2014

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Published December 12, 2014

Use of ultrasound scanning and body condition score to evaluate composition traits in mature beef cows[1,2,3]

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ABSTRACT: The experiment was designed to validate the use of ultrasound to evaluate body composition in mature beef cows. Both precision and accuracy of measurement were assessed. Cull cows (*n* = 87) selected for highly variable fatness were used. Two experienced ultrasound technicians scanned and assigned BCS to each cow on 2 consecutive days. Ultrasound traits were backfat thickness (UBFT), LM area (ULMA), body wall thickness (UBWT), rump fat depth (URFD), rump muscle depth (URMD), and intramuscular fat (UIMF; %). Cows were then harvested. Carcass traits were HCW, backfat thickness (CBFT), LM area (CLMA), body wall thickness (CBWT), and marbling score (CMS). Correlations between consecutive live measurements were greatest for subcutaneous fat ($r > 0.94$) and lower for BCS ($r > 0.74$) and URMD ($r > 0.66$). Repeatability bias differed from 0 for only 1 technician for URMD and UIMF ($P < 0.01$). Technicians differed in repeatability SE for only ULMA ($P < 0.05$). Correlations between live and carcass measurements were high for backfat and body wall thickness ($r > 0.90$) and slightly less for intramuscular fat and LM area (r = 0.74 to 0.79). Both technicians underestimated all carcass traits with ultrasound, but only CBFT and CBWT prediction bias differed from 0 ($P < 0.05$). Technicians had similar prediction SE for all traits ($P > 0.05$). Technician effects generally explained <1% of the total variation in precision. After accounting for technician, animal effects explained 50.4% of remaining variation in differences between repeated BCS ($P < 0.0001$) but were minimal for scan differences. When cows with mean BCS <4 or >7 were removed, the portion of remaining variation between repeated measurements defined by animal effects increased for most traits and was significant for UBFT and URFD ($P = 0.03$). Technician effects explained trivial variation in accuracy ($P > 0.24$). Animal effects explained 87.2, 75.2, and 81.7% ($P < 0.0001$) of variation remaining for CBFT, CLMA, and CBWT prediction error, respectively, and remained large and highly important ($P < 0.0001$) when only considering cows with BCS from 4 to 7. We conclude that experienced ultrasound technicians can precisely and accurately measure traits indicative of composition in mature beef cows. However, animal differences define substantial variation in scan differences and, especially, prediction errors. Implications for technician certification, carcass pricing, and genetic evaluation are discussed.

Key words: body condition score, beef cow, carcass, composition, ultrasound, validation

J. Anim. Sci. 2014.92:3868–3877
doi:10.2527/jas2014-7920

[1]The authors wish to thank the technical staff at the Roman L. Hruska U.S. Meat Animal Research Center (Clay Center, NE) for their support of the experimental program and E. Stephens (Blacksburg, VA) for technical editing. We appreciate the assistance of C. Hays (Critical Insights, Inc., Maryville, MO) with ultrasound image interpretation, and of the management and staff at the commercial cow plant for facilitating carcass data collection.

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Received April 9, 2014.
Accepted July 7, 2014.

INTRODUCTION

Body condition varies with mature size (Klosterman et al., 1968) and influences nutrient requirements (NRC, 2000), reproductive efficiency (Richards et al., 1986), and cull value (Apple, 1999) of beef cows. Accordingly, it has key implications for profitable cow–calf systems. Subjective BCS is commonly used to assess body reserves (Miller et al., 2004; Odhiambo et al., 2009) and is predictive of fat and muscle percentages after slaughter (Apple et al., 1999). Real-time ultrasound allows energy depots to be measured objectively.

Standard carcass measurements reflect composition (Greiner et al., 2003b). Since ultrasound can reliably predict carcass measurements (Greiner et al., 2003c; Emenheiser et al., 2010), it follows that ultrasound can estimate composition indirectly. That syllogism has been validated in young animals with carcass dissection (Greiner et al., 2003a; Tait et al., 2005) but has not been widely explored in mature cows.

