight and physiological maturity. Unfortunately, these strategies inevitably result in an increase in fatness, which causes a decrease in percent yield (Southam and Field, 1969) and adds cost and inefficiency at the packer level due to increased trimming. Feeding lambs longer also has economic disadvantages at the feedlot level due to reduced feed efficiency and increased overhead, which have become especially disconcerting in the face of rising feed costs.

The genetic evaluation and marketing of lambs based on composition indicator traits requires knowledge of their growth and development. Relatively few studies have been done to assess the direct growth of compositional indicator traits in sheep; most studies assessing growth and final carcass composition have taken a more indirect approach. The rate of growth and the weight at which lambs produced carcasses of certain composition have been shown to be significantly influenced by feeder lamb frame size (Tatum et al., 1998a) and muscularity (Tatum et al., 1998b), and it has been proposed that a feeder lamb grading system utilizing the known interrelationships between frame size, muscularity, finished weight and carcass fatness be developed and implemented as has been the case in the U.S. cattle industry (USDA, 1979). While the use of indirect indicators of eventual composition would have positive ramifications for the feeder lamb industry, the lack of direct studies on the changes to the indicators themselves during growth causes limitations to potential for genetic improvement.

In a substantial study using serial ultrasound scans on a large number of Australian Poll Dorset lambs over a wide range of ages (60 to 360 d), Fischer et al. (2006) reported trends for ultrasonic means over time that correspond with the general principles understood in carcasses. In the study population, weight gain was nearly linear

from 60 until around 180 days, corresponding with the onset of physiological maturity (fattening), and growth slowed for the remainder of the study. Ultrasonic backfat increased throughout the entire study, and sharply increased at around 200 d, corresponding with the slowing of growth. Ultrasonic loin depth increased steadily with age, but decreased after 200 d. While the age at physiological maturity is certainly expected to be different for other breeds of sheep under different management, the concepts of relative tissue accretion rates (measured ultrasonically) revealed in this study (Fischer et al., 2006) should generalize to most other populations.

Although changes in real-time ultrasound measurements of fat (GR) and muscle (loin eye depth) in growing Australian lambs were best explained by linear models (Hopkins et al., 1996), and linear models are presently used for adjustment of scan traits in the beef industry (Rumph et al., 2007), the possibility of non-linear allometric growth patterns for ultrasound scan measurements exists as has been described for direct measures of body tissue components (Notter et al., 1983; Jenkins and Leymaster, 1993).

Rate of lean growth (and improvement thereof) is strongly influenced by the growth rate of body weight, and sheep, when unrestricted by environment (Emmans, 1988), journey along a reasonably predictable growth path toward a final mature weight (Lewis et al., 2002). Particularly if lipid-free weight is used as the measure of mature size, the separate concepts of growth and fatness are more distinguishable, but it is important (and challenging) to discern which factor is more economically important.

In any case, the single most important concept in evaluating composition is the animal's relative stage of maturity (Stanford et al., 1998). If a value is known for anticipated mature size or for the expected point of physiological maturity, growth patterns of carcass traits relative to that expectation are easily available from the literature. However, the purity of theoretical mathematics is often clouded by real world challenges, i.e. the robustness of predictions made from such descriptive equations is questionable for other populations. The sheep species includes many breeds of distinct genetic makeup, and with vastly different degrees of environmental restriction resulting from diverse management approaches. The resulting variation in the relative rates of growth and fattening makes the point at which maturity of these variables occurs difficult to ascertain, and even more difficult to generalize for large populations.

Adjustment endpoints for ultrasound measures

Evaluation of different endpoints for adjustment of carcass data is a common theme in beef literature. Most beef carcass trait adjustments and thus their respective genetic parameters are on an age-constant basis, but alternative endpoints including constant carcass weight, backfat, loin muscle area, or marbling score have been considered (Rios-Utrera, 2004). The major concern with alternative endpoint strategies is whether the choice of endpoint affects genetic parameters for particular traits, thus influencing EPDs calculated using those parameters and the relative ranking of sires. In a study by Rumph et al. (2007), heritabilities for common beef carcass traits, including carcass weight, backfat, loin muscle area, marbling, and percentage retail cuts, did not change, and minimal sire reranking occurred with the differing endpoint strategies, results confirmed with other literature cited. The exception to this generality was for heritability estimates for percentage retail cuts, which were highest when adjusted to a constant fat basis. A possible explanation given for this was the fact that backfat is clearly a component trait of percent retail cuts, thus such an adjustment may alter the trait so as to not truly reflect PRC (Rumph et al., 2007).

The U.S. lamb industry has peculiarities that cause some of the beef industry concerns regarding endpoint adjustment to be less important or inapplicable, including the relative unimportance of marbling in lamb pricing or the relative lack of progeny carcass yield data in U.S. sheep versus beef cattle. However, several principles have emerged from the beef literature that can apply to both species. Age-constant adjustments have their limitations for industry applicability if the choice of harvest time is dependent on other endpoints. Age, however, is an important variable in that a constant-age endpoint reflects tissue growth, an attribute that is important in beef but even more so in lambs under current pricing structures. Additionally, carcass traits to be adjusted and the differing endpoints themselves are not independent, implying that the different choices of adjustment endpoint for a trait of interest may actually alter the trait to represent something other than what it is perceived to be (Rumph et al., 2007). The biological connotation is that selection for traits based on variables adjusted differently can produce different results, some with a more preferable economic outcome.

Implications for Genetic Improvement

The “call to arms” for genetic improvement of lamb carcass composition appeared in U.S. literature over four decades ago (Bradford, 1967). Legitimate concerns were discussed in subsequent literature concerning the implementation of programs for genetic improvement in composition. It was clearly outlined that methods of collecting and analyzing composition data would need to be accurate and cost-effective for the producer (Wilson, 1992) and, if measured *ex vivo*, feasible for the packer, who must incorporate them into modern high-speed production lines (Stanford et al., 1998). Despite a clear outline of the need, the U.S. lamb industry has made relatively little progress in improving the composition of slaughter lambs (Beermann et al., 1995). It is possible that the infrastructure (or lack thereof) of the U.S. lamb industry was simply not conducive to adoption of the necessary programs. Another part of the reason for the slow response by the U.S. sheep industry to address the issue was the relative unavailability of technology to assess composition *in vivo* at the time the problem was first discussed. However, a wide variety of selection tools are now available, and genetic improvement in composition following selection using these tools has been reported in other countries (Simm and Murphy, 1996; Simm et al., 2002; van Heelsum et al., 2003), indicating that the U.S. sheep industry is running out of excuses.

The majority of U.S. studies that have investigated methods of animal breeding for improving composition have used between-breed selection, and compositional differences between sheep breeds are well-documented in the U.S. (Makarechian et al., 1978; Leymaster and Jenkins, 1993; Snowden et al., 1994). However, results of these studies have mostly been adopted at the production level, and potential industry gain from additional between-breed selection studies is therefore limited. In the pyramidal diagrams of industry infrastructure and gene flow described by textbooks, the improved composition of the slaughter lamb population must begin with improvement within pure breeds or composite lines in the elite seedstock sector, and then proceed through the multiplier and commercial sectors. The fact that the improvement of composition should

be addressed by within-breed selection is reinforced by the high heritabilities (Simm et al., 2002) and thus the low levels of heterosis reported for carcass traits.

As implied, the success of genetic improvement relies on a variety of phenotypic and genetic parameters. In addition to heritability, the traits of interest must also have sufficient phenotypic variation to allow discernible differences among animals to be accurately measured. Knowledge of the genetic variation in economically important traits, as well as the genetic covariance between these traits, is vital for effective genetic improvement (Fischer et al., 2006). The populations of interest must also include enough genetic diversity that genetic change, and hopefully genetic improvement, is possible (Wilson, 1992). Wolf (1982) reported heritability estimates of 0.15 to 0.46 for lean cut percentage, but coefficients of variation were generally low for traits of high heritability.

Safari et al. (2005) provides an exhaustive summary of genetic and phenotypic parameter estimates for measured traits in sheep. In a very general sense, heritabilities for carcass weight (0.20), fat depth (0.30 at C site and 0.32 for GR site), and eye muscle area (0.41) were moderate to high when measured in carcasses, and slightly less when measured *in vivo* (0.26 for fat and 0.12 for muscle area). Slightly higher heritabilities were shown for eye muscle depth measured *in vivo* (0.24) than eye muscle area, which may simply be a reflection of the number and scope of studies (11 vs. 3), but nonetheless is interesting. Also of note, coefficients of variation for fat depth measured in carcasses (46.1% for C site and 40.1% for GR site) were substantially higher than for *in vivo* fat depth (20.4%).

Heritability for carcass lean meat yield was 0.35, reinforcing that genetic progress in composition is achievable. Moderate genetic correlations were reported between live weight and ultrasound fat depth (0.36) and muscle depth (0.34) and between fat and muscle depth. (0.33). Phenotypic correlation estimates were similar for live measures. Mean genetic correlations between carcass weight and carcass fat depth (0.39) and muscle depth (0.54) were higher. Wide confidence intervals reported for all estimates are a reflection of the wide range of estimates generally derived from small data sets. These results provide insight for expected correlated responses, as well as a starting point for genetic analysis using BLUP, but also imply that further studies are necessary and that populations vary considerably.

Three other pertinent reports of genetic parameters for carcass traits in sheep were found that were not summarized by Safari et al (2005). Fernandes et al., (2004) reported direct heritability estimates for ultrasound traits from weight-constant analysis of 0.29 for both loin eye depth and backfat thickness, and 0.26 for loin eye width. Genetic correlations were -0.17 between loin depth and backfat thickness, 0.43 between loin depth and loin width, and 0.23 between loin width and backfat thickness. Using age as the alternative covariate increased all estimates, giving direct heritabilities of 0.38 for loin depth, 0.35 for backfat, and 0.30 for loin width, and genetic correlations of 0.29 between loin depth and backfat thickness, 0.61 between loin depth and loin width, and 0.44 between loin width and backfat thickness. Variance and covariance components were also estimated, and this study appears to provide a source of information on sheep very similar to those in the U.S.

Genetic parameters for three common terminal sires breeds in the U.K. were reported by Jones et al. (2004). While much of the study focused on estimates from CT scanning, a technology with greater measurement accuracy but less feasible for adoption by the U.S. lamb industry in the immediate future (Macfarlane et al., 2006), ultrasound measures were also analyzed. For Suffolks, the breed of the three most common in the U.S., heritability estimates included 0.30 for live weight, 0.32 for ultrasonic muscle depth, and 0.35 for ultrasonic fat depth. Genetic correlations with live weight were 0.41 for UMD and 0.42 for UFD. Phenotypic correlations between muscle and fat depth were higher than the genetic correlations (0.31 vs. 0.23).

Slightly lower heritabilities (0.17 for body weight, 0.16 for muscle depth, and 0.08 for fat depth) were reported for Suffolks in the Czech Republic (Maxa et al., 2007). This study is particularly interesting in that the mean body weight (approximately 28 kg) at 100 days was less than is typical for Suffolks at similar age in the U.S. If this is a result of additional environmental restriction in growth, the results of this study may have applicability to management scenarios in the U.S. feeding lambs to achieve lower rates of gain than is typical.

As was previously discussed in the context of common-endpoint adjustment, one of the critical concerns for ultrasonic estimation of carcass traits is the ideal age or weight at which to measure the traits. A similar situation arises for genetic evaluations because

parameters for traits are expected to change with age or weight. Over a 300-day growth period, Fischer et al. (2006) showed heritability estimates for Australian Poll Dorset sheep to range from 0.20 to 0.31 for weights, 0.24 to 0.34 for fat depth, and 0.24 to 0.40 for muscle depth. Although genetic correlations between fat and muscle remained moderate to high (0.5 to 0.7) throughout, genetic correlation between weight and fat and weight and muscle (0.6 to 0.8) declined slightly with age. Genetic correlations between repeated serial measures of both fat and muscle depth declined with age, with a minimum correlation of only 0.31 for fat. It was generally concluded that, in light of these results, specific breeding objectives should target slaughter endpoints described as precise weight, muscle, and fat combinations at certain ages (Fischer et al., 2006).

If use of *in vivo* ultrasonic estimates of carcass composition traits becomes a more significant part of the selection process for sheep breeding stock in the U.S., one important consideration that will need to be further and continually addressed is the relationship between scan traits of seedstock (ram) lambs and feedlot wethers. Often potential seedstock lambs and their eventual crossbred progeny are managed in very different environments; an understanding of the dissemination of genetic gain through all sectors of the industry is important to the bottom line. Studies exist in cattle investigating the genetic relationships between indicator traits measured in yearling beef bulls and finished feedlot steers (Bergen et al., 2005) but these questions will also need to be asked and answered for sheep in the U.S. as they have been in the U.K. (Lewis et al., 1996).

