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Validation of live animal ultrasonic measurements of body composition in market lambs

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ABSTRACT: Market lambs from the state fair of Virginia (n = 172) were ultrasonically evaluated by 4 scan technicians and 3 image interpreters to determine accuracy of ultrasonic estimates of loin muscle area (ULMA), backfat thickness (UBF), and body wall thickness (UBW). Lambs were initially scanned at the preferred magnification setting of each technician; 2 chose 1.5× and 2 chose 2.0×. Lambs were then scanned a second time for ULMA and UBF with machine magnification settings changed from 1.5 to 2.0×, or vice versa, midway through the second scan. Lambs were then slaughtered, and analogous measurements [carcass loin muscle area, carcass backfat thickness, and carcass body wall thickness (CBW)] were recorded on chilled carcasses. Pooled, residual correlation coefficients within technicians and interpreters between ultrasonic measurements from the first scan and carcass measurements were 0.66 for loin muscle area, 0.78 for backfat thickness, and 0.73 for body wall thickness, but were reduced to 0.43, 0.69, and 0.50, respectively, by inclusion of linear effects of carcass weight in the model. Mean bias for technicians and interpreters ranged from −1.30 to −2.66 cm^2 for loin muscle area, −0.12 to −0.17 cm for backfat thickness, and 0.14 to −0.03 cm for body wall thickness; prediction errors ranged from 1.86 to 2.22 cm^2, 0.12 to 0.14 cm, and 0.35 to 0.38 cm, respectively. Pooled correlations between repeated measures were 0.67 for ULMA, 0.79 for UBF, and 0.68 for UBW at the same magnification and 0.73 for ULMA and 0.76 for UBF across different magnification settings. Mean differences between repeated measures were more variable among technicians and interpreters than statistics comparing ultrasound to carcass measures. Standard errors of repeatability ranged from 1.61 to 2.45 cm^2 for ULMA, 0.07 to 0.11 cm for UBF, and 0.36 to 0.42 cm for UBW. The effect of changing magnification setting on technician and interpreter repeatability was small for UBF and ULMA. The accuracy of prediction of CBW from UBW was similar to that achieved for backfat thickness; further assessment of the value of ultrasonic measurements of body wall thickness in lambs is warranted. These results indicate that ultrasound scanning can reliably predict carcass loin muscle area and backfat thickness in live lambs and, accordingly, has value in selection programs to improve composition. Development of certification standards for US lamb ultrasound technicians based on results of this study and others is proposed.

Key words: accuracy, carcass, sheep, ultrasound, validation

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INTRODUCTION

Real-time (B-mode) ultrasound technology allows prediction of carcass characteristics associated with carcass composition in live breeding animals and thus is promising for use in selection to improve composition. Most recent studies (e.g., Tait et al., 2005; Sahin et al., 2008; Leeds et al., 2008b) report correlation coefficients between ultrasonic predictors and actual carcass measures in the range of 0.72 to 0.81 for backfat thickness (**BF**) and 0.75 to 0.88 for loin muscle area (**LMA**).

Correlations are limited as an indicator of accuracy because they are influenced by the variation present in the scanned population and do not reflect bias. Alternative statistics commonly used to validate accuracy of ultrasonic predictors in the swine and beef industries, such as total bias and SE of prediction (**SEP**), have not been widely reported for lambs. Few studies have considered effects of technician, machine, or image interpretation on ultrasound accuracy, and even fewer studies have addressed the consistency of ultrasonic measurements across repeated scans of the same lambs. Guidelines for accuracy and repeatability are necessary to develop certification standards for ultrasound tech-

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nicians, and such standards are critical for large-scale genetic evaluation of lamb composition.

Few studies in the United States have considered alternative scanning sites that may result in measurements that are more accurate or more indicative of body composition. In particular, carcass body wall thickness has been shown to be a useful predictor of carcass composition (Oliver et al., 1967; Smith et al., 1969; Smith and Carpenter, 1973) and can potentially be estimated using ultrasound in live animals (Thériault et al., 2009). This experiment was designed to assess accuracy and predictive value of ultrasonically derived measures of BF, LMA, and body wall thickness and to aid in development of certification standards for lamb ultrasound technicians.