Bullock et al. (1991) confirmed that ultrasound adds value to BCS for predicting cow composition. Consistency across repeated scans of the same cows has not been considered. The accuracy of cow carcass trait prediction has been evaluated only by correlation, which does not reflect measurement bias (Houghton and Turlington, 1992). Statistics used by the Ultrasound Guidelines Council (**UGC**) to certify technicians for submission of ultrasound body composition data from young animals to U.S. breed associations for genetic evaluation (Tess, 2012) have not been reported for cows. These UGC statistics include bias, SE of repeatability (**SER**), and SE of prediction (**SEP**).

This experiment was designed to evaluate 1) relationships among predictors of live animal body composition and carcass traits in cows varying appreciably in BW, BCS, and therefore fatness; 2) precision and accuracy of ultrasound scanning and BCS in cows using UGC statistics; and 3) consequences of variation in BCS among cows on these statistics.

MATERIALS AND METHODS

This study was conducted at the Roman L. Hruska U. S. Meat Animal Research Center (**USMARC**), Clay Center, NE, in November 2012. Animals were raised in accordance with the *Guide for the Care and Use of Animals in Agricultural Research and Teaching* (FASS, 2010), and their care was approved by the USMARC Animal Care and Use Committee.

Animals

Beef cows ($n = 87$) targeted for cull (for age or reproductive failure) were used. Cows originated from multiple research herds at USMARC with variable breed composition (primarily *Bos taurus*) and production history and ranged in age from 2 to 13 yr. The experimental population therefore provided considerable variation in BCS and BW, which was focal to the hypotheses tested.

Experimental Design

Each cow was ultrasonically scanned in random order on 2 consecutive days by 2 experienced technicians. A cow remained in the chute until evaluated by both technicians, who operated independently and in alternating order. Cows were then harvested at a commercial plant and related measurements were taken on carcasses.

Live Animal Measurements

With the exception of 1 record from 94 d before, all BW were collected within 3 wk of scanning. The BW were used with no date adjustment.

Ultrasonic images were captured on the left side of the animals using UGC techniques as described by Hays and Meadows (2012). Each technician collected 1 rib, 1 rump, 1 body wall, and 5 intramuscular fat images per cow per day. Rib and body wall images were captured between the 12th and 13th ribs. Those images were used to estimate subcutaneous backfat thickness (**UBFT**), LM area (**ULMA**), and body wall thickness (**UBWT**). The UBFT was measured three-fourths of the length ventrally on the LM, and the UBWT was measured perpendicular to the external body surface 4 cm from the ventral tip of the LM. Rump images were collected midway between the hook and pin bones (ischium and ilium) and approximately 7.5 cm from, and parallel to, the dorsal midline. Rump images were used to measure ultrasound rump fat depth (**URFD**) at the interface of the biceps femoris and gluteus medius muscles. The ultrasound rump muscle depth (**URMD**) was measured as the lean tissue depth from the ventral endpoint of URFD to the hip bone. Intramuscular fat images were collected over the LM, approximately perpendicular to, and including, the last 3 ribs, and were used to measure ultrasound intramuscular fat (**UIMF**; %). Acronyms assigned to live animal measurements are provided in Table 1.