The extent to which selection for carcass traits in terminal males affects productivity or value traits in related females must also be considered. A study of economically important traits in Mule wethers in the UK (van Heelsum et al., 2006) showed that selection for improved growth and carcass merit had a nonexistent or positive effect on the subjective type traits used to determine the value of related ewe lambs as breeding animals. It was noted by this study that live slaughter weight in wethers was highly correlated ($r = 0.72$) to live weight at constant age in ewes, a relationship that could have implications for ewe nutritional requirements at maturity.

While a detailed statistical discussion is outside the scope of this paper, a concern for the genetic evaluation of carcass traits that is also worth mentioning is the possibility for non-normality in carcass measurements. Carcass traits are sometimes transformed

(log-transformations are most common) to conform to normality assumptions of BLUP theory and thus avoid bias in genetic parameter estimation. Van Heelsum et al. (2001) concluded that only ultrasonic fat depth showed enough non-normality to merit transformation, and that heritability estimates for UFD were slightly reduced (0.43 to 0.30) when calculated on transformed variables. These results are somewhat encouraging with respect to other scan traits, but should be given some consideration when evaluating parameters for or from log-transformed UFD.

The biological relationship between fat and muscle is adequately documented to conclude that selection for increased muscle is likely to correspond with an increase in fat. Because fat-free lean weight requires the removal of fat, selection for weight of product is expected to increase animal size, but will not necessarily improve composition (Greiner, 1997, Bradford, 1967). Accordingly, the biological pursuit of improved carcass composition must focus on increasing muscle and decreasing fat simultaneously, preferably with respective economic weightings that reflect current industry pricing structures. Simm and Dingwall (1989) proposed relative economic values of +3 for lean and -1 for fat, so as to maximize the response for lean, but optimize the balance between responses in both traits. A summary of the response achieved from 9 years of selection on this index in Suffolk sheep showed favorable results (Simm et al., 2002).

Lean weight and fat weight were the selection objectives in the above study (Simm et al., 2002), but live weight was an important criterion. Particularly under current pricing structures, consideration given to the relationship between composition and growth traits is paramount, i.e. growth traits are of high economic importance and should not be ignored in the pursuit of better composition. Carcass weight is of equal or greater importance in determining carcass value than composition; the two selection objectives should therefore be considered together and balanced according to their relative economic values (Waldron, 2002). However, deriving the relative economic values of growth and composition for a pure economic approach is difficult, and these REVs are subject to change with pricing structures and fluctuating input costs. Selection on biological indices incorporating both composition and growth, such as lean tissue growth rate (LTGR) does not require derivation of economic values, but certainly has implied economic value (Bennett, 1992; Simm and Dingwall, 1989). However, because growth

traits are commonly more variable than composition traits, they tend to dominate in biological indices such as LTGR (Simm and Dingwall, 1989). Similarly, Bradford and Spurlock (1972) reported that lean meat production is best improved by selection for weight per day of age. Muscle size or weight is primarily driven by carcass weight, which is in turn driven primarily by live weight (Houghton and Turlington, 1992; Wilson, 1992). The primary concern for growth-dominated selection indices is an adverse effect on conformation, a trait which has been shown to be difficult to change or appropriately weight (Nsoso et al., 2000; Simm and Murphy, 1996; van Heelsum et al., 2003). Additionally, the inclusion of feed intake in the selection goal would have economic importance, but is often overlooked because of the relative unavailability of genetic parameters for feed intake (James, 1986).

Ultimately, genetic improvement in carcass composition requires that seedstock producers be financially rewarded for producing a superior product (Simm and Dingwall, 1989). Consumer surveys clearly indicate preferences for leaner cuts (Waldron, 2002; Stanford et al., 1998), but these preferences must result in either a greater price paid for, or an increase in consumption of, improved product. Currently, the majority of lambs in the U.S. are sold on a live weight basis, with few price incentives for high-cutability sheep and only modest discounts for low-cutability animals (Waldron, 2002; Beermann et al., 1995). If commercial producers and growers do not receive some premium for leaner lamb carcasses (or a discount for fat carcasses), there is little incentive to pay premium prices for leaner seedstock or feeder lambs. In short, some benefit from improvement in composition must exist for all tiers of the industry. If all industry segments are not equally motivated and engaged in a common goal, then an exhaustive analysis of the best methods for improving composition is little more than an exercise in futility.

Even if an incentive for improved composition were in place, not all researchers involved with the U.S. sheep industry are equally optimistic about the genetic improvement strategies discussed in this report. Waldron (2002) states that the difficulty in measuring composition in live animals coupled with the cost of carcass measurements indicate that lean composition in U.S. sheep is unlikely to be changed by traditional quantitative techniques in the absence of a major gene effect. However, because genetic selection for carcass composition has yet to be widely embraced by the U.S. sheep

industry, genetic variation continues to exist, both between and within breeds. Utilization of this variation and the tools now available to select for improved composition in seedstock sheep and slaughter lambs is absolutely essential in attempt to remedy the continually declining market share of the struggling U.S. lamb industry. Perpetuation of the current path casts bleak predictions for the future.

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CHAPTER 1: VALIDATION OF LIVE ANIMAL ULTRASONIC MEASUREMENTS OF BODY COMPOSITION IN MARKET LAMBS

ABSTRACT

One hundred seventy two market lambs were ultrasonically evaluated by four scan technicians and three image interpreters to determine the accuracy of ultrasonic estimates of carcass 12th/13th rib loin eye area (ULEA), backfat thickness (UBF), and body wall thickness (UBW). Lambs were harvested and analogous measurements (CLEA, CBF, and CBW) were recorded on chilled carcasses. Overall correlation coefficients (pooled across technicians and interpreters) between ultrasonic and carcass measures were 0.66 for LEA, 0.78 for BF, and 0.73 for BW. Mean estimation bias for technicians and interpreters ranged from -1.30 to -2.66 cm² for LEA, from -0.12 to -0.17 cm for BF, and from 0.14 to -0.03 cm for BW, with standard errors of prediction ranging from 1.86 to 2.22 cm², 0.12 to 0.14 cm, and 0.35 to 0.38 cm, respectively. Lambs were scanned twice; each technician changed machine magnification settings from 1.5x to 2.0x or vice versa for measurement of ULEA and UBF midway through the second scan. Pooled correlations between repeated measures at the same magnification were 0.67 for ULEA, 0.79 for UBF, and 0.68 for UBW, and 0.73 for ULEA and 0.76 for UBF across different magnification settings. The impact of changing magnification setting on technician and interpreter repeatability was thus negligible for both ULEA and UBF. Repeatability statistics were more variable among technicians and interpreters than accuracy statistics relating ultrasound to carcass measures. Standard errors of repeatability ranged from 1.61 to 2.45 cm² for ULEA, from 0.07 to 0.11 cm for UBF, and from 0.36 to 0.42 cm for UBW. These results indicate that ultrasound scanning can reliably predict carcass measures of LEA and BF in live lambs, and accordingly can be useful in selection programs to improve composition. Measures of ultrasonic body wall thickness require further study. The development of certification standards for U.S. lamb ultrasound technicians based on the results of this study and others is a critical next step.

INTRODUCTION

Improvement of lean composition in U.S. slaughter lambs is one strategy to combat declining demand for lamb meat. Real-time (B-mode) ultrasound technology allows prediction of carcass traits associated with carcass composition in live breeding animals, and thus is promising for use in selection to improve composition. Generally, ultrasound is a reasonably accurate means by which to estimate actual carcass backfat thickness and loin eye area in sheep; the majority of recent studies report correlation coefficients between ultrasonic predictors and actual carcass measures in the range of 0.72 to 0.81 for backfat and 0.75 to 0.88 for loin eye area.

However, correlations are limited as a true measure of accuracy because they are influenced by the amount of variation present in the scanned population and do not reflect bias, the tendency to consistently over or under-estimate the actual carcass measurement. Alternative statistics commonly used by the swine and beef industries, such as total bias and standard error of prediction, have not been widely reported for lambs.

Few studies have sought to specifically describe the effects of technician, machine, or image interpretation on ultrasound accuracy, and even fewer studies have reported the consistency of ultrasonic measurements across repeated scans of the same lambs. Guidelines for both accuracy and repeatability are necessary to develop uniform certification standards for ultrasound technicians. Such standards are critical if large-scale genetic evaluation of lamb composition using ultrasound scanning is to become a reality in the U.S.

Furthermore, while the sites commonly scanned in live lambs were originally chosen to directly correspond with carcass backfat thickness and loin eye area, few studies have been done to evaluate alternative scanning sites in lambs that may potentially be more accurately measured or more indicative of body composition.

This experiment was therefore designed to: 1) determine overall correlations between ultrasonic predictors and actual carcass measurements associated with carcass composition; 2) investigate the accuracy and predictive value of ultrasonically-derived measures of body wall thickness as compared to traditional measures of backfat thickness and loin eye area; 3) assess measurement bias and prediction standard error statistics as

additional indicators of ultrasound accuracy; 4) measure repeatability of technicians and interpreters, both with and without changes in machine magnification settings; and 5) provide a comprehensive ultrasound validation study for use in developing certification standards for lamb ultrasound technicians in the U.S.

MATERIALS AND METHODS

In October 2007, 172 market lambs from the State Fair of Virginia were ultrasonically scanned by four trained technicians. Images indicating loin eye area (ULEA) and backfat thickness (UBF) were captured on the lamb's right side between the 12th and 13th ribs using Aloka 500 ultrasound machines (Corometrics Medical Systems; Wallingford, CT) equipped with 12.5cm, 3.5mHz transducers. Transducers were fitted with a Superflab standoff guide (Mick Radio-Nuclear Instruments, Inc.; Mt. Vernon, NY) to ensure proper contact with the animals. Lambs had been closely sheared and washed for show prior to scanning. Vegetable oil was applied to the area being scanned as a couplant to obtain adequate acoustic contact. When images for each lamb were deemed suitable by the technician, they were captured and recorded to a PC. Each technician chose a machine magnification setting (1.5x or 2.0x) for the initial scans based on personal preference. Two technicians used 1.5x and two used 2.0x. All lambs were scanned once by each technician at their preferred magnification setting. All lambs were then scanned a second time. In order to estimate true technician repeatability, half (n=86) of the lambs were scanned for the second time at the same magnification level used for the first scan. For the remaining half (n=86), technicians changed machine magnification settings from 1.5x to 2.0x, or vice versa.

In addition to ULEA and UBF, two technicians recorded images of body wall thickness (UBW) between the 12th and 13th ribs, which showed the lateral edge of the *longissimus dorsi* (LD). Wave guide standoff pads were removed for measures of UBW, and only the first half of lambs (n=86) were scanned for the second time, at the same magnification settings (one at 1.5x and one at 2.0x) that these two technicians had used for the first scan.

Images were organized into coded subsets and sent to Walter and Associates, LLC, Ames, IA, a centralized ultrasound processing lab, for interpretation. All images were interpreted once to determine ULEA, UBF, or UBW by each of three professional interpreters. The perimeter of the LD was traced to determine ULEA, and UBF was measured at the midpoint of the LD. The UBW was determined by total tissue thickness 6 cm from the lateral edge of the LD. The measurement of UBW was designed to correspond with the carcass measurement as closely as possible, given that images including both the spine and the carcass body wall location were not possible to capture with the 12.5cm transducers used. Measurements for interpretations were calculated with computer software, which was calibrated to reflect changes in magnification settings, and then returned to Virginia Tech for analysis.

Immediately following scanning, all lambs were transported to the Wolverine Packing, Inc. plant in Detroit, MI for harvest. Carcasses measurements were taken on chilled carcasses within three days of scanning. Lambs were ribbed between the 12th and 13th ribs by plant personnel. Carcass weights (CWT) used for analysis were recorded from hot carcass weight tags that had been previously assigned on the production line. Carcass measurements, including backfat thickness (CBF, probed at the midpoint of the LD), loin eye area (CLEA, measured with a dot grid), and body wall thickness (CBW, probed 12.7 cm (5 inches) from the midpoint of the spine) were taken independently on each carcass by two experienced recorders according to USDA yield grade specifications (USDA, 1992). Due to the manner in which the lambs were ribbed, most carcass measurements were taken on the lamb's left side, opposite to the side scanned. Lambs with workmanship errors on the left side were measured on the right side; however, the side that was measured was not recorded. Carcass measurements from the two recorders were not significantly different ($r = 0.91, 0.88, \text{ and } 0.94$ for CBF, CLEA, and CBW, respectively) and were averaged for final analysis.

Data were analyzed using the Statistical Analysis System (SAS). Accuracy statistics were calculated using ultrasound interpretations from the first set of scans and the analogous carcass measures, and included mean bias, standard error of prediction for ultrasound measures (adjusted for bias), and correlation between ultrasonic and actual carcass measurements. Repeatability statistics were calculated separately for lambs

measured twice at the same magnification and for lambs measured at different magnifications, and included mean difference, standard error of repeatability, and the correlation between repeated measurements.