MATERIALS AND METHODS

Animals and Measurements

In October, 2007, 172 market lambs from the State Fair of Virginia were ultrasonically scanned following university Institutional Animal Care and Use Committee protocols by 4 experienced technicians. Images of LMA (**ULMA**) and BF (**UBF**) were captured on the right sides of lambs between 12th and 13th ribs using Aloka 500 ultrasound machines (Corometrics Medical Systems, Wallingford, CT) equipped with 11-cm, 3.5-mHz transducers and Superflab standoff guides (Mick Radio-Nuclear Instruments Inc., Mt. Vernon, NY) to ensure proper contact with the animals. Lambs had been closely sheared and washed for show before 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 laptop computer. Each technician used their preferred magnification setting (1.5× or 2.0×) for the initial scans. Two technicians used 1.5×, and 2 used 2.0×. All lambs were scanned once by each technician at this preferred magnification setting. All lambs were then scanned a second time. At the second scanning, one-half (n = 86) of the lambs were scanned at the same magnification level used for the first scan. For the remaining 86 lambs, technicians changed machine magnification settings from 1.5 to 2.0×, or vice versa.

Two of the technicians also recorded images showing body wall thickness (**UBW**) between the 12th and 13th ribs. These images included the lateral edge of the LM but not the spine. Standoff guides were removed to measure UBW, and only the first one-half of lambs (n = 86) were scanned twice, at the same magnification settings that the 2 technicians used for the first scan.

Images were organized into coded subsets and sent to Walter and Associates LLC (Ames, IA), a centralized ultrasound processing laboratory, for interpretation. Each image was interpreted independently by each of 3 professional interpreters to determine ULMA, UBF, or UBW. The perimeter of the LM was traced to determine ULMA, and UBF was measured at the midpoint of the LM. The UBW was determined as total tissue thickness 6 cm from the lateral edge of the LM. The UBW measurement was chosen to correspond as closely as possible with the carcass body wall measurement (USDA, 1992), but capture of both spine and carcass body wall site in the same image was not possible with 12.5-cm transducers. Measurements were calibrated to reflect differences in magnification settings and then returned to Virginia Polytechnic Institute and State University, Blacksburg, for analysis.

Immediately after scanning, lambs were transported from Richmond, VA, to Wolverine Packing Inc., Detroit, MI, for slaughter. Hot carcass weights were recorded, carcasses were ribbed between the 12th and 13th ribs by plant personnel, and carcass measurements were taken on chilled carcasses within 3 d of scanning. Measurements of carcass BF (**CBF**) at the midpoint of the LM, LMA (**CLMA**, measured with a dot grid), and body wall thickness (**CBW**) at 12.7 cm from the midpoint of the spine were taken independently on each carcass by 2 experienced recorders. Due to the manner in which the lambs were ribbed, most carcass measurements were taken on the left side of the lambs, opposite to the side that was 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 by the 2 recorders did not differ significantly and were averaged. Correlations between measurements of BF, LMA, body wall thickness taken by the 2 recorders were 0.91, 0.94, and 0.88, respectively. When carcass measurements are based on the average of 2 recorders, correlations are expected to be increased by $2/(1 + c)$ compared with individual measurements where c is the correlation between measurements taken by the 2 recorders. Correlations with US measurements based on averages of the 2 recorders were thus expected to be only 3 to 6% greater than correlations involving only a single recorder.

Validation Statistics

Data were analyzed using SAS (SAS Inst. Inc., Cary, NC). Accuracy statistics were calculated using ultrasound interpretations from only the first set of scans and analogous carcass measures. Only 2 technicians performed body wall scans. Measurements of UBW from one interpreter had substantially smaller correlations (r) with carcass measures than those of the other 2 interpreters ($r = 0.55$ vs. 0.72 and 0.74) and were excluded from analysis.

Residual correlations between ultrasound and carcass measurements were calculated for each technician using a model that included effects of interpreter and for each interpreter using a model that included effects of technician. Pooled residual correlations between measurements were also derived using a model that included effects of both technician and interpreter, and with or without linear adjustment for effects of carcass weight.