Ultrasonic images were collected with an Aloka SSD-500 machine (Corometrics Medical Systems, Wallingford, CT) fitted with a 17 cm, 3.5 mHz linear transducer using vegetable oil as a couplant. To avoid tissue distortion in rib images affecting ULMA, the transducer was typically fitted with a Superflab wave guide standoff pad (Mick Radio-Nuclear Instruments,

Table 1. Description of acronyms

Acronym	Definition
Live measurements	
UBFT	Ultrasound backfat thickness, cm
ULMA	Ultrasound LM area, cm^2
UBWT	Ultrasound body wall thickness, cm
URFD	Ultrasound rump fat depth, cm
URMD	Ultrasound rump muscle depth, cm
UIMF	Ultrasound intramuscular fat, %
Carcass measurements	
CBFT	Carcass backfat thickness, cm
CLMA	Carcass LM area, cm^2
CBWT	Carcass body wall thickness, cm
CMS[1]	Carcass marbling score

[1]200 = practically devoid^0; 300 = traces^0; 400 = slight^0; 500 = small^0; 600 = modest^0; 700 = moderate^0; 800 = slightly abundant^0; 900 = moderately abundant^0; 1000 = abundant^0.

Inc., Mt. Vernon, NY). Rib images were occasionally collected without use of a standoff pad for thin or lightly muscled cows (<10%). Images were captured and stored to a laptop computer using Scanning Partner software (UltraInsights, Inc., Maryville, MO), and sent to an UGC-certified lab for interpretation. Measurements were based on 1 interpretation of a single image for UBFT, ULMA, UBWT, URFD, and URMD and the average interpretations of the best 4 of 5 repeated images of the same site for UIMF.

Each technician independently assigned a subjective BCS to each animal before ultrasound scanning on each day. The BCS were assigned using a standard 9-point scale based on the technicians' visual estimations of fatness and muscling. When visual evaluation was obstructed by long hair, cows were palpated. Detailed descriptions of the characteristics for each score are provided by Eversole et al. (2009). In this study, scores were assigned when cows were confined to the chute, and only the cows' left sides were used for evaluation.

To coordinate with the operations of the commercial plant, cows were sent in 3 harvest groups of 29 cows each at 4, 6, and 11 d after the second scanning. Harvest groups were stratified by the average of the 2 BCS and a chute-side measurement of UBFT collected on d 1.

Carcass Measurements

On each harvest day, HCW were collected. The following day, carcasses were ribbed between the 12th and 13th ribs by a single worker. After a "bloom" period of approximately 15 min, 12th rib cross-section images were captured on both halves of the split carcass using the USMARC beef carcass image analysis system (Shackelford et al., 2003). Carcass measurements predicted by the system that was used in this study included backfat thickness (**CBFT**), LM area (**CLMA**), and marbling score (**CMS**). Due to inability to consistently capture 4 cm of the lower rib region on all images, carcass body wall thickness was measured manually with a probe on both carcass sides. If the probe measurement was noticeably affected by fat tear or other workmanship artifacts, that side was not used. When measurements were recorded on both sides, the 2 were averaged. Acronyms assigned to carcass measurements are shown in Table 1.

Statistical Analyses

Data were analyzed using the MEANS, CORR, GLM, and MIXED procedures of SAS (SAS Inst. Inc., Cary, NC). For repeatability and accuracy statistics, animals lacking complete data for each analysis were excluded to avoid imbalance.

Relationships among Traits. The UGC certification statistics are used to define differences among technicians. Because UGC certification focuses primarily on yearling seed stock, an initial interest was to define general relationships among body composition traits in mature cows. Pooled residual correlations among all traits were calculated for combined data (both technicians and both days) using a model that included the fixed effects peculiar to our design: technician, day, and technician × day interaction. Then, to determine whether certain trait relationships were more than a function of animal BW, similar correlations were generated when concurrently fitting a linear adjustment for the effects of HCW.