Validation statistics were calculated as

$$\text{Mean bias} = \sum_i(\text{scan}_i - \text{carcass}_i) / n,$$

$$\text{SE of prediction} = [\sum_i(\text{scan}_i - \text{mean bias} - \text{carcass}_i)^2 / (n - 1)]^{1/2}, \text{ and}$$

$$\text{SE of repeatability} = [\sum_i(\text{scan2}_i - \text{scan1}_i)^2 / n]^{1/2},$$

for each technician and interpreter, where scan_i is the ultrasonic measurement on the i^{th} lamb; carcass_i is the carcass measure on the i^{th} lamb, and n is the number of lambs used in the respective calculation.

Any lamb that did not have complete data for all relevant technicians, interpreters, and repetitions was excluded from analysis, resulting in a final dataset of 163 animals for accuracy analysis. For repeatability analysis, any observation missing its corresponding repeated scan was excluded. Data for final analysis included 1015 pairs of observations at the same magnification, and 1012 pairs of observations across magnification settings. Data were analyzed in SAS GLM. For accuracy statistics, each observation was coupled with measured carcass values for that animal, and residual correlations among all traits were calculated using a model that included the effects of technician and interpreter, as well as their interaction. Pooled correlations (across all technicians and interpreters) between repeated measurements on the same lambs were generated using a similar model. In addition, accuracy and repeatability statistics were calculated for each technician and interpreter. Statistics for each technician were calculated from a model that included effects of interpreter and vice versa.

Standard errors of prediction and repeatability were expressed as coefficients of variation (CV) to facilitate comparisons of the accuracies of assessment among different measurements. Coefficients of variation were calculated using carcass least squares means. Only two technicians performed body wall scans. One less-experienced interpreter's measurements of UBW were substantially less correlated to carcass measures than the other two interpreters ($r = 0.55$ versus 0.72 and 0.74) and were excluded from the final analysis.

RESULTS AND DISCUSSION

Means, standard deviations (SD), and coefficients of variation (CV) for ultrasonic estimates of loin eye area (ULEA), backfat thickness (UBF), and body wall thickness (UBW), analogous carcass measures (CLEA, CBF, and CBW, respectively), and carcass weight (CWT) are presented in Table 1.1. Ultrasound means are pooled across four technicians and three interpreters for LEA and BF, and across two technicians and two interpreters for BW. Means for BF and LEA were larger when measured in carcasses. The LEA had greater CV when measured ultrasonically than when measured directly in the carcass, but CBF and CBW had larger CV than UBF and UBW, respectively.

Correlations among ultrasonic and carcass measurements (pooled across technicians and interpreters) are shown in Table 1.2. Correlations between ultrasonic and actual carcass measurements ranged from 0.66 for LEA to 0.73 for BW and 0.78 for BF. All measurements were significantly correlated to carcass weight ($P < 0.0001$). Correlations with CWT were greater for carcass fat measurements (CBF and CBW) than for ultrasonic fat measurements (UBF and UBW; $r = 0.58$ and 0.72 vs. 0.50 and 0.65 , respectively), but CWT had similar correlations with ultrasonic ($r = 0.64$) and carcass ($r = 0.62$) LEA. Correlations between fatness measurements were greater when measured in carcasses ($r = 0.73$ between CBF and CBW) than when measured ultrasonically ($r = 0.58$ between UBF and UBW). Measures of CLEA were nearly independent of measures of backfat (UBF and CBF; $r = 0.06$ and 0.11 , respectively), but were more highly correlated to measures of body wall (UBW and CBW; $r = 0.21$ and 0.30 , respectively). Measures of ULEA were more correlated to backfat (UBF and CBF; $r = 0.25$ and 0.33) and body wall thickness (UBW and CBW; $r = 0.44$ and 0.43) than when measured in carcasses. Although correlations between ultrasound and carcass measurements are merely “predictions of predictors” (Houghton and Turlington, 1992), correlations between either ultrasonic and carcass measurements and actual carcass composition are usually similar (McLaren et al., 1991).

Correlation coefficients between ultrasound and carcass traits for each technician and interpreter are reported in Table 1.3. Correlations for UBW include only two technicians and two interpreters.

Correlation coefficients between ultrasound and carcass loin eye area from the individual technicians in this study (0.62 to 0.73) are somewhat lower than most in recent reports including: 0.70 (Hiemke et al., 2004), 0.75 (Leeds et al., 2007), 0.82 (Sahin et al., 2007), 0.88 (Fernández et al., 1997), and 0.95 (Silva et al., 2006). The high correlation reported by Silva et al. (2006) is particularly interesting due to the amount of tissue distortion visible in the representative images and attributable to the absence of a standoff pad. Each of these studies, with the exception of Leeds et al. (2007), used a transducer of higher frequency than was used in our study (5 to 8mHz vs. 3.5mHz), and this difference could result in greater image quality and perhaps explain the higher correlations. However, since our loin eye correlations are consistently low across all technicians and interpreters, it is possible the measurement error occurred in the cooler. The potential for error resulting from the relative lack of precision of the loin eye grid, improper ribbing of carcasses, or bilateral asymmetry has been of some concern in the carcass literature (Rust et al., 1970). The likelihood of carcass measurement error in our study is supported by the results of other ultrasound studies when our methods are compared. The only other study measuring CLEA with a grid (Notter et al., 2004) reported lower correlations between ULEA and CLEA ($r = 0.51$) than ours. Correlations reported in studies where CLEA was traced on acetate paper and measured with a planimeter (Sahin et al., 2008, Leeds et al., 2007, Fernandez et al., 1997) were higher than in our study. The highest reported correlations between ultrasound and carcass LEA ($r = 0.95$; Silva et al., 2006) measured CLEA using image analysis of digital photographs. Furthermore, the higher correlations between ultrasonic and carcass LEA in the majority of studies were between measures taken on the same side (Sahin et al., 2008, Leeds et al., 2007, Silva et al., 2006, Fernandez et al., 1997), indicating that the discrepancy in our correlations for LEA could be attributed at least in part to bilateral asymmetry. No other study explicitly reported correlations between LEA measures taken on opposite sides.

Correlation coefficients between ultrasound and carcass backfat from this study (0.76 to 0.81) are generally consistent with those reported in recent literature, including:

0.72 (Sahin et al., 2007), 0.74 (Fernández et al., 1997), 0.77 (Notter et al., 2004; Hiemke et al., 2004), and 0.81 (Leeds et al., 2007), although they are lower than the 0.97 BF correlation reported by Silva et al. (2006). The consistent, high correlations for BF reported in our study and others indicate that current protocol for ultrasound BF scanning gives a reasonable prediction of carcass BF. Because of the low mean of BF commonly observed in lambs and the associated limited precision in measurement, it is questionable whether the comparatively high correlations reported for ultrasonic BF are truly due to better protocol, or simply a result of greater variation in BF as compared to LEA.

Although mean body wall thickness is larger than mean BF and therefore is considered to be potentially measured with greater precision, correlation coefficients from this study do not provide conclusive evidence of its value as an alternative ultrasound measure. The CV of body wall thickness was approximately two thirds that of backfat thickness, and correlations between ultrasonic and carcass measures of body wall thickness are less than for analogous measures of backfat thickness, indicating that further study is needed if this measure is to be more widely used. Body wall correlations have not been reported in other studies, and thus there is no outside standard for comparison. Improvement in accuracy of ultrasonic body wall measurement could be as simple as a need for more time to train technicians and develop protocols. Meat science literature clearly shows that carcass body wall thickness can be used to predict percentage yield, and is often a more accurate predictor than backfat thickness (Tschirhart et al., 2002). Our results for ultrasound body wall indicate that UBW is more highly correlated to CBW than is UBF (pooled $r = 0.73$ versus 0.65).

Although widely reported in ultrasound studies, simple correlation coefficients are limited as a true measure of predictive ability because they are influenced by the amount of variation present in the scanned population and do not reflect bias. Other statistics developed for beef (BIF, 2002) and swine (Bates and Christians, 1994), including technician bias, standard error of prediction, and standard error of repeatability, have been reported for lambs in a limited number of studies, including Panting et al. (2000), Tait et al. (2005), and Leeds et al. (2007).

Measures of mean ultrasound bias as well as prediction error SD and CV for each technician and interpreter are shown in Table 1.4. Performance was generally consistent

among technicians and interpreters, with negative measurement bias for LEA and BF but no consistent bias for BW. As expected, prediction error CV was less for LEA than for BF. Ultrasonic measurements of body wall were less biased than those for backfat, but prediction error CV was only slightly less for UBW compared to UBF.

Measures of ULEA in this study were more biased (-2.66 to -1.30 cm²) than in other recent studies (-0.004 cm², Leeds et al., 2007; -1.50 to 0.21 cm², Tait et al., 2005). Measures of UBF in this study were also more biased (-0.17 to -0.12 cm) than those in recent studies (0.07 cm, Leeds et al., 2007; -0.03 to 0.13 cm, Tait et al., 2005). If the greater bias in this study is due to measurement error, it is unclear whether the error occurred in live animal or carcass measures. Although carcass measures are the standard to which ultrasound estimates are typically compared, measurement error is possible in both. In our study, ultrasonic estimates were consistent among technicians and interpreters, and carcass measurements differed very little among two recorders. The source of the discrepancy between ultrasonic and carcass measures thus remains unclear.

Some concern exists for the consistency of ultrasound bias as measured traits increase or decrease in magnitude (Leeds et al., 2008). The tendency for an ultrasound technician to overestimate carcass measurements in lean or light-muscled lambs, and/or underestimate those measures in fat or heavy-muscled lambs, reduces variability in ultrasonic measurements as compared to carcass measures. The UBF and UBW in this study were less variable than their analogous carcass measures (Table 1.1). Using plots of ultrasonic estimates against actual carcass measures, bias was judged to be acceptably linear for all three traits in our study, although goodness of fit was better for quadratic forms than linear (data not shown). Coefficients for regression of ultrasonic on carcass measures were 0.90, 0.73, and 1.00 for LEA, BF, and BW, and ranged from 0.87 to 0.94, 0.70 to 0.77, and 0.96 to 1.04, respectively, for individual technicians or interpreters. The departure from unity of regression coefficients for BF resulted primarily from UBF more substantially underestimating CBF in fatter lambs. The quadratic component was negative in the best-fitting second-order polynomial equations for LEA, BF, and BW. The R² values for best-fitting quadratic equations were higher than for linear forms for all three measures, improving from 0.38 to 0.41 for LEA, from 0.50 to 0.58 for BF, and from 0.32 to 0.53 for BW across all technicians and interpreters.

SEP for ULEA in this study (1.86 to 2.22 cm²) were greater than those reported by Leeds et al. (2007) (1.55 cm²), but less than those reported by Panting et al. (2000) (1.74 to 2.69 cm²), and very similar to those reported for three technicians by Tait et al. (2005) (1.92 to 2.18 cm²). SEP for UBF in this study (0.12 to 0.14 cm) were very similar to those reported in other studies, including 0.14 cm (Leeds et al., 2007), 0.084 to 0.137 cm (Panting et al., 2000), and 0.12 to 0.13 cm (Tait et al., 2005).

Bias and SEP statistics for BW have not been reported by other studies, and thus we have no standard for comparison. Potential continues to exist for ultrasonic estimation of body wall thickness, and its use may become more logical as experience with and protocols for UBW become more solidified. To fairly evaluate the accuracy of UBW as compared to traditional UBF in predicting the analogous carcass measures, comparisons of prediction error CV seems logical. Future studies should also evaluate ultrasonic estimates of body wall thickness as a predictor of carcass cut-out data.

When comparing correlations between ultrasound estimates and actual carcass measures using the whole dataset, differences among technicians and interpreters were often significant for loin eye area than for backfat thickness. Significant technician by interpreter interactions also existed more frequently for loin eye area than for backfat thickness (data not shown).

In addition to ability to predict carcass measures, the consistency of ultrasound estimates across repeated scans of the same lambs has important implications for the accuracy of the technology and the technician using it. Repeatability statistics, including correlation, mean difference, and repeatability standard deviation (SER) for technicians and interpreters within and across magnification settings are shown in Tables 1.5, 1.6, and 1.7. Statistics are reported for two groups. Second scans on lambs in Group A (n=86) were done at the same magnification setting as the first; magnification setting was switched (from 1.5x to 2.0x or vice versa) prior to the second scan for lambs in Group B (n=86). Trait means and standard deviations for Groups A and B were nearly identical (data not shown).