Validation statistics included prediction bias = $\Sigma_i(\text{scan}_{i1} - \text{carcass}_i)/n$, repeatability bias = $\Sigma_i(\text{scan}_{i2} - \text{scan}_{i1})/n$, SEP = $[\Sigma_i(\text{scan}_{i1} - \text{mean bias} - \text{carcass}_i)^2/(n - 1)]^{1/2}$, and SE of repeatability = $[\Sigma_i(\text{scan}_{i2} - \text{scan}_{i1})^2/n]^{1/2}$ for each technician and interpreter, where scan_{i1} and scan_{i2} are the 2 ultrasonic measurements on the ith lamb; carcass_i is the carcass measure on the ith lamb, and n is the number of lambs used in the respective calculation. Lambs that did not have complete data for LMA and BF for all relevant technicians, repetitions, and interpreters were excluded from analysis, resulting in a final data set of 163 animals.

Repeatability statistics were calculated separately for lambs measured twice at the same magnification and for lambs measured at different magnifications. Observations that were missing their corresponding repeated scan was excluded, leaving 1,015 pairs of observations at the same magnification and 1,012 pairs of observations at different magnifications.

The CV of prediction and repeatability were used to compare accuracies of assessment among different measurements and were based on carcass least squares means. Heterogeneity of SEP and repeatability was assessed using Bartlett's test of homogeneity of variance. Confidence intervals for, and heterogeneity of, correlation coefficients was assessed using procedures of Snedecor and Cochran (1967).

Table 1. Means for traits measured in live animals and carcasses[1]

Item	Mean	SD	CV, %
Ultrasound variable[2]			
ULMA, cm^2	19.1	2.7	14.1
UBF, cm	0.45	0.14	32.2
UBW, cm	2.27	0.46	20.2
Carcass variable[3]			
CLMA, cm^2	21.1	2.4	11.4
CBF, cm	0.59	0.21	34.9
CBW, cm	2.22	0.52	23.5
HCW, kg	33.1	4.4	13.4

[1]n = 163.

[2]Scans were performed on the right side of the lambs between the 12th and 13th ribs using Aloka 500 ultrasound machines (Corometrics Medical Systems, Wallingford, CT) equipped with 11-cm, 3.5-mHz transducers and fitted with Superflab standoff guides (Mick Radio-Nuclear Instruments Inc., Mt. Vernon, NY) to minimize tissue distortion in the images. ULMA = ultrasonic loin muscle area; UBF = ultrasonic backfat thickness measured at the midpoint of LM; UBW = ultrasonic body wall thickness measured as total tissue thickness 6 cm from the lateral edge of the LM.

[3]Carcass measurements of loin muscle area (CLMA), backfat thickness (CBF), body wall thickness (CBW), and HCW.

RESULTS AND DISCUSSION

Means, SD, and CV for ULMA, UBF, and UBW and for analogous carcass measures (CLMA, CBF, and CBW, respectively) and carcass weight are presented in Table 1. Statistics for ultrasound measurements are based on individual measurements by the 4 technicians and 3 interpreters for LMA and BF, and the 2 technicians and 2 interpreters for body wall thickness.

Correlation Analysis of Ultrasound and Carcass Measurements

Pooled residual correlations between the first ultrasonic measurement and corresponding carcass measurements (indicated above the diagonal in Table 2) were 0.66 for LMA, 0.78 for BF, and 0.73 for body wall thickness. Approximate 95% confidence intervals for pooled residual correlations with 1,944 df were 0.46 to 0.53 for r = 0.50, 0.57 to 0.63 for r = 0.60, 0.68 to 0.72 for r = 0.70, and 0.78 to 0.82 for r = 0.80. Correlations between ultrasound and carcass measurements (Table 2) were thus greater for BF than for body wall thickness and greater for body wall thickness than for LMA. These differences among measurements in accuracy of estimation (as measured by correlation) correspond directly to differences in CV of measured variables (Table 1).

Correlations with HCW were significant for all measurements and larger for carcass fat measurements (CBF and CBW; r = 0.58 and 0.72) than for ultrasonic fat measurements (UBF and UBW; r = 0.50 and 0.65, respectively). Correlations between backfat and body wall thicknesses were larger when measured in carcasses than when measured ultrasonically (r = 0.73 vs. 0.58, respectively). Correlations between ultrasound and carcass measurements are merely "predictions of predictors" (Houghton and Turlington, 1992), but correlations between ultrasound or carcass measurements and actual composition are usually similar (McLaren et al., 1991).