Precision of Live Animal Measurements. Precision of measurement was evaluated for ultrasound traits and BCS by comparing repeated measurements taken by the same technician on the same animal on consecutive days. This was assessed using 3 statistics suggested by the UGC (Tess, 2012) for each trait. The first statistic was the simple within-trait correlation among a technician's repeated measurements. The second statistic was the mean difference between these repeated measurements, which is referred to as repeatability bias. Repeatability bias was calculated for each technician as $\mu_{RB_j} = \sum_i^n \left(y_{2_{ij}} - y_{1_{ij}}\right)/n$, in which $y_{2_{ij}}$ and $y_{1_{ij}}$ were the second and first measurements of a trait, respectively, on the ith of n cows by the jth technician. The third statistic was the SE of the differences between repeated ultrasound or BCS measurements, which is referred to as SER. The SER was calculated for each technician as $SER_j = \left[\sum_i^n \left(y_{2_{ij}} - y_{1_{ij}}\right)^2/n\right]^{1/2}$. To facilitate comparison of measurement precision among traits, SER for each trait was also presented as CV and scaled to the mean of the first and second live measurements for each technician.

Repeatability of ultrasound measurements may vary among technicians. To test that possibility, the differences between repeated live animal measurements (i.e., scan differences) were analyzed by fitting a linear model with technician as the fixed effect and residual as the random effect. Comparisons of precision between technicians were made using Levene's test for homogeneity of variance.

Accuracy of Carcass Trait Prediction. Accuracy was assessed by comparing measurements in live animals to their analogous measurements on the same animal's carcass. Again, 3 statistics suggested by the UGC were assessed. These were calculated within each technician for each trait on each scanning day. The first statistic was the simple correlation between live and carcass measurements of corresponding traits on the same animals. The second statistic was the mean difference between these measurements, which is referred to as prediction bias. Prediction bias was calculated as $\mu_{PB_j} = \sum_i^n \left(y_{U_{ij}} - y_{C_i}\right)/n$, in which $y_{U_{ij}}$ was the ultrasound measurement for a trait on the ith of n cows by the jth technician on a given day and y_{C_i} was the carcass measurement for that trait on the ith cow. The third statistic was the SE of the difference between corresponding ultrasound and carcass measurements, and is referred to as SEP.

The SEP was calculated as $\text{SEP}_j = \left[\sum_i^n \left(y_{U_{ij}} - \mu_{PB_j} - y_{C_i}\right)^2/(n-1)\right]^{1/2}$. To facilitate comparison of measurement accuracy among traits, SEP for each trait was also presented as CV and scaled to the mean carcass measurement for the trait.

Differences in accuracy among technicians were tested by analyzing the differences between live animal and corresponding carcass measurements (i.e., prediction errors). A linear model with technician, day, and their interaction as the fixed effects and residual as the random effect was initially fitted. In preliminary analyses, neither day ($P > 0.76$) nor technician × day interaction ($P > 0.70$) defined substantial variation in prediction errors for UBFT, ULMA, or UBWT. Least squares means for ultrasound–carcass bias also did not differ ($P > 0.72$) within technician across days. In light of this, and to better represent the application of ultrasound in practical settings, the accuracy statistics reported in this study consider only scans collected on the first day. The effects of day and technician × day interaction were then necessarily removed from the model. Comparisons of accuracy between technicians were made using Levene's test for homogeneity of variance.

Technician and Animal Variation. In the construct of the UGC guidelines, variation in live and carcass composition among animals is not explicitly considered. However, animal effects may impact both the precision and accuracy of ultrasound evaluations. The animal component of scan differences (i.e., the difference between second and first ultrasound or BCS measurement) and prediction errors (i.e., the difference between first ultrasound and the analogous carcass measurement) was assessed in 2 ways. First, the relative contributions of technician and animal effects to overall phenotypic variation in these differences were considered for each live animal measurement by fitting both technician and animal as random effects, in addition to the residual. Second, a random animal effect was added to the statistical models assessing scan differences and prediction errors; doing so allowed the variation remaining after accounting for a fixed technician effect to be partitioned into animal and residual components. By fitting animal in these models, the probability of detecting differences in precision and accuracy between technicians would be expected to increase.

The cows for this study were chosen to be widely variable in BCS. To investigate the animal effects on technician performance in a population that was more likely to represent a typical breeding herd, the same analyses were repeated on a reduced data set of 67 cows that excluded cows with an average BCS <4 or >7.