Correlation coefficients between repeated ultrasonic measures for each technician and interpreter are shown in Table 1.5. For repeated measures taken at similar magnification settings on lambs in Group A, correlation coefficients for ULEA ranged

from 0.57 to 0.79, and were generally higher for UBF, ranging from 0.72 to 0.85. Repeated measures of UBW had correlation coefficients more similar to those for ULEA, ranging from 0.58 to 0.78. All correlation coefficients between repeated measures done at different magnification settings on lambs in Group B were within the respective ranges reported for Group A. Pooled correlations between repeated measurements (across all technicians and interpreters) were slightly less for UBF in Group B as compared to Group A ($r = 0.76$ vs. 0.79), but were greater for ULEA when second scans were at different magnification settings than the first ($r = 0.73$ vs. 0.67). Repeatability of UBW was not considered across magnification settings. Because of the inherent limitations of correlations, it is recommended that alternative repeatability statistics be considered in the development of certification standards for technician repeatability.

Mean differences between repeated ultrasound measures are shown in Table 1.6. Differences were calculated by subtracting the first ultrasound scan on a lamb from the second, for each technician and interpreter combination. Differences between loin eye area scans (LEAD) were less uniform across technicians and interpreters than ultrasound-carcass bias statistics for LEA reported in Table 1.4. This variation implies that technician repeatability may be the more critical aspect of ULEA accuracy. Bias structure among technicians was considerably different for Group B (different magnifications) as compared to Group A (same magnification); LEAD generally increased for technicians as they moved away from their native magnification setting for the second scan. Differences between backfat scans (BFD) were more uniform among technicians and interpreters than LEAD, and the effect of changing magnification setting was less striking for BF.

Repeatability SD (SER) and CV associated with repeated scans of the same lamb are reported for each technician and interpreter in Table 1.7. The majority of technicians were more repeatable across magnification settings than within their native setting, a result that is counter-intuitive, but may simply be the result of greater care exercised while scanning on an unfamiliar magnification. Interpreters showed more subtle changes in repeatability across magnification settings for both ULEA and UBF, as compared to technicians. One technician showed greater repeatability error CV for UBW than for UBF (18.9% vs. 13.2%), but the opposite result was true for the other technician scanning BW (14.5% vs. 16.4%).

The SER for ULEA in this study (1.61 to 2.45 cm²) were greater than the 1.31 cm² reported by Leeds et al., (2007), but within the range of 1.07 to 3.25 cm² reported by Panting et al. (2000) for seven technicians. The SER for UBF in this study (0.07 to 0.11 cm) were comparable to the 0.08 cm reported by Leeds et al. (2007), and toward the lower end of the range of 0.079 to 0.16 cm reported by Panting et al. (2000).

When comparing repeatability of ultrasound estimates, more significant differences existed between technicians than interpreters, and more significant differences existed for loin eye area than for backfat thickness (data not shown). Additionally, more technician by interpreter interactions were significant for repeated loin eye area measures than for backfat thickness (data not shown).

As compared to the simple ultrasound-carcass correlation coefficients generally discussed for lambs, developing lamb ultrasound technician certification guidelines using statistics assessed by the beef and swine industries is logical (Leeds et al., 2007). Tait et al. (2005) proposed the following guidelines for certification of U.S. sheep scan technicians: SEP, SER, and bias ≤ 0.10 in (0.254 cm) with $r \geq 0.60$ for fat thickness, and SEP, SER, and bias ≤ 0.50 in² (3.23 cm²) with $r \geq 0.50$ for loin eye area. Additionally, Leeds et al. (2008) reported maximum allowable SEP values of 0.125 cm for BF and 1.53 cm² for LEA in order to achieve expected rank correlations of 0.85 (arbitrary) between ultrasound and carcass data in simulated data. No other reports proposing certification guidelines for U.S. sheep ultrasound technicians were found. A summary of these accuracy statistics for each technician and interpreter from our study is reported in Table 1.8 along with the guidelines proposed to date in both other studies.

In general, technicians in our study easily met the certification criteria outlined by Tait et al. (2005), but either barely met (BF) or did not achieve (LEA) the SEP standards described by Leeds et al. (2008). Based on these results, it appears the guidelines of Tait et al. (2005) may be more accepting of technician inaccuracy than should be allowed; there is at least clear evidence that skilled technicians are able to do considerably better. Further analysis of these parameters as well as greater consideration for the amount of variation present in different lamb populations is clearly needed for the development of certification standards.

IMPLICATIONS

Results from this study support the generally accepted idea that ultrasound technology can predict backfat thickness and loin eye area in lambs when traditional protocols are used by a trained technician and images are traced by an experienced interpreter. Therefore, ultrasound estimates of carcass traits are useful as a selection tool for improving lamb carcass composition. Development of certification standards for ultrasound technicians is clearly necessary, and standards should involve statistics that indicate measurement bias and reveal inconsistencies in repeated measures of the same lambs. Because immediate use of ultrasound in sheep is likely to not include assessment of market readiness in feedlot animals as is common in cattle, it is likely that technician repeatability (given the ability to simply rank animals correctly within contemporary groups), will be as or more important for genetic evaluation than accuracy statistics comparing ultrasonic estimates to carcass values. Additional studies in lamb ultrasound should further investigate the ultrasonic estimation of body wall, and, if possible, include actual carcass yield data to more reliably assess its effect on composition.

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Table 1.1: Means for traits measured in live animals and carcasses

Ultrasound				Carcass			
variable	Mean	SD	CV	variable	Mean	SD	CV
ULEA (cm ²)	19.1	2.7	14.1%	CLEA (cm ²)	21.1	2.4	11.4%
UBF (cm)	0.45	0.14	32.2%	CBF (cm)	0.59	0.21	34.9%
UBW (cm)	2.27	0.46	20.2%	CBW (cm)	2.22	0.52	23.5%
				CWT (kg)	33.1	4.4	13.4%

Table 1.2: Overall correlations among and between ultrasonic and carcass measurements^a

Variable	Ultrasonic measurements			Carcass measurements			
	ULEA	UBF	UBW	CWT	CLEA	CBF	CBW
ULEA							
UBF	0.25**						
UBW	0.44**	0.58**					
CWT	0.64**	0.50**	0.65**				
CLEA	0.66**	0.06*	0.21**	0.62**			
CBF	0.33**	0.78**	0.60**	0.58**	0.11**		
CBW	0.43**	0.65**	0.73**	0.72**	0.30**	0.73**	

^aCorrelations between the same measurements in live animal and carcass are shown in bold.

* $P=0.0103$; ** $P<0.0001$

Table 1.3: Correlations between ultrasonic and carcass measurements of loin eye area, backfat thickness, and body wall thickness for four scan technicians and three image interpreters^a

	ULEA, CLEA	UBF, CBF	UBW, CBW
Technician 1	0.73	0.81	
2	0.63	0.78	0.70
3	0.62	0.76	
4	0.66	0.77	0.76
Interpreter 1	0.65	0.77	0.74
2	0.68	0.80	0.72
3	0.65	0.78	
Pooled	0.66	0.78	0.73

^aCorrelations for body wall thickness include only two technicians and two interpreters.

P<0.0001

Table 1.4: Average bias and prediction error SD and CV associated with ultrasonic estimation of loin eye area, backfat thickness, and body wall thickness for four scan technicians and three image interpreters^a

		Loin eye area, cm ²			Backfat thickness, cm			Body wall thickness, cm		
		Bias	SEP	CV	Bias	SEP	CV	Bias	SEP	CV
Technician	1	-1.90	1.86	8.8%	-0.17	0.12	20.9%	-0.03	0.38	17.2%
	2	-2.29	2.22	10.6%	-0.14	0.13	22.3%			
	3	-1.93	2.16	10.3%	-0.12	0.14	23.1%			
	4	-1.73	2.06	9.8%	-0.14	0.13	22.4%	0.14	0.35	15.7%
Interpreter	1	-1.30	2.07	9.8%	-0.14	0.13	22.6%	0.07	0.36	16.2%
	2	-1.93	2.03	9.6%	-0.16	0.13	22.0%	0.04	0.37	16.6%
	3	-2.66	2.13	10.1%	-0.12	0.13	21.8%			

^aCorrelations for body wall thickness include only two technicians and two interpreters.

Table 1.5: Correlations between repeated ultrasonic measurements of loin eye area, backfat thickness, and body wall thickness for four scan technicians and three image interpreters^a

	ULEA1, ULEA2 (A)	ULEA1, ULEA2 (B)	UBF1, UBF2 (A)	UBF1, UBF2 (B)	UBW1, UBW2 (A)
Technician 1	0.79	0.78	0.83	0.75	
2	0.57	0.68	0.85	0.85	0.57
3	0.64	0.72	0.72	0.72	
4	0.68	0.78	0.76	0.72	0.77
Interpreter 1	0.67	0.75	0.77	0.75	0.71
2	0.71	0.77	0.83	0.79	0.64
3	0.62	0.69	0.77	0.74	
Pooled	0.67	0.73	0.79	0.76	0.68

^aCorrelations for body wall thickness include only two technicians and two interpreters.

Table 1.6: Mean difference between repeated ultrasound measures of loin eye area, backfat thickness, and body wall thickness for four scan technicians and three image interpreters^a

	Loin eye area, cm ²		Backfat thickness, cm		Body wall, cm
	LEAD (A)	LEAD (B)	BFD (A)	BFD (B)	BWD (A)
Technician 1	-0.24	0.40	0.00	0.03	
2	0.24	0.91	0.02	0.00	-0.06
3	0.78	-0.47	0.01	-0.06	
4	-0.94	-1.61	-0.01	0.01	-0.02
Interpreter 1	0.02	-0.26	0.01	-0.01	-0.09
2	-0.48	-0.43	0.01	0.00	0.01
3	0.35	0.11	0.00	0.00	

^aDifferences for body wall include only two technicians and two interpreters

Table 1.7: Repeatability SD (SER) and CV associated with ultrasonic estimation of loin eye area, backfat thickness, and body wall thickness for four scan technicians and three image interpreters^a

		Loin eye area, cm ²				Backfat thickness, cm				Body wall, cm	
		Group A		Group B		Group A		Group B		Group A	
		SER	CV	SER	CV	SER	CV	SER	CV	SER	CV
Technician	1	1.61	7.7%	1.72	8.1%	0.08	13.4%	0.11	18.0%		
	2	2.45	11.6%	2.31	11.0%	0.08	13.2%	0.07	12.5%	0.42	18.9%
	3	2.20	10.4%	1.95	9.3%	0.11	18.0%	0.10	17.2%		
	4	1.92	9.1%	1.87	8.9%	0.10	16.4%	0.10	17.5%	0.32	14.5%
Interpreter	1	2.09	9.9%	1.93	9.2%	0.09	16.0%	0.10	16.6%	0.36	16.2%
	2	1.89	9.0%	1.80	8.6%	0.07	12.0%	0.08	13.5%	0.39	17.5%
	3	2.22	10.5%	2.18	10.3%	0.10	17.6%	0.11	18.9%		

^aRepeatability statistics for body wall include only two technicians and two interpreters

Table 1.8: Summary of accuracy statistics associated with ultrasonic estimation of loin eye area and backfat thickness for four scan technicians and three image interpreters

	Loin eye area, cm ²				Backfat thickness, cm			
	Bias	SEP	SER	r	Bias	SEP	SER	r
Scanner 1	-1.90	1.86	1.61	0.73	-0.17	0.12	0.08	0.81
2	-2.29	2.22	2.45	0.63	-0.14	0.13	0.08	0.78
3	-1.93	2.16	2.20	0.62	-0.12	0.14	0.11	0.76
4	-1.73	2.06	1.92	0.66	-0.14	0.13	0.10	0.77
Interpreter 1	-1.30	2.07	2.09	0.65	-0.14	0.13	0.09	0.77
2	-1.93	2.03	1.89	0.68	-0.16	0.13	0.07	0.80
3	-2.66	2.13	2.22	0.65	-0.12	0.13	0.10	0.78
Proposed 1 ^a	3.23	3.23	3.23	0.50	0.25	0.25	0.25	0.50
2 ^b		1.53				0.125		

^aTait et al., 2005

^bLeeds et al., 2008

**CHAPTER 2: LONGITUDINAL CHANGES IN ULTRASONIC
MEASUREMENTS OF BODY COMPOSITION DURING GROWTH IN
SUFFOLK RAM LAMBS, AND EVALUATION OF ALTERNATIVE
ADJUSTMENT STRATEGIES FOR ULTRASONIC SCAN DATA**

ABSTRACT

Four equations were used to describe changes in ultrasonic estimates (Y) of backfat thickness (BF) and loin eye area (LEA) relative to body weight (W) in a series of seven scans on 24 Suffolk ram lambs in 2007. Four weight-dependent equations were reported: Linear (L), Linear + Quadratic (LQ), Allometric (A; $y = \alpha W^\beta$), and Allometric + Weight (AW; $y = \alpha W^\beta e^{\gamma W}$). Goodness of fit was nearly identical among equations over the range of the data. Resulting adjustment equations were tested using three serial scans taken at approximately 30-day intervals during the 1999-2002 Virginia Ram Tests on 150 Suffolk, 36 Hampshire, and 43 Dorset winter-born ram lambs, and 52 fall-born Dorset ram lambs. The BF and LEA at the second scan were predicted from the data recorded at the first or third scan and compared to actual values. Partial correlations (accounting for the effect of year) between predicted and actual measures ranged from 0.78 to 0.87 for BF and 0.66 to 0.93 for LEA in winter-born rams, and from 0.70 to 0.71 for BF and 0.72 to 0.78 for LEA in fall-born Dorsets. Almost no difference in predictive ability existed between equations for BF. For LEA prediction, the AW equation was less accurate than the other forms, and there was no indication that the A equation was a better predictor than the L form within the range of the data. Adjustment equations were also tested using seven serial scans from 37 Suffolk ewe lambs contemporary to the ram lambs used to develop the equations but fed for a substantially lower rate of gain than the males. Correlations between actual values of BF and LEA at the seventh scan and predicted values derived from the first three scans indicated lambs were too young and light at the first scan (77 d, 32.4 kg) to reliably predict carcass measures at typical slaughter weights. For prediction using data from the two subsequent scans, correlations between predicted and actual values were 0.72 to 0.74 for BF and 0.54 to 0.76 for LEA. Little difference

existed between equations for predicting BF. For LEA, the AW form was a weaker predictor than the others, and the L equation was slightly superior to the A form. Therefore, it appears the L and A forms are suitable for use in central ram test and farm flocks contributing data to NSIP.