When linear effects of HCW were included in the model (below the diagonal in Table 2), residual correlations between ultrasonic and carcass measurements were reduced to 0.43 for LMA, 0.69 for BF, and 0.50 for body wall thickness, but remained highly significant ($P < 0.001$). After adjusting for average differences among scanners and interpreters, effects of HCW alone accounted for 38.9, 33.2, and 51.4% of variation in LMA, BF, and body wall thickness, respectively, and effects of the ultrasonic estimator alone accounted for 43.4, 60.8, and 53.1% of variation, respectively. Inclusion of HCW and the ultrasonic estimator in the model increased these percentages to 50.2, 65.3, and 63.5%, respectively. The HCW and ultrasonic estimates thus provided important information for prediction of carcass measurements. These results are similar to those reported by Leeds et al. (2008b), who found that correlations of 0.75 and 0.80 between ultrasound and carcass measures of LMA and BF, respectively, were reduced to 0.49 and 0.67, respectively, by linear adjustment for effects of BW.

Correlations in Table 2 are based on individual scans and interpretations and would be increased by multiple independent scans of the same animal or multiple interpretations of each scan. To ascertain the potential accuracy of ultrasonic predictors of LMA, BF, and body

Table 2. Residual correlations among and between ultrasonic and carcass measurements with and without prior adjustment for carcass weight[1,2]

	Ultrasonic measurement			Carcass measurement			
Variable	ULMA	UBF	UBW	HCW	CLMA	CBF	CBW
ULMA		0.25**	0.44**	0.64**	0.66**†	0.33**	0.43**
UBF	−0.10**		0.58**	0.50**	0.06*	0.78**†	0.65**
UBW	0.03	0.38**		0.65**	0.21**	0.60**	0.73**†
HCW	[3]	[3]	[3]		0.62**	0.58**	0.72**
CLMA	0.43**†	−0.38**	−0.32**			0.11**	0.30**
CBF	−0.07*	0.69**†	0.36**	[3]	−0.39**		0.73**
CBW	−0.06*	0.48**	0.50**†	[3]	−0.28**	0.55**	

[1]n = 163. ULMA = ultrasonic loin muscle area; UBF = ultrasonic backfat thickness measured at the midpoint of LM; UBW = ultrasonic body wall thickness measured as total tissue thickness 6 cm from the lateral edge of the LM. CLMA = carcass measurement of loin muscle area; CBF = carcass measurement of backfat thickness; CBW = carcass measurement of body wall thickness.

[2]Correlations above the diagonal are from a model that included only effects of scanner and interpreter. Correlations below the diagonal are further adjusted for linear effects of HCW.

[3]Not available when HCW is included in the model.

$^{*}P = 0.01$; $^{**}P < 0.0001$.

†Indicates correlation between the same measurements in live animal and carcass.

wall thickness, correlations between ultrasound measurements and comparable carcass measurements were recalculated after averaging the 12 estimates of ULMA and UBF or the 4 estimates of UBW available for each animal and with or without previous adjustment for HCW. Simple correlations between average ultrasound and corresponding carcass measurements were 0.77 for ULMA, 0.87 for UBF, and 0.82 for UBW. Corresponding residual correlations after adjustment for effects of HCW were 0.59 for ULMA, 0.81 for UBF, and 0.62 for UBW.

Approximate 95% confidence intervals for these correlations, with 162 (for simple correlations) or 161 (for residual correlations) df, would be 0.49 to 0.69 for r = 0.60, 0.61 to 0.77 for r = 0.70, and 0.74 to 0.85 for r = 0.80. Correlations involving means of several scans and interpretations were thus greater than correlations involving individual scans and interpretations, but prior adjustment for HCW still resulted in significant reductions in the correlations between mean ultrasound and actual carcass measurements.

Correlation coefficients between ultrasound and carcass LMA for individual technicians ranged from 0.62 to 0.73, but did not differ among either technicians or interpreters. Correlation coefficients between ultrasound and carcass BF of 0.76 to 0.81 likewise did not differ among technicians or interpreters.

Correlation in Table 2 involving LMA were somewhat smaller than reported values of 0.88 (Fernández et al., 1997), 0.70 (Hiemke et al., 2004), 0.95 (Silva et al., 2006), 0.75 (Leeds et al., 2008b), and 0.82 (Sahin et al., 2008). The strong correlation reported by Silva et al. (2006) is interesting because of the amount of tissue distortion visible in their representative images and attributable to the absence of a standoff pad. All of these studies except that of Leeds et al. (2008b) used a transducer of greater frequency than that used in the current study (5 to 8 mHz vs. 3.5 mHz), which could result in greater image quality and perhaps partially explain the greater correlations. However, our LMA correlations were consistent across technicians and interpreters and may also reflect cutting and measurement errors in the cooler.