RESULTS AND DISCUSSION

Summary Statistics

Summary statistics for live variables and for analogous carcass measurements are presented in Table 2. With the exception of BW, each live trait was measured 4 times per cow (2 technicians and 2 d). In rare cases, ultrasound data were excluded based on image quality assessment by the technician interpreting the scans, which is reflected by fewer than 348 observations for the trait. No ultrasound measurements were missing for UBFT, ULMA, or UIMF. Carcass variables reflect a single measurement for each trait per carcass ($n = 87$).

Compared to the few other studies evaluating ultrasound in mature beef cows, this study was larger in size and included a wider range in BW and fatness. Although BW used in our study were not collected on the scanning day, the correlation between the BW used and HCW was $r = 0.96$. The minimum BW in the current study (383 kg) was comparable to the average of the lightest group reported by Bullock et al. (1991); additionally, the average of the heaviest group in that study (528.7 kg) was lighter than the overall mean (608 kg) and, therefore necessarily, maximum BW (869 kg) in the current study. Means for BW reported by Miller et al. (2004) were similar to ours but did not approach either our maximum or minimum BW; their BW were also affected by pregnancy. In addition, neither Bullock et al. (1991) nor Miller et al. (2004) evaluated cows with the extremes in carcass fatness found in our study. Furthermore, with increases in cow mature weights generally over the past decades (Cundiff et al., 2007), periodic evaluation of current cow types is warranted.

Measurements of subcutaneous fat (URFD, UBFT, and CBFT) were most variable, while those for weight

Table 2. Summary statistics for traits measured in live animals and carcasses[1]

Item	No.	Mean	Minimum	Maximum	SD	CV, %
Live variable[2]						
BW, kg	87	608	383	869	96.9	15.9
BCS	348	5.9	2.0	9.0	1.4	23.5
UBFT, cm	348	0.61	0.10	2.64	0.50	81.9
ULMA, cm^2	348	73.97	34.52	108.84	12.41	16.8
UBWT, cm	347	3.19	1.52	7.90	1.15	36.1
URFD, cm	346	0.92	0.10	5.84	0.87	94.3
URMD, cm	346	8.41	5.21	11.86	1.00	11.9
UIMF, %	348	4.04	2.00	8.56	1.28	31.6
Carcass variable[3]						
HCW, kg	87	322.7	176.9	521.6	65.9	20.4
CBFT, cm	87	0.77	0.10	2.51	0.50	64.2
CLMA, cm^2	87	74.59	23.16	101.81	12.15	16.3
CBWT, cm	87	3.72	1.50	9.05	1.51	40.7
CMS	87	386.1	237.0	710.0	96.7	25.0

[1]UBFT = ultrasound backfat thickness; ULMA = ultrasound LM area; UBWT = ultrasound body wall thickness; URFD = ultrasound rump fat depth; URMD = ultrasound rump muscle depth; UIMF = ultrasound intramuscular fat; CBFT = carcass backfat thickness; CLMA = carcass LM area; CBWT = carcass body wall thickness; CMS = carcass marbling score.

[2]Live measurements, with the exception of BW, were measured by 2 technicians on 2 consecutive days.

[3]Carcass measurements of CBFT, CLMA, and CMS were recorded from rib images of both sides of split carcasses using the U. S. Meat Animal Research Center beef carcass image analysis system (Shackelford et al., 2003). The CBWT was measured manually with a probe, on both carcass sides when possible.

and muscle (URMD, CLMA, and ULMA) traits were least variable (Table 2). Larger CV for subcutaneous fat as compared to BCS, weight, and muscle traits suggests that variation in fatness may offer the greatest potential to describe overall variation in composition. The evaluation of subcutaneous fat may therefore be the most valuable application of ultrasound technology in cows, provided it remains sufficiently precise when absolute measurements are small. By definition, BCS measures energy reserves, which include both fat and muscle depots (Eversole et al., 2009). Both BCS and muscle traits were considerably less variable than fat (substantially smaller CV), suggesting that muscling has an important impact on visual evaluations of body condition.