INTRODUCTION

Ultrasound scanning technology has proven to be a useful tool for estimating carcass merit in swine, cattle, and sheep. Ultrasonic estimates of backfat thickness and loin eye area are able to predict their analogous measurements in carcasses with an acceptable degree of accuracy and repeatability when scanning is performed by an experienced technician and images are traced by a trained interpreter (Leeds et al., 2007). Although other technologies allow carcass traits to be measured *in vivo* with greater precision and accuracy, real-time ultrasound is most advantageous from a standpoint of cost and portability (Macfarlane et al., 2006; Stanford et al., 1998). Carcass indicator traits, whether measured in actual carcasses or estimated *in vivo* using ultrasound (Berg et al., 1997), are correlated to carcass lean yield. Technology permitting *in vivo* estimation of carcass traits allows records to be collected on a greater number of animals, including those intended for breeding. Selection on ultrasonic measurements of carcass traits in live animals is therefore a logical strategy to improve lean composition of the U.S. slaughter lamb population and attempt to combat declining demand for lamb meat.

Genetic progress in lean composition resulting from the use of ultrasound in selection is well-documented in swine, cattle, and, in other countries, sheep (Simm et al., 2002). However, the U.S. sheep industry lags considerably behind with regard to large-scale genetic evaluation of carcass traits. Currently, no carcass trait Expected Progeny Differences (EPDs) are generated by the U.S. National Sheep Improvement Program (NSIP). Calculation of ultrasound EPDs requires that the scan data be adjusted to a constant endpoint; growth and development in carcass traits is generally considered in association with changes in age or weight. Few studies have reported longitudinal changes in ultrasound traits for lambs, and the most substantial research using a number of repeated ultrasonic measures (Fischer et al., 2006) focused on patterns of variation in the traits and not on the statistical comparison of descriptive models. Evaluation of ultrasound traits is currently practiced within only a few flocks in the U.S., and opportunity for across-flock evaluation and selection on ultrasound is limited to a few centralized ram tests. In either of these cases, scan adjustments are typically made to

traditional constant-weight endpoints using linear equations without consideration of alternative functional forms.

This study was therefore conducted to: 1) investigate the changes in ultrasonic estimates of backfat thickness and loin eye area that occur during growth in lambs, 2) describe changes in ultrasound measures using several functional forms, and 3) evaluate alternative strategies for the adjustment of scan measures, particularly as they apply to other populations differing in breed, sex, age, weight, and management. The ultimate objective is to provide additional information on the adjustment of scan data to individual flock owners and central test stations, as well as to NSIP for use in developing procedures for across-flock genetic evaluation of lamb carcass composition traits.

MATERIALS AND METHODS

Prior to the start of our study, linear equations were developed from a series of three ultrasound scans of backfat thickness (BF) and loin eye area (LEA) conducted on Suffolk ram lambs from the Virginia Ram Test between 1999 and 2002. The following equations were used for Suffolks and other breeds in subsequent years by the VA Ram Test, within the Virginia Tech purebred Suffolk flock, and by several other Suffolk breeders in the U.S., to adjust ultrasonic measures of BF (in) and LEA (in²) to a constant weight of 125 lbs (56.7 kg):

$$\text{Adjusted BF} = \text{Actual BF} + ((125 - \text{Actual Weight}) * 0.0018942)$$

$$\text{Adjusted LEA} = \text{Actual LEA} + ((125 - \text{Actual Weight}) * 0.012577)$$

Equivalent metric equations to adjust BF (cm) and LEA (cm²) for body weight (kg) are:

$$\text{Adjusted BF} = \text{Actual BF} + ((56.7 - \text{Actual Weight}) * 0.0106)$$

$$\text{Adjusted LEA} = \text{Actual LEA} + ((56.7 - \text{Actual Weight}) * 0.179)$$

Although changes in real-time ultrasound measurements of fat and muscle in growing Australian lambs were best explained by linear models (Hopkins et al., 1996), and linear adjustments are presently used for scan traits in the beef industry (Rumph et al., 2007), the possibility of non-linear allometric growth patterns for ultrasound traits exists as has been described for direct measures of body tissue components (Notter et al., 1983; Jenkins and Leymaster, 1993). In order to investigate the potential of nonlinear,

higher-order adjustment equations that would both be more descriptive of ram test data and could also potentially be generalized to other populations or management systems and to the genetic evaluation of ultrasound traits in NSIP, a study using a greater number of serial scan points and covering a wider range of body weights seemed warranted.

Seven serial ultrasonic measurements of BF and LEA were taken on 26 Suffolk ram lambs from the Virginia Tech flock between April 27 and August 10, 2007. Lambs were delivered to the Virginia Ram Testing Station on May 1, and were officially on test from May 15 to July 17. After completion of the test, rams underwent a “cool-down” period until August 25. The feeding program emphasized rapid growth and development and was thought to be representative of the feeding regimen in Suffolk farm flocks contributing data to NSIP. Rams were scanned at approximately 21-d intervals on April 27, May 18, June 8, June 29, July 24, and August 10. Scans on June 8 were repeated June 11, in order to have a greater number of scans available when rams were near 120 d in age, the point to which postweaning weights are currently adjusted for NSIP.

Weights on the day of scanning were recorded by the scan technician on April 27, June 11, and August 10; interpolations using these weights and official test weights from May 15, June 5, June 19, July 3, and July 17 were used to estimate body weights on the other scanning dates. Growth was linear over the weight range, and linear interpolations were used. Weight per day of age (WDA) was used to identify suspected outliers for growth, any lamb with WDA consistently more than 2.5 standard deviations (+ or -) from the mean WDA (calculated after suspects were removed) was excluded from analysis.

The same ultrasound technician scanned all lambs throughout the entire study. All scans were performed on the lamb’s right side between the 12th and 13th ribs, using an Aloka 500 ultrasound machine (Corometrics Medical Systems; Wallingford, CT) equipped with a 12.5-cm, 3.5-mHz transducer. The transducer was fitted with a Superflab standoff guide (Mick Radio-Nuclear Instruments, Inc.; Mt. Vernon, NY) to ensure proper contact with the animals and to minimize tissue distortion in the images. Lambs were held in a relaxed position by an assistant. Wool was shorn from the scan site and vegetable oil was applied as a couplant in order to obtain adequate acoustic contact.

When images for each lamb were deemed suitable by the technician, they were captured and recorded to a PC. One image was captured per animal per day; the same

image was used to measure both LEA and BF. All images were collected at 2.0x magnification setting. Images were interpreted by the scan technician using Rib-O-Matic V2.0 software (Critical Vision, Inc.; Atlanta, GA). The perimeter of the *longissimus dorsi* (LD) was traced to determine LEA, and BF was traced at the midpoint of the LD. Two independent interpretations were made for each image, and values for both interpretations were averaged prior to analysis.

Data were analyzed using the GLM procedure of the Statistical Analysis System (SAS). The model included individual animal effects, and four different functional forms were used to describe relationships of BF and LEA to body weight (W):

Linear (L)	$y = \alpha + \beta W$
Linear + Quadratic (LQ)	$y = \alpha + \beta W + \gamma W^2$
Allometric (A)	$y = \alpha W^\beta$
Allometric + Weight (AW)	$y = \alpha W^\beta e^{\gamma W}$

Log transformations were used to linearize allometric equations (A and AW) as: $\ln y = \ln(\alpha) + \beta \ln(W)$ and $\ln y = \ln(\alpha) + \beta \ln(W) + \gamma W$, respectively. Adjustment equations using an ultrasonic trait (U_1) measured at a known body weight (W_1) to estimate the same ultrasonic trait (U_2) at a different body weight (W_2) were then derived for each form:

Linear (L)	$\hat{U}_2 = U_1 + \beta (W_2 - W_1)$
Linear + Quadratic (LQ)	$\hat{U}_2 = U_1 + \beta (W_2 - W_1) + \gamma (W_2^2 - W_1^2)$
Allometric (A)	$\hat{U}_2 = U_1 (W_2 / W_1)^\beta$
Allometric + Weight (AW)	$\hat{U}_2 = U_1 (W_2 / W_1)^\beta e^{(\gamma W_2 / \gamma W_1)}$

In order to compare and validate the adjustment equations, they were used to predict BF and LEA in two other independent data sets. The first validation data set included 281 ram lambs of four groups scanned three times serially at the Virginia Ram Test between 1999 and 2002. Groups included Suffolks (n=150), Hampshires (n=36), and Dorsets (n=43) born primarily in the winter (January and February) of their respective test year, and Dorsets (n=52) born in the fall (September, October, or November) of the previous year. Two different predictions for ultrasonic BF or LEA at the second scan weight were made, using weights and ultrasonic measurements from either the first or third scan. Predicted values at the second scan were compared to actual values using partial correlations (accounting for the effect of year) for each breed and each equation.

Management (feeding regimen) for these rams was nearly identical to the on-test period for the 2007 rams, although the 2007 data covered a wider range of ages and weights and thus were thought to be more robust for development of predictive equations.

Similar comparisons were made between predicted and actual measurements of BF and LEA using serial scan data on 40 Suffolk ewe lambs from the same flock and year as the ram lambs that were used to develop the adjustment equations. Compared to the ram lambs, these 40 ewe lambs remained at the Virginia Tech Sheep Center and were fed for a substantially slower rate of gain. The scan data were collected by the same technician using the same methods as described for the 2007 Suffolk rams. The ewe lamb data included nine scan periods, but only the first, second, third, and seventh were used for this study, as weights were unavailable for some intermediate scan periods and not all lambs were present for the last two scans. The mean weight of the ewe lambs at the seventh scan corresponded most closely to the 120 d weight of approximately 56 kg measured in the ram lambs and was chosen as the reference point. For validation of our equations, measures from the third, second, and first scans were used to predict ultrasonic measures in the seventh, and correlation coefficients between predicted and actual variables were reported.

RESULTS AND DISCUSSION

Development of descriptive equations and adjustment strategies

Means for age, weight, backfat thickness (BF) and loin eye area (LEA) on each scan date for the Suffolk ram lambs measured in 2007 are reported in Table 2.1. Age at scanning ranged from 67 to 200 d for all rams, and averaged 76 d on the first scan (April 27) and 181 d on the last scan (August 10). Weights ranged from 32 to 87 kg, and averaged 38 kg on April 27 and 78 kg on August 10. Weight per day of age (WDA) was used to identify growth outliers (data not reported). Two ram lambs were identified as outlier suspects based on WDA; mean WDA was calculated for each scan date excluding weights for these two suspects. One lamb with WDA >2.5 s.d. below this mean for five of the seven scan dates was considered a growth outlier and excluded from analysis.

Another ram lamb was missing data for one of the scan periods and was also excluded. The means and standard deviations in Table 2.1 thus include 24 ram lambs with complete records for all four variables on each of the seven serial scan dates.

Scatter diagrams of body weight, BF, and LEA as they relate to age are shown in Figure 2.1. Body weight followed a nearly linear growth pattern, particularly over the on-test period. These results concur with the trends for weight data from the 1999-2002 study (unpublished). Descriptive equations were developed using both age and weight as the dependent variable, but goodness of fit was better for weight-dependent equations ($R^2 = 0.69$ vs. 0.56 for BF and $R^2 = 0.73$ vs. 0.58 for LEA), and we chose to report only weight-dependent descriptive and predictive equations.