The potential for error resulting from the relative lack of precision of the loin muscle grid, improper ribbing of carcasses or bilateral asymmetry has been of some concern (Rust et al., 1970). The only other study measuring CLMA with a grid (Notter et al., 2004) reported a smaller correlation between ULMA and CLMA (r = 0.51) than ours. Correlations reported in studies where CLMA was traced on acetate paper and measured with a planimeter (Fernandez et al., 1997; Leeds et al., 2008b; Sahin et al., 2008) were greater than those in our study. The greatest reported correlation between ultrasound and carcass LMA (r = 0.95; Silva et al., 2006) resulted from measurement of CLMA using image analysis of digital photographs. Correlations of CLMA measurements taken by the 2 recorders of carcass data were large (0.88), indicating consistency (though not necessarily lack of bias) in grid interpretations. The greater correlations reported between ultrasonic and carcass LMA in the majority of studies were between measures taken on the same side (Fernandez et al., 1997; Silva et al., 2006; Leeds et al., 2008b; Sahin et al., 2008). A correlation of 0.91 between measures of CLMA taken on different sides of the carcass was observed by T. D. Leeds (USDA-ARS, Kearneysville, WV, unpublished data), demonstrating some potential for bilateral asymmetry.

Correlation involving BF were generally consistent with reported values of 0.74 (Fernández et al., 1997), 0.77 (Hiemke et al., 2004; Notter et al., 2004), 0.72 (Sahin et al., 2008), 0.81 (Leeds et al., 2008b), and 0.78 to 0.82 (Thériault et al., 2009), but less than the correlation of 0.97 reported by Silva et al. (2006). The consistent, large correlations for BF reported in our

Table 3. Average bias and prediction error SD (SEP) and CV associated with ultrasonic estimation of loin muscle area, backfat thickness, and body wall thickness for 4 scan technicians and 3 image interpreters[1]

	Loin muscle area, cm^2			Backfat thickness, cm			Body wall thickness, cm		
Item	Bias[2]	SEP[3]	CV, %	Bias[2]	SEP[3]	CV, %	Bias[2]	SEP[3]	CV, %
Technician 1	−1.90	1.86	8.8	−0.17	0.12	20.9			
2	−2.29	2.22	10.6	−0.14	0.13	22.3	−0.03	0.38	17.2
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			
Pooled	−1.96	2.08	9.9	−0.14	0.13	22.4	0.05	0.36	16.4

[1]Statistics for body wall thickness include only 2 technicians and 2 interpreters.

[2]Magnitude of bias differed ($P < 0.05$) among technicians for all measurements and among interpreters for loin muscle area and backfat thickness. The SE for bias in loin muscle area were 0.094 cm^2 for technician means, 0.081 cm^2 for interpreter means, and 0.047 cm^2 for the pooled mean. Corresponding SE were 0.006, 0.005, and 0.003 cm respectively, for backfat thickness, and 0.020, 0.020, and 0.014 cm, respectively, for body wall thickness.

[3]No significant differences ($P > 0.10$) in SEP among technicians or interpreters by Bartlett's test for loin muscle area and backfat thickness or F-test for body wall thickness.

study and by others indicate that current protocols for ultrasound BF scanning provide a reasonable prediction of carcass BF.

Mean body wall thickness was considerably larger than mean BF and therefore considered to be potentially measured with greater relative precision. However, resulting correlation coefficients do not provide conclusive evidence supporting additional accuracy and utility for the ultrasound body wall measurement. The correlation between ultrasonic and carcass measures of body wall thickness was smaller than the correlation between analogous measures of BF (0.73 vs. 0.78). However, correlations between ultrasound and carcass measures of body wall have not been reported for lambs, and some improvement in accuracy of ultrasonic body wall measurement could be hypothesized to accompany more experience with this measurement. Tschirhart et al. (2002) reported that carcass body wall thickness is often superior to BF as a predictor of percentage lean yield. In New Zealand, ultrasonic estimates of the rib tissue thickness (GR), defined as the total tissue depth between the surface of the carcass and the rib at a point 11 cm from the midline in the region of the 12th rib (Kirton et al., 1991), were shown to account for 64 and 49% of the variation in percentage of carcass fat and protein, respectively, and were highly correlated (r = 0.87) to the corresponding carcass measurement (Ramsey et al., 1991). In a recent Canadian study, Thériault et al. (2009) reported a correlation between ultrasound and carcass measurements at the GR site of 0.83, slightly greater than their reported correlations of 0.78 to 0.82 between ultrasound and carcass measurements of BF.