Residual Correlation

Residual correlations remove systematic effects in an experimental design, in our case technician, day, and their interaction, to more robustly evaluate relationships among traits. Pooled residual correlations between ultrasonic measurements and corresponding carcass measurements (Table 3) were high ($r = 0.73$ to 0.94). Correlations between fat and muscle traits were modest to high, and all were positive. Correlations with HCW were significant for all traits and slightly greater for ultrasonic vs. carcass measurements of backfat thickness and LM area. This implies that relationships among traits are largely a function of animal BW.

After adjustment for HCW (data not shown), most of the residual correlations between measurements of fat and muscle were not different from 0 ($P > 0.05$) or were even significantly negative. The latter case implies that fat and muscle became antagonistic in cows of a given weight; that is, in our study, fatter animals tended to be relatively lighter muscled. Residual correlations between corresponding ultrasound and carcass traits were also consistently lower after accounting for HCW, although they remained positive and significant ($P < 0.0001$).

Precision of Live Animal Measurements

Correlation. Within-technician correlations between live measurements taken on consecutive days are shown in Table 4. Correlations differed more among measurements than between technicians and were greatest ($r =$ 0.94 to 0.99) for measurements of subcutaneous fat or body wall thickness. Noticeably lower correlations between repeated measurements were observed for BCS ($r = 0.74$ and $r = 0.75$) and URMD ($r = 0.73$ and $r =$ 0.66). The former is not surprising as BCS is subjectively rather than objectively assessed and was collected while cows were confined to the chute. Variation in shape of cows' hip bones and in body shape due to fatness and muscling likely causes the distance between the reference point (hook bone) and spine to differ among cows. This may have resulted in difficulty in assessing URMD at the same anatomical location across days.

Although correlations among repeated ultrasound measurements were not found in the literature for beef cows, our correlations exceeded those required by the UGC (Tess, 2012) for UBFT, ULMA, UIMF, and URFD ($r \geq 0.90$, $r \geq 0.85$, $r \geq 0.85$, and $r \geq 0.90$, respectively). Repeatability correlations in our study were also greater than those reported for ULMA, UBFT, and UBWT in lambs ($r = 0.66$, $r = 0.79$, and $r = 0.67$, respectively) by Emenheiser et al. (2010). This is likely attributable to the greater variation in these traits in cows as compared to lambs.

Repeatability Bias. Mean values for the differences between repeated measurements on live animals are reported for the 2 technicians in Table 4. Measurements were generally consistent across days ($P > 0.05$). The only exceptions were for Technician A for URMD and UIMF ($P < 0.01$). In both cases, the repeatability bias was negative, meaning the measurement was less on the second day. No comparative results were available in the literature for cows.

Standard Error of Repeatability. Standard errors of repeatability between measurements taken on

Table 3. Residual correlations among and between live animal and carcass measurements[1,2]

Variable	Live animal measurement							Carcass measurement				
	BCS	UBFT	ULMA	UBWT	URFD	URMD	UIMF	HCW	CBFT	CLMA	CBWT	CMS
BW	0.65***	0.60***	0.74***	0.65***	0.58***	0.60***	0.36***	0.96***	0.59***	0.72***	0.70***	0.40***
BCS	–	0.68***	0.66***	0.72***	0.68***	0.51***	0.34***	0.73***	0.66***	0.55***	0.75***	0.41***
UBFT		–	0.55***	0.92***	0.93***	0.38***	0.59***	0.72***	**0.91*****	0.29***	0.93***	0.48***
ULMA			–	0.65***	0.53***	0.59***	0.22***	0.82***	0.56***	**0.78*****	0.68***	0.38***
UBWT				–	0.90***	0.44***	0.55***	0.78***	0.88***	0.39***	**0.94*****	0.48***
URFD					–	0.36***	0.62***	0.69***	0.84***	0.29***	0.90***	0.55***
URMD						–	0.10	0.65***	0.41***	0.57***	0.47***	0.22***
UIMF							–	0.39***	0.54***	0.00	0.57***	**0.73*****
HCW								–	0.70***	0.75***	0.81***	0.45***
CBFT									–	0.27***	0.91***	0.47***
CLMA										–	0.43***	0.31***
CBWT											–	0.51***