The choice of weight or age as the dependent variable to describe changes in ultrasonic measurements is the subject of some discussion in the literature, but most studies have chosen weight as the basis for adjustment of ultrasound scans. Statistically, growth traits are much more variable in sheep than carcass composition traits (Simm and Dingwall, 1989), thus selection on age-adjusted scans will change composition by altering the growth curve; lambs that appear leaner at a constant age are essentially demonstrating later maturity relative to larger mature size. An advantage for weight-adjustment of carcass traits is that lambs are more typically marketed at a constant weight rather than constant age. If increasing slaughter weight is not a goal, assessment of weight-constant scans gives a more direct assessment of composition with less confounding with growth traits.

Evaluation of different endpoints for adjustment of carcass data is a common theme in beef literature. Most beef carcass trait adjustments are made on an age-constant basis, but alternative endpoints including constant weight, backfat, loin muscle area, or marbling score have been considered (Rios-Utrera, 2004). Although many of the genetic implications are outside the scope of this paper, the particular challenge with carcass traits is that their inter-relationship may cause traits of interest to represent something different if adjusted to an endpoint that is itself a component trait, e.g. adjusting percentage retail cuts to a constant backfat endpoint (Rumph et al., 2007).

Scatter diagrams of actual LEA and BF, and plots of the four weight-dependent descriptive equations (L, LQ, A, and AW) derived from them, are shown in Figure 2.2.

Over the range of the data, goodness of fit was nearly identical for the four equations for both ultrasonic measurements. Particularly during the on-test growth period, no striking results were found to indicate that the traditional assumptions of linear growth (and adjustment) of scan traits was clearly erroneous, although significant nonlinearity was observed for the relationship between LEA and W using both the Linear + Quadratic (LQ) and Allometric + Weight (AW) equations. For BF, the four equations remain very similar, even when extrapolated beyond the range of the data. In contrast, the LQ and AW forms are projected to diverge from the simpler L and A equations at, or beyond, the limits of these data for LEA.

Variation in both LEA and BF increased with weight, as expected. We anticipated that the allometric form may better describe this behavior as compared to the linear. We also anticipated that the A form, because of its fewer associated parameters, may be more robust than the LQ or AW equations if applied to different data sets involving animals managed under differing conditions, a situation which is common to the use of field records in programs such as NSIP.

Coefficients for descriptive equations of all four functional forms are presented in Table 2.2 for both ultrasonic LEA and BF. The linear regression (β) coefficients for LEA and BF of 0.169 and 0.00854 were similar to the equivalent metric coefficients from the original linear adjustment equations developed from the 1999-2002 ram test Suffolk data ($\beta = 0.179$ for LEA and 0.0106 for BF). The slightly lower β -values in our study may reflect the fact that the final scan in our data was on rams slightly older than the Suffolks from 1999-2002, although the one early scan on rams prior to introduction to the test also included in our data should compensate for this to some degree.

The observed allometric coefficient (β) for LEA in our data was 0.61 ± 0.0209 , which was only slightly less than the value of $\beta = 0.67$ anticipated for the relationship between body weight and a two-dimensional cross-sectional measurement associated with body size. The corresponding allometric coefficient for BF was 1.06 ± 0.0397 , indicating that BF was, as expected, increasing relatively more rapidly with body weight. Backfat was more variable than loin eye area (CV = 17.4 to 23.4% versus 9.8 to 12.7%), particularly in heavier lambs. The relative growth of BF in this study, particularly at heavier weights, was somewhat different from that expected in growing lambs

unrestricted by diet. Although the rate of fattening is expected to increase at heavier weights, the quadratic components for BF in the LQ and AW equations were negative, but not significant ($p = 0.35$ and 0.54 , respectively). This result could be a reflection of the “cooling off period” which began after conclusion of test July 17 when rams weighed approximately 70 kg. This weight is slightly before the point in Figure 2.2 where rams appear to become more variable in ultrasonic BF and a portion appear to plateau for BF. An interesting dilemma thus arises; the cooling off and hardening of rams lambs is necessary to facilitate their readiness to breed ewes in a pasture setting, but this may mask true fatness in lambs of earlier physiological maturity or distort the variation in fatness at later weights (although clearly well beyond typical market weights). From a selection perspective, it is questionable whether it is best to keep ram lambs on full feed beyond their point of physiological maturity to in order to accurately assess fatness, or direct the feeding regimen toward preparing ram lambs (which should be genetically superior to older rams for lean gain) to breed a greater number of ewes.

In light of this concern, descriptive equations using only the four scan periods for which rams were on full feed were determined (not shown), but were not differentiable from those using all seven scans over the range of our data. Additionally, equations generated from all scans were statistically stronger, and likely more representative of the feeding regimen for ram lambs in a practical setting.

Using the descriptive equations determined for all seven scan points, (Figure 2.2 and Table 2.2), constant-weight adjustment equations were developed for each descriptive form for ultrasonic loin eye area:

L	$\hat{LEA}_2 = LEA_1 + 0.169 (W_2 - W_1)$
LQ	$\hat{LEA}_2 = LEA_1 + 0.422 (W_2 - W_1) - 0.00215 (W_2^2 - W_1^2)$
A	$\hat{LEA}_2 = LEA_1 (W_2 / W_1)^{0.611}$
AW	$\hat{LEA}_2 = LEA_1 (W_2 / W_1)^{1.31} e^{(-0.0127 (W_2 / W_1))}$

and for ultrasonic backfat thickness:

L	$\hat{BF}_2 = BF_1 + 0.00854 (W_2 - W_1)$
LQ	$\hat{BF}_2 = BF_1 + 0.0113 (W_2 - W_1) - 0.0000234 (W_2^2 - W_1^2)$
A	$\hat{BF}_2 = BF_1 (W_2 / W_1)^{1.06}$
AW	$\hat{BF}_2 = BF_1 (W_2 / W_1)^{1.25} e^{(-0.00338 (W_2 / W_1))}$

Validation of predictive equations using data on rams from other years and breed groups

Adjustment equations derived from the 2007 serial scans of Suffolk rams were applied to the Virginia Ram Test scan data collected from 1999–2002. These data included 281 rams in four breed groups, including winter-born Suffolk (n=150), Hampshire (n=36), and Dorset (n=43) rams, and fall-born Dorset (n=52) rams. Rams were fed in the same ram test facility used in our 2007 study, were given a similar diet and achieved similar rates of gain. The nutritional regimen included similar time on test followed by a cool down period. Within each of the 4 years, ultrasonic scans of BF and LEA were collected on three serial dates approximately 30 d apart. Means and standard deviations for actual measures of age, body weight, BF, and LEA for these rams are reported by breed group in Table 2.3. The L, LQ, A, and AW adjustment equations from our study were applied to the first and third scans and used to predict the second. Effect of year was accounted for in the model, and partial correlations between predicted and actual measures of BF and LEA were calculated for equations of each of the four forms.

The Suffolk and Hampshire rams in these data had mean ages and weights that were very comparable to those for the Suffolks used to develop equations in our 2007 study, although our data extended the range in age approximately 20 d in either direction. Winter-born Dorset rams were older on average than Suffolks and Hampshires, and thus fit toward the upper end of the age range in our data, but winter-born Dorsets were slightly slower growing, and accordingly lighter at similar ages. Means for BF in Suffolks, Hampshires, and winter-born Dorsets were nearly identical to ours at similar weight. Means for LEA in these breeds were slightly higher than in our data, by approximately 2 cm² at similar weights. Scan technician bias, the consistent over or under-estimation of actual carcass measurements with ultrasound, is known to exist (Leeds et al., 2007, Tait et al., 2005). Bias therefore may contribute to this difference, considering the data were collected by two different technicians.

Fall-born Dorsets were the only breed group exhibiting considerably different means than our data. The use of rams from this group to test our equations was of particular interest because these rams, having been born in the fall prior to the test year, were considerably older and heavier than the rams used to develop our predictive

equations, or than the other three breed groups in the 1999-2002 data. Means for fall-born Dorsets for BF and LEA also extended well beyond the range of our data. A peculiarity of fall-born rams on ram tests is that they often are not fed for maximum growth until the onset of the test period, thus they are typically considerably lighter, and expectedly, leaner, when compared to winter-born rams at similar ages. The effects of differing feeding regimen on the timing of physiological maturity is a concern in adjustment of scan traits, particularly BF. The best adjustment strategy for ultrasound measures on fall-born rams remains unclear; adjustment equations that are robust predictors of scan traits for rams of both birth seasons would be especially valuable for central ram tests.

Comparison of the standard deviations for traits in the 1999-2002 data showed these rams were commonly more variable than those used in our study, as might have been expected for a greater number of rams, originating from multiple flocks and representing multiple years within each breed group.

For each of the four breed groups, ultrasound traits at the second scan (BF2 or LEA2) were predicted using analogous scan measures and weights from the first (1BF2 or 1LEA2) or third scan (3BF2 or 3LEA2) using each of the four adjustment equations (L, LQ, A, and AW). Partial correlations (after accounting for differences in year) between predicted and actual values for BF and LEA at the second scan event are presented in Table 2.4.

Correlation coefficients revealed that our adjustment equations were highly predictive of scan traits in the 1999-2002 data, and differed little in predictive ability, with partial correlations ranging from 0.78 to 0.87 for BF and 0.66 to 0.93 for LEA in winter-born rams, and from 0.70 to 0.71 for BF and 0.72 to 0.78 for LEA in fall-born rams. The relatively high prediction accuracy for fall-born rams was particularly surprising and pleasing based on the mean differences previously discussed. Comparison of these correlations to the repeatabilities of sequential ultrasound measurements taken by the same operator on the same day of 0.79 for BF and 0.67 for LEA from Chapter 1 suggests that predicted values were not much more variable than repeated scans.

Very few striking differences in predictive ability existed between equations. Within each subset of forward or backward-predicted variables for each breed, the greatest range in correlation coefficients was 0.08 for 1LEA2 in Hampshire rams.

Differences between equations were more evident for LEA, but almost no difference existed within subsets for BF. Correlations for equations were more variable for forward (1LEA2) than backward-predicted (3LEA2) LEA. As compared to the other three forms, the AW equation seemed less accurate for LEA prediction, especially using values from the first scan. This could be the result of a quadratic component peculiar to our 2007 data set that may not extend well to other populations. There was no indication that the A equation was a more robust predictor than the L form within the range of these data.

Validation of predictive equations using data on Suffolk ewe lambs under different management

The same predictive and adjustment strategies tested on 1999-2002 ram test data were also applied to scan data from the Suffolk ewe lamb siblings of the rams from which the equations were derived in 2007. Data included nine serial scans of BF and LEA; the first, second, third, and seventh were chosen based on means for analysis in this study. Our L, LQ, A, and AW adjustment equations were applied to the third, second, and first scans and used to predict the seventh. Simple correlations between predicted and actual measures of BF and LEA were calculated for each of the four equations.

Table 2.5 shows means and standard deviations for recorded variables on the 2007 Suffolk ewe lambs at each of the four scan periods used to validate our predictive equations. These statistics reflect data on 37 ewe lambs; two lambs that were deemed to be growth outliers based on WDA and one lamb that did not have a record for one of the four scan periods were removed prior to analysis. These data were of particular interest because the ewe lambs were managed in strikingly different fashion than their male counterparts (from the same flock and birth season) and thus had substantially lighter weights at similar ages.

The third and seventh scans from the ewe lamb data were deliberately chosen for this study because the mean age at scan 3 (118 d) corresponds with the age to which post weaning weights are adjusted for NSIP (120 d) and the mean weight at scan 7 (55.7 kg at 181 d) corresponds with the approximate weight exhibited by the ram lambs in our study at approximately 120 d. In terms of practical application, it is questionable whether scanning ewe lambs similar to these (i.e. under a feeding regimen that may delay the

detectable onset of physiological maturity) at the same time when postweaning weights are recorded gives an accurate prediction of their carcass merit at heavier, more commonly-evaluated live weights.

Although rams and ewe lambs were scanned on slightly different days in 2007, range and means for age are nearly identical. Mean weights for ewe lambs, however, were approximately 5 kg lighter than rams at similar ages for the first two scans, a value which increased to over 20 kg less by the seventh scan, reflecting the different goals for daily gain between the respective feeding regimens. Ranges in BF were very similar; mean BF was nearly the same at similar ages, and thus was expected to be higher in ewes at similar weight. Mean LEA was approximately 2 cm² less for ewe lambs than rams at the same age.

Ultrasound traits at the seventh scan (BF7 or LEA7) were predicted using appropriate measures from the third (3BF7 or 3LEA7), second (2BF7 or 2LEA7), and first scan (1BF7 or 1LEA7) with each of the four adjustment equations (L, LQ, A, and AW). Because no breed or year differences existed in the ewe lamb data, simple correlations between predicted and actual variables were reported (Table 2.6).