Bias and Prediction Error

Although widely reported in ultrasound studies, simple correlation coefficients are limited as a measure of predictive ability because they are influenced by the variation present in the scanned population and do not reflect bias. For example, the relatively large correlation of 0.88 between ultrasound and carcass LMA reported by Fernandez et al. (1997) was based on 60 lambs of 3 breed types that were similar in BW at scanning (22 to 28 kg) but diverse in CLMA, with breed means ranging from 10.1 to 12.2 cm^2. Silva et al. (2006) reported a correlation of 0.95 between ultrasound and carcass LMA, but used animals of 2 distinct breed types with an SD for CLMA that was approximately twice that of our lambs.

Other statistics used in beef (BIF, 2002) and swine (Bates and Christians, 1994), such as technician bias and the SE and CV of prediction, have been reported for lambs in a limited number of studies (Panting et al., 2000; Tait et al., 2005; Leeds et al., 2008b) and are shown in Table 3 for data in the current study. Performance was generally consistent among technicians and interpreters, with significant negative measurement bias for LMA and BF but no consistent bias for body wall thickness. The magnitude of bias differed among technicians and interpreters for LMA and BF and among technicians for body wall thickness, but there was no difference in SEP among technicians or interpreters for any measurements. However, technician bias is generally not a serious source of error in genetic evaluation programs because mean differences among technicians are normally included in contemporary groups for scanning traits and are therefore removed in the genetic analysis.

As expected, the prediction error CV was less for LMA than for body wall thickness and less for body wall thickness than for BF. These differences, like those for correlations in Table 2, correspond to differences in CV among carcass measures. Thus, as discussed by Leeds et al. (2008a), differences among traits or species in accuracy of ultrasonic predictions are not easily determined independent of the variability in the underlying predictand. In data from the current study, the

CV for CBF was approximately 1.5-fold larger than that for CBW and 3.1-fold larger than that for CLMA, and the CV for CBW was approximately 2.1-fold larger than that for CLMA. The corresponding prediction error CV for BF was 1.3-fold larger than that for body wall thickness but only 2.3-fold larger than that for LMA, and the prediction error CV for body wall thickness was 1.7-fold greater than that for LMA. Comparison of these proportional relationships between actual and prediction error CV among traits should minimize effects of underlying variation on apparent accuracy of measurement. The similar relationship between actual and prediction error CV for BF and body wall thickness suggests similar innate accuracies of measurement for these traits, but the proportionally smaller prediction error CV for BF and body wall thickness compared with LMA indicates less innate accuracy of measurement for LMA. Tait et al. (2005) likewise reported that the CV for CBF was 3.5-fold larger than that for CLMA, but that the prediction error CV for CBF was only 2.6-fold larger than that for CLMA. However, Leeds et al. (2008b) reported that carcass and prediction error CV for CBF were only 2.7- and 2.4-fold larger, respectively, than those for CLMA.

Measures of ULMA in this study were more biased (-2.66 to -1.30 cm^2) than in other recent studies (-0.004 cm^2, Leeds et al., 2008b; -1.50 to 0.21 cm^2, Tait et al., 2005). Measures of UBF in this study were also more biased (-0.17 to -0.12 cm) than recently reported values of 0.07 cm (Leeds et al., 2008b) and -0.03 to 0.13 cm (Tait et al., 2005). Measurement error can occur in either live animal or carcass measures, although carcass measures are the standard to which ultrasound estimates are typically compared. Because carcass measures of LMA and BF were consistently underestimated with similar magnitude by all technicians and interpreters, some of the discrepancy may be attributable to effects of processing or measurement errors in the cooler.