Correlation coefficients between predicted values and actual measures were lower when our adjustment equations were applied to these Suffolk ewe lambs than when applied to other ram lambs, but based on the striking difference in management and according rate of gain, they are higher than might have been expected. Ultrasonic measurements of both BF and LEA at the third scan were acceptable predictors of analogous measures at the seventh scan, as were measures of BF at the second scan. This latter result is somewhat surprising due to the relative differences in both magnitude and variability in BF as compared to LEA at such young ages and light weights. Based on these results, it is not recommended that scans similar to the first scan in these ewe lamb data (77 d, 32.4 kg) be used to predict carcass measures at typical slaughter weights in ewe lambs fed for similar rates of gain.

Excluding correlations involving predicted measures from the first scan, little difference existed between the predictive values of the separate equations for BF. For predicting LEA, the AW form appeared to be a weaker predictor than the other forms, supporting our inference from the other validation study that this equation may generalize

more poorly to different populations. More conclusively than when applied to the 1999-2002 ram test data, the L equation appeared to be a slightly more robust predictor of LEA than the A form. The consistency of this result should continue to be tested in additional populations with other peculiarities.

IMPLICATIONS

It was generally concluded that the range of our data sufficiently covered the age range relevant for the postweaning growth period evaluated by NSIP (postweaning weights are adjusted to 120 d), and that scans performed within the age range acceptable for PWW (120 ± 30 d) can very confidently be adjusted to PWW using our predictive equations. Adjustment strategies developed using serial scans on Suffolk ram lambs accurately predicted values for ultrasonic BF and LEA in similar ram test sheep of four breeds, two birth seasons, and four years, and in Suffolk ewe lambs managed under considerably different expectations for rate of gain and with accordingly different weight per day of age. The use of ultrasound adjustment strategies from this study for ram lambs of similar genetic makeup and under feeding conditions similar to those of central ram tests seems reasonably secure based on the results of our tests. While future experimental focus should be directed toward finding instances in which these adjustment strategies are not valid, the range of ages or weights across which ultrasound traits are adjusted for practical application should remain relatively conservative in order to assure the merit of the strategies in real selection programs and for large-scale genetic evaluation. Ideally, a representative series of at least four scans should first be performed in any flock wishing to adjust future scan data, and predictive equations of either the allometric or linear form described in this study should be developed specific for the genetic profile and management system of that contemporary group. It appears that as long as management strategy is reasonably similar from year to year, as was the case on the VA Ram Test, adjustment equations for BF and LEA developed for other groups should have reasonable predictive accuracy when applied to lambs in subsequent years. Periodic testing of any adjustment strategy, when feasible, is certainly recommended.

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Table 2.1: Means and standard deviations of recorded variables for Suffolk ram lambs at each of seven serial ultrasound scan dates in 2007

Scan Date	Age (days)		Weight (kg)		BF (cm)		LEA (cm²)	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
27-Apr	77	6	38.0	3.7	0.32	0.07	12.5	1.6
18-May	98	6	43.5	3.8	0.31	0.06	14.1	1.8
8-Jun	119	6	55.3	4.2	0.47	0.11	16.1	1.6
11-Jun	122	6	57.4	4.4	0.47	0.08	17.2	1.9
29-Jun	140	6	65.3	5.3	0.55	0.11	18.3	2.0
24-Jul	165	6	74.1	5.8	0.65	0.13	19.4	2.3
10-Aug	182	6	78.2	5.5	0.60	0.13	19.1	2.0

Table 2.2: Coefficients for four equations used to describe changes in ultrasonic measurements of loin eye area and backfat thickness during growth in Suffolk ram lambs

Equation	α	β	γ
Loin eye area, cm²			
Linear (L)	6.71	0.169	
Linear + Quadratic (LQ)	-0.257	0.422	-0.00215
Allometric (A)	1.38	0.611	
Allometric + Weight (AW)	0.171	1.31	-0.0127
Backfat thickness, cm			
Linear (L)	-0.0218	0.00854	
Linear + Quadratic (LQ)	-0.0973	0.0113	-0.0000234
Allometric (A)	0.00615	1.06	
Allometric + Weight (AW)	0.00352	1.25	-0.00338

Table 2.3: Means and standard deviations of recorded variables for ram lambs of four breed groups on the Virginia Ram Test between 1999 and 2002

Breed	Scan	Age (days)		Weight (kg)		BF (cm)		LEA (cm ²)	
		mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Suffolk (n=150)	1	103	15	51.2	7.0	0.37	0.13	16.5	2.5
	2	135	15	64.6	7.2	0.50	0.13	18.9	2.5
	3	167	15	78.8	7.5	0.66	0.17	21.4	2.8
Hampshire (n=36)	1	100	21	50.1	10.5	0.35	0.16	15.1	2.9
	2	133	24	65.7	10.7	0.53	0.18	18.3	2.5
	3	164	22	78.4	12.9	0.65	0.19	20.2	3.2
Winter Dorset (n=43)	1	118	23	49.2	11.1	0.32	0.12	15.9	3.7
	2	150	23	62.4	11.7	0.49	0.16	18.6	4.0
	3	182	23	73.8	12.4	0.62	0.17	21.5	4.7
Fall Dorset (n=52)	1	222	24	72.8	11.4	0.52	0.14	20.9	3.8
	2	256	25	84.7	10.9	0.63	0.16	23.9	3.7
	3	287	25	94.7	11.2	0.72	0.19	26.1	4.0

Table 2.4: Partial correlation coefficients between predicted and actual variables using four equations developed from Suffolk ram lambs in 2007 to predict the second BF and LEA measurements from first and third scans and weights for ram lambs of four breeds on the 1999-2002 Virginia Ram Test

Backfat thickness					
Suffolk			Hampshire		
	<i>BF2</i>	<i>BF2</i>		<i>BF2</i>	<i>BF2</i>
<i>L_1BF2</i>	0.79	<i>L_3BF2</i> 0.80	<i>L_1BF2</i>	0.86	<i>L_3BF2</i> 0.78
<i>LQ_1BF2</i>	0.79	<i>LQ_3BF2</i> 0.80	<i>LQ_1BF2</i>	0.85	<i>LQ_3BF2</i> 0.78
<i>A_1BF2</i>	0.78	<i>A_3BF2</i> 0.81	<i>A_1BF2</i>	0.86	<i>A_3BF2</i> 0.77
<i>AW_1BF2</i>	0.78	<i>AW_3BF2</i> 0.81	<i>AW_1BF2</i>	0.86	<i>AW_3BF2</i> 0.77
Winter Dorset			Fall Dorset		
	<i>BF2</i>	<i>BF2</i>		<i>BF2</i>	<i>BF2</i>
<i>L_1BF2</i>	0.81	<i>L_3BF2</i> 0.86	<i>L_1BF2</i>	0.70	<i>L_3BF2</i> 0.70
<i>LQ_1BF2</i>	0.81	<i>LQ_3BF2</i> 0.86	<i>LQ_1BF2</i>	0.70	<i>LQ_3BF2</i> 0.71
<i>A_1BF2</i>	0.81	<i>A_3BF2</i> 0.87	<i>A_1BF2</i>	0.70	<i>A_3BF2</i> 0.70
<i>AW_1BF2</i>	0.80	<i>AW_3BF2</i> 0.87	<i>AW_1BF2</i>	0.70	<i>AW_3BF2</i> 0.71
Loin eye area					
Suffolk			Hampshire		
	<i>LEA2</i>	<i>LEA2</i>		<i>LEA2</i>	<i>LEA2</i>
<i>L_1LEA2</i>	0.81	<i>L_3LEA2</i> 0.81	<i>L_1LEA2</i>	0.74	<i>L_3LEA2</i> 0.69
<i>LQ_1LEA2</i>	0.80	<i>LQ_3LEA2</i> 0.82	<i>LQ_1LEA2</i>	0.70	<i>LQ_3LEA2</i> 0.70
<i>A_1LEA2</i>	0.80	<i>A_3LEA2</i> 0.82	<i>A_1LEA2</i>	0.71	<i>A_3LEA2</i> 0.72
<i>AW_1LEA2</i>	0.78	<i>AW_3LEA2</i> 0.82	<i>AW_1LEA2</i>	0.66	<i>AW_3LEA2</i> 0.71
Winter Dorset			Fall Dorset		
	<i>LEA2</i>	<i>LEA2</i>		<i>LEA2</i>	<i>LEA2</i>
<i>L_1LEA2</i>	0.93	<i>L_3LEA2</i> 0.90	<i>L_1LEA2</i>	0.77	<i>L_3LEA2</i> 0.75
<i>LQ_1LEA2</i>	0.92	<i>LQ_3LEA2</i> 0.91	<i>LQ_1LEA2</i>	0.72	<i>LQ_3LEA2</i> 0.78
<i>A_1LEA2</i>	0.92	<i>A_3LEA2</i> 0.91	<i>A_1LEA2</i>	0.75	<i>A_3LEA2</i> 0.76
<i>AW_1LEA2</i>	0.89	<i>AW_3LEA2</i> 0.91	<i>AW_1LEA2</i>	0.72	<i>AW_3LEA2</i> 0.78

(*P*<.0001)

Table 2.5: Means and standard deviations of recorded variables for Suffolk ewe lambs at four scan times in 2007

Scan	Age (days)		Weight (kg)		BF (cm)		LEA (cm ²)	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
1	77	6	32.4	3.8	0.35	0.08	12.6	1.6
2	97	6	39.2	4.1	0.41	0.09	14.4	2.0
3	118	6	40.7	4.0	0.44	0.11	15.1	1.8
7	181	6	55.7	5.1	0.66	0.16	18.5	2.1

Table 2.6: Simple correlation coefficients between predicted and actual variables using four equations developed from Suffolk ram lambs in 2007 to predict the seventh BF and LEA measurements using third, second, and first scans and weights for Suffolk ewe lambs scanned in 2007

Backfat thickness					
	<i>BF7</i>		<i>BF7</i>		<i>BF7</i>
<i>L_3BF7</i>	0.72	<i>L_2BF7</i>	0.74	<i>L_1BF7</i>	0.53
<i>LQ_3BF7</i>	0.73	<i>LQ_2BF7</i>	0.74	<i>LQ_1BF7</i>	0.53
<i>A_3BF7</i>	0.72	<i>A_2BF7</i>	0.73	<i>A_1BF7</i>	0.47
<i>AW_3BF7</i>	0.72	<i>AW_2BF7</i>	0.73	<i>AW_1BF7</i>	0.46
Loin eye area					
	<i>LEA7</i>		<i>LEA7</i>		<i>LEA7</i>
<i>L_3LEA7</i>	0.76	<i>L_2LEA7</i>	0.65	<i>L_1LEA7</i>	0.63
<i>LQ_3LEA7</i>	0.73	<i>LQ_2LEA7</i>	0.60	<i>LQ_1LEA7</i>	0.58
<i>A_3LEA7</i>	0.73	<i>A_2LEA7</i>	0.60	<i>A_1LEA7</i>	0.56
<i>AW_3LEA7</i>	0.67	<i>AW_2LEA7</i>	0.54	<i>AW_1LEA7</i>	0.43

($P < .0001$)

Figure 2.1: Relationship of body weight, loin eye area, and backfat thickness with age in growing Suffolk ram lambs born in 2007