Some concern exists about consistency of ultrasound bias as measured traits increase or decrease (Leeds et al., 2008b). A tendency for ultrasound measurements to overestimate carcass measurements in lean or light-muscled lambs or to underestimate those measurements in fat or heavily muscled lambs reduces variability in ultrasonic measurements compared with carcass measurements. The UBF and UBW in this study were less variable than their analogous carcass measures (Table 1). Coefficients of regression of carcass measures on ultrasonic values were 0.90, 0.73, and 1.00 for LMA, BF, and body wall thickness, 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. Departures from unity for regression coefficients for BF resulted primarily from underestimation of CBF in fatter lambs. The quadratic component was negative and significant in second-order polynomials for LMA, BF, and body wall thickness. When pooled across all technicians and interpreters, R^2 for quadratic equations improved from 0.38 to 0.41 for LMA, from 0.50 to 0.58 for BF, and from 0.32 to 0.53 for body wall thickness when compared with linear equations.

The SEP for ULMA in this study (1.86 to 2.22 cm^2) were greater than those reported by Leeds et al. (2008b; 1.55 cm^2), but less than those reported by Panting et al. (2000; 1.74 to 2.69 cm^2), and very similar to those reported for 3 technicians by Tait et al. (2005; 1.92 to 2.18 cm^2). The SEP for UBF in this study (0.12 to 0.14 cm) were very similar to those reported in other studies, including 0.14 (Leeds et al., 2008b; Thériault et al., 2009), 0.084 to 0.137 (Panting et al., 2000), and 0.12 to 0.13 cm (Tait et al., 2005). The SEP for UBW in this study (0.35 to 0.38 cm) were somewhat larger than the value of 0.25 reported for the GR measurement by Thériault et al. (2009).

Repeatability of Ultrasonic Measurements

Repeatability statistics, including correlation, mean difference, and repeatability standard error (**SER**) for technicians and interpreters within and across magnification settings are shown in Tables 4, 5, and 6 for lambs scanned at the same or different magnification settings. For repeated measures taken at the same magnification setting, repeatabilities for UBF ranged from 0.72 to 0.85 and were generally greater than those for ULMA, which ranged from 0.57 to 0.79, and for UBW, which ranged from 0.57 to 0.77 (Table 4). Approximate 95% confidence intervals for pooled repeatabilites in Table 4, with approximately 1,000 df for each group, would be 0.56 to 0.64 for r = 0.60, 0.67 to 0.73 for r = 0.70, and 0.78 to 0.82 for r = 0.80. Measures of BF taken at the same magnification were thus more repeatable than other pairs of measurements, but the repeatability of LMA was greater when the second measurement was taken at a different magnification setting.

Mean differences between repeated ultrasound measures, calculated by subtracting the first ultrasound scan from the second (Table 5), indicate that differences between LMA scans were less uniform across technicians and interpreters than ultrasound-carcass bias statistics associated with the first scan (Table 3). This variation implies that technician repeatability may be an issue in prediction of LMA. Mean differences in LMA generally increased as technicians moved away from their preferred magnification setting for the second scan. However, SER and CV (Table 6) reveal that 3 of 4 technicians had decreased SER for LMA across magnification settings than at their preferred setting. This result is counterintuitive but may reflect greater care exercised when the second scan was made at an unfamiliar magnification.

The SER for ULMA in this study (1.61 to 2.45 cm^2) were greater than the 1.31 cm^2 reported by Leeds et al. (2008b), but within the range of 1.07 to 3.25 cm^2 reported by Panting et al. (2000) for 7 technicians. The SER for UBF in this study (0.07 to 0.11 cm) were comparable with the 0.08 cm reported by Leeds et al.

Table 4. Correlations between repeated ultrasonic measurements of loin muscle area, backfat thickness, and body wall thickness at the same (A) or different (B) magnifications for 4 scan technicians and 3 image interpreters[1]

Item	ULMA (A)	ULMA (B)	UBF (A)	UBF (B)	UBW (A)[2]
Technician 1	0.79	0.82	0.83	0.71	
2	0.57	0.69	0.85	0.84	0.57
3	0.63	0.73	0.72	0.69	
4	0.66	0.80	0.76	0.73	0.77
Interpreter 1	0.66	0.77	0.77	0.73	0.72
2	0.70	0.79	0.84	0.79	0.62
3	0.62	0.71	0.78	0.71	
Pooled	0.66	0.75	0.79	0.74	0.67

[1]Correlations for body wall thickness include only 2 technicians and interpreters. ULMA = ultrasonic loin muscle area; UBF = ultrasonic backfat thickness measured at the midpoint of LM; UBW = ultrasonic body wall thickness measured as total tissue thickness 6 cm from the lateral edge of the LM.