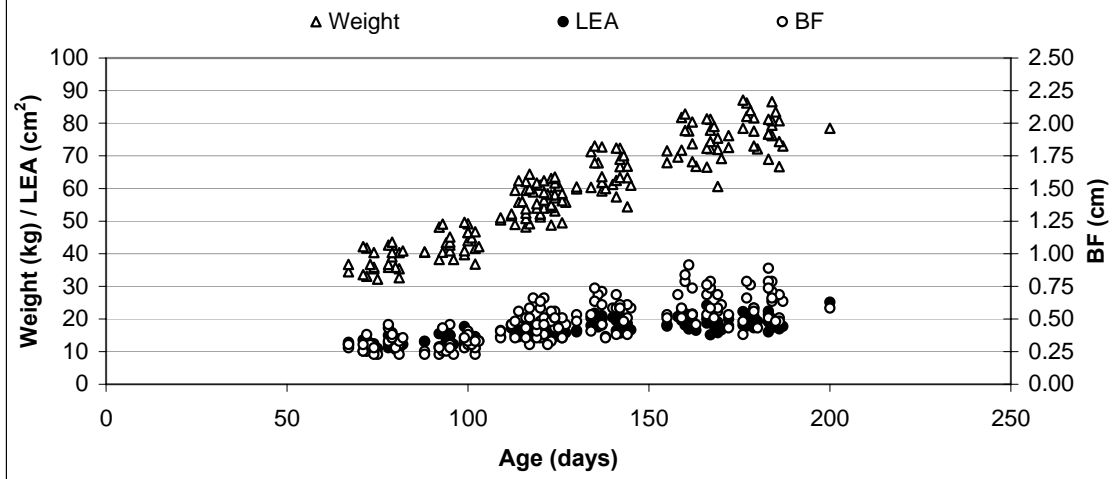
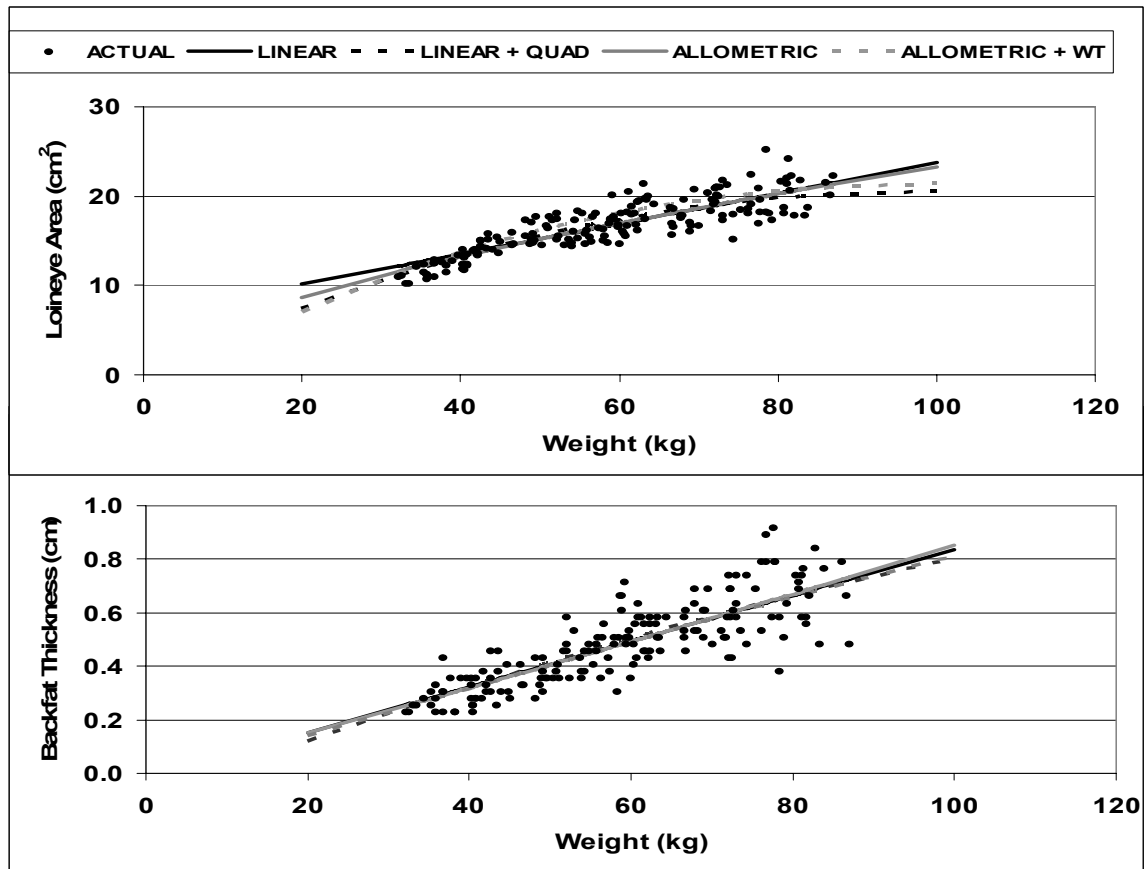


Figure 2.2: Relationship of ultrasonic loin eye area and backfat thickness to body weight in growing Suffolk ram lambs in 2007



CHAPTER 3: ULTRASONIC ESTIMATION OF LAMB CARCASS COMPOSITION: IMPLICATIONS FOR GENETIC IMPROVEMENT

SUMMARY OF RESULTS

Two studies were undertaken with the following objectives: 1) provide a comprehensive validation study on the accuracy and repeatability of ultrasonic estimates of carcass traits and the factors that may affect them for use in developing certification standards for lamb ultrasound technicians in the U.S., and 2) provide additional information on the longitudinal changes that occur in ultrasonic measurements during growth in lambs, and propose common endpoint adjustment strategies for scan data to be used by individual flock owners and central test stations, as well as by NSIP in developing procedures for across-flock genetic evaluation of lamb carcass composition.

Correlations between ultrasonic estimates of 12th/13th rib loin eye area (ULEA), and backfat thickness (UBF) and their analogous carcass measurements (CLEA and CBF) were high (0.66 for LEA, 0.78 for BF) and in general agreement with other reported literature. Correlation coefficients were also high (0.73) between ultrasonic estimates and actual measures of carcass body wall thickness, indicating that this measure may merit further investigation. Ultrasound-carcass correlations were generally similar for all technicians, although more variable for LEA than for BF. Pooled correlations between repeated measures were 0.67 for ULEA, 0.79 for UBF, and 0.68 for UBW. Repeatability measures were more variable among technicians and interpreters than accuracy statistics relating ultrasound to carcass measures. The impact of changing magnification setting on technician and interpreter repeatability was negligible.

Several other accuracy statistics used for ultrasound technician certification programs in the beef and swine industries were reported. Mean bias for technicians and interpreters ranged from -1.30 to -2.66 cm² for LEA, from -0.12 to -0.17 cm for BF, and from 0.14 to -0.03 cm for BW, with standard errors of prediction ranging from 1.86 to 2.22 cm², 0.12 to 0.14 cm, and 0.35 to 0.38 cm, respectively. Standard errors of repeatability ranged from 1.61 to 2.45 cm² for ULEA, from 0.07 to 0.11 cm for UBF, and

from 0.36 to 0.42 cm for UBW. These validation statistics were also within the range reported in the literature.

The second study served to develop equations to describe changes in ultrasonic estimates of (BF) and (LEA) relative to increasing body weight. Linear, quadratic, allometric, and allometric + quadratic forms had similar goodness of fit and derived adjustment equations were tested in two other data sets. For ram lambs of three breeds managed very similarly to the (winter born) rams from which the equations were developed, partial correlations between predicted and actual measures ranged from 0.78 to 0.87 for BF and 0.66 to 0.93 for LEA in winter-born rams, and from 0.70 to 0.71 for BF and 0.72 to 0.78 for LEA in fall-born rams. For ewe lambs from the same flock as the ram lambs but managed for substantially slower rate of gain, correlations between predicted and actual values were 0.72 to 0.74 for BF and 0.54 to 0.76 for LEA. Scan measures on these ewe lambs were not reliably adjusted to typical market weights if taken much before 90 day of age.

In both test populations, almost no difference in predictive ability existed between equations for BF. For LEA, the linear and allometric forms were best for both rams and ewes, and the linear slightly better for ewes. It appears these two adjustment equations are suitable for use in central ram test and farm flocks contributing data to NSIP:

For ultrasonic LEA (cm²):

$$\text{Linear} \quad \text{LEA}_2 = \text{LEA}_1 + 0.169 (W_2 - W_1)$$

$$\text{Allometric} \quad \text{LEA}_2 = \text{LEA}_1 (W_2 / W_1)^{0.611}$$

and for ultrasonic BF (cm):

$$\text{Linear} \quad \text{BF}_2 = \text{BF}_1 + 0.00854 (W_2 - W_1)$$

$$\text{Allometric} \quad \text{BF}_2 = \text{BF}_1 (W_2 / W_1)^{1.06}$$

Our results generally support the idea that ultrasound scanning can accurately and consistently predict carcass measures of LEA and BF in live lambs, and, accordingly, it has merit in for use in selection programs aiming to improve composition. If ultrasound estimation of carcass traits is to become more commonplace in the U.S. lamb industry, the development of certification standards for U.S. lamb ultrasound technicians is a

critical next step. It also appears that, although further testing should be done, our linear and allometric adjustment strategies are suitable for general use in medium wool breeds of sheep managed under typical farm flock conditions, a scenario common to flocks contributing scan data to NSIP. For populations suspected to develop differently, a representative series of four to six scans should generate predictive equations that can apply to other lambs managed similarly in subsequent years.

CONCLUSIONS

Although the U.S. lamb industry lags behind other countries and species in adopting large scale genetic evaluation of carcass composition, the development of ultrasound EPDs by NSIP is now underway. The success of these EPDs relies on three main criteria: 1) technology and technicians that provide reliable *in vivo* estimations of composition, 2) a strategy for adjusting scan measures to a common endpoint and clear understanding of its limitations, and 3) reliable estimates of phenotypic and genetic parameters for the traits of interest.

Reliability of ultrasound estimations

Results of this study and others conclude that ultrasonic estimates of backfat thickness and loin eye area are able to predict their analogous measurements in carcasses with an acceptable degree of accuracy and repeatability, when scanning is performed by an experienced technician and images are traced by a trained interpreter. Those studies that compare ultrasonic estimates to actual carcass composition offer even more important information to the value of ultrasound and, for the most part, have been reassuring that ultrasonic estimates of carcass traits are as or more predictive of carcass cut-out data than the carcass measures themselves. Evaluation of body wall thickness in this capacity should be included in future studies. The effects of machine and specific protocol on scanning accuracy appear to have become less critical than in the early literature due to the advancements in technology and experience since that time.

The more critical aspect of ultrasound reliability is the skill level of the technician performing the scans and the interpreter tracing the images. Several options exist that will affect the future of scan procedure and EPDs. It is currently common practice that scan images are interpreted either by the scan technician or by automated tracing software on site. The alternative, as is common in the beef industry and the procedure for our study, is to send all images to a centralized processing lab for interpretation. It seems, based on the results of our study and others, that the latter option is the best alternative to provide uniform, reliable estimations. Either way, a certification requirement for both technicians and interpreters is only logical. It is difficult to determine from the range of results that have been reported exactly what level of accuracy or repeatability should qualify as “acceptable,” but two major conclusions arose from our review of the literature: 1) statistics used for certification should include measures of technician bias and repeatability, and 2) the level of variation that exists within the population to be scanned is as or more important to the certification statistics as the skills of the technician, and accordingly, this aspect should be understood and managed when evaluating and certifying technicians.

Adjustment strategy

Our results did not provide evidence of major differences among functional forms of descriptive or adjustment equations within the range of age or weights that scans are typically reported for NSIP. The coefficients derived for our experimental population generalized reasonably well to other breeds and management scenarios that were thought to cover the scope of flocks currently contributing scan data to NSIP. At this point, it appears that either linear or allometric adjustment will adequately generalize to multiple populations and that neither would result in considerable issues with reranking. It therefore seems that focus should shift from comparison of functional forms to definition of the ranges in endpoints that should be recommended.

The high economic importance of growth traits under current pricing structures, as well as the critical role that weight plays in lean tissue yield, indicate that focus on composition traits should not eclipse attention to genetic progress in growth. Relative economic weightings for growth and composition traits are difficult to calculate and are

subject to change with price structure and input costs. Biological indices such as lean tissue growth avoid this issue but have other limitations. In particular, growth traits are expected to dominate such biological indices because they are substantially more variable. The use of these indices could result in an increase in lean gain but a corresponding decrease in conformation. Attempts at genetic evaluation of conformation traits have been shown to be particularly difficult, but conformation undoubtedly plays a role in the marketing and perceived value of both live sheep and carcasses.

The balance between growth and composition traits in selection programs will be affected by the choice of adjustment endpoint for scan traits. Adjusting scans to a constant weight, as is common practice in the current industry, yields EPDs that are largely independent of genetic merit for growth rate. Selection on EPDs adjusted to a common age is likely to result in growthier animals with larger mature size, i.e. animals that are relatively more immature at typical slaughter weights. Relative lack of maturity could result in reduced carcass quality and conformation. A proposed compromise is to adjust scans to the animal's 120-d adjusted postweaning weight (PWW). Currently, postweaning weights are only acceptable when recorded within 120 ± 30 days of age. Our results indicate that scans taken within this range of ages (which, given different populations and management regimens, represent an even wider range of weights) can be reliably adjusted to the weight corresponding to 120 days of age. We therefore propose that for use in NSIP EPDS, scans be accepted only within this 60 day window and be adjusted to 120-d PWW. Our results imply that placing these bounds on scan dates would be conservative, but clearly safe for the range of breeds and management systems that are expected to be contributing data to NSIP in the near future.

Genetic parameters

A review of the literature reveals a critical mass of estimates for both the phenotypic and genetic parameters for ultrasonic backfat thickness, loin eye area, and growth traits. A wide range of reported parameters exists, but selection of estimates obtained from animals of similar breed, age, weight, and management as those for which EPDs are to be calculated should provide a reasonable starting point for BLUP analysis. Once enough records exist in the database, periodic testing of parameters is encouraged.

APPLICATIONS

The ultimate success of any EPDs requires on the level of connectedness between purebred flocks reporting data, the level of supporting validation data from multiplier or commercial flocks, and, most importantly, an economic incentive for producers to improve the trait. Despite completion of this research project and meeting of its objectives, the success of and motivation for genetic improvement of lamb carcass composition traits is ultimately contingent upon a pricing system that rewards superior lean content. Whether the chicken or the egg comes first, interesting changes appear to be in the near future of the U.S. lamb industry.