[2]Repeated scans for body wall were made only at the same magnification.

Table 5. Mean difference between repeated ultrasound measures of loin muscle area (LMAD), backfat thickness (BFD), and body wall thickness (BWD) at the same (A) or different (B) magnifications for 4 scan technicians and 3 image interpreters[1,2]

	Loin muscle area, cm^2		Backfat thickness, cm		Body wall, cm
Item	LMAD (A)	LMAD (B)	BFD (A)	BFD (B)	BWD (A)[3]
Technician 1	−0.23	0.40	0.00	0.03	
2	0.25	0.91	0.02	0.00	−0.06
3	0.78	−0.49	0.01	−0.06	
4	−0.96	−1.67	−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	
Pooled	−0.04	−0.19	0.01	0.01	−0.04

[1]Differences for body wall include only 2 technicians and 2 interpreters.

[2]The mean difference between repeated scans varied significantly among both technicians and interpreters for loin muscle area and body wall thickness but only among technicians for backfat thickness. The SE for mean differences in loin muscle area were approximately 0.116 cm^2 for technician means, 0.112 cm^2 for interpreter means, and 0.065 cm^2 for the pooled mean. Corresponding SE were 0.006, 0.005, and 0.003 cm, respectively, for backfat thickness, and 0.026, 0.032, and 0.023 cm, respectively, for body wall thickness.

[3]Repeated scans for body wall were made only at the same magnification.

Table 6. Repeatability SD (SER) and CV associated with ultrasonic estimation of loin muscle area, backfat thickness, and body wall thickness at the same (A) or different (B) magnifications for 4 scan technicians and 3 image interpreters[1]

	Loin muscle area,[2] cm^2				Backfat thickness,[3] cm				Body wall,[4] cm	
	Group A		Group B		Group A		Group B		Group A[5]	
Item	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		
Pooled	2.07	9.8	1.97	9.3	0.09	15.3	0.10	16.6	0.38	16.9

[1]Repeatability statistics for body wall include only 2 technicians and 2 interpreters.

[2]SER for loin muscle area differ among technicians ($P < 0.001$ for group A and $P = 0.025$ for group B) but not among interpreters.

[3]SER for backfat thickness differ among both technicians ($P = 0.005$ for group A and $P < 0.001$ for group B) and interpreters ($P < 0.025$ for both groups).

[4]SER for body wall thickness differ between technicians ($P = 0.01$) but not between interpreters.

[5]Repeated scans for body wall were made only at the same magnification.

(2008b) and toward the smaller end of the range of 0.079 to 0.16 cm reported by Panting et al. (2000).

Development of Certification Guidelines

Development of guidelines for certification of lamb ultrasound technicians using statistics used by the beef and swine industries would be desirable. Tait et al. (2005) proposed the following guidelines for certification of US sheep scan technicians: SEP, SER, and bias of less than 0.25 cm (0.10 in) with r $\geq$ 0.60 for fat thickness, and less than 3.23 cm^2 (0.50 in^2) with r $\geq$ 0.50 for LMA. However, Leeds et al. (2008a) compared means and SD for carcass and ultrasonic measurements in cattle, swine, and sheep and proposed more rigorous certification standards than those recommended by Tait et al. (2005): SEP <0.125 cm for UBF and <1.53 cm^2 for ULMA, to achieve rank correlations of 0.85 between ultrasound and carcass measurements in simulated data. Comparisons of accuracy statistics from the current study confirm that certification guidelines proposed by Tait et al. (2005) are relatively more liberal than those used for cattle and pigs. Our technicians easily met certification criteria of Tait et al. (2005), but either barely met (for BF) or did not achieve (for LMA) standards proposed by Leeds et al. (2008a).

Results from this study support the generally accepted idea that ultrasound technology can predict BF and LMA in lambs with acceptable accuracy when current protocols are used by trained technicians and images are traced by experienced interpreters. Therefore, ultrasound estimates of carcass traits are useful as a selection tool to improve lamb carcass composition. Development of certification standards for ultrasound technicians is needed, and standards should involve statistics that indicate measurement bias and recognize inconsistencies in repeated measures on the same lambs. Additional studies are required to assess the value of ultrasonic estimates of body wall thickness as a predictor of carcass lean yield.

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