[1]UBFT = ultrasound backfat thickness; ULMA = ultrasound LM area; UBWT = ultrasound body wall thickness; URFD = ultrasound rump fat depth; URMD = ultrasound rump muscle depth; UIMF = ultrasound intramuscular fat; CBFT = carcass backfat thickness; CLMA = carcass LM area; CBWT = carcass body wall thickness; CMS = carcass marbling score.

[2]Correlations are from a model that included the effects of technician, day, and technician × day interaction. Bold typeface indicates a correlation between the same measurements in live animal and carcass.

**P* < 0.05; ***P* < 0.01; ****P* < 0.0001.

Table 4. Within-technician (A or B) correlation, repeatability bias, SE of repeatability (SER), and CV associated with live animal measurements repeated on consecutive days[1]

Live variable	Correlation[2]		Repeatability bias[3]		SER[4]		CV,[5] %	
	A	B	A	B	A	B	A	B
BCS, 1 to 9	0.74***	0.75***	–0.01	0.10	0.96	1.06	16.2	18.1
UBFT, cm	0.98***	0.99***	–0.00	–0.01	0.09	0.09	14.9	14.6
ULMA, cm^2	0.86***	0.94***	–0.13	–0.04	6.35[a]	4.32[b]	8.6	5.8
UBWT, cm	0.94***	0.95***	–0.03	0.02	0.38	0.39	12.4	11.8
URFD, cm	0.98***	0.99***	0.02	0.00	0.15	0.13	16.4	14.0
URMD, cm	0.73***	0.66***	–0.28*	–0.12	0.75	0.81	9.0	9.6
UIMF, %	0.93***	0.90***	–0.14*	0.01	0.50	0.55	12.1	13.9

[a,b]Means for technicians only differed for ULMA (*P* < 0.05).

[1]UBFT = ultrasound backfat thickness; ULMA = ultrasound LM area; UBWT = ultrasound body wall thickness; URFD = ultrasound rump fat depth; URMD = ultrasound rump muscle depth; UIMF = ultrasound intramuscular fat.

[2]Simple correlation between repeated measurements taken on consecutive days.

[3]Calculated by averaging the subtraction of first day measurement from the second.

[4]$SER_j = \left[\sum_i^n \left(y_{2_{ij}} - y_{1_{ij}}\right)^2 / n\right]^{1/2}$, in which $y_{2_{ij}}$ and $y_{1_{ij}}$ are the second and first measurement of a trait, respectively, on the *i*th of *n* cows by the *j*th technician.

[5]SER relative to the mean for the trait in both days, within technician.

*Bias differs from 0 (*P* < 0.01); ***Correlation differs from 0 (*P* < 0.0001).

consecutive days for both technicians are shown in Table 4. The 2 technicians were similar in their SER for most traits, only differing for ULMA (*P* < 0.05). Both technicians met or exceeded UGC certification standards for SER for UBFT, ULMA, UIMF, and URFD. The other 2 traits, UBWT and URMD, are not routinely evaluated by UGC and hence there are not standards with which to compare. When expressed relative to the mean for the trait across both days and within technician, the SER was greatest for BCS (CV = 16.2 to 18.1%), least for ULMA and URMD (CV = 5.8 to 9.6%), and varied little among remaining measurements of fatness (CV = 11.8 to 16.4%). Compared to a similar ultrasound validation study in lambs (Emenheiser et al., 2010), our repeatability CV were slightly less than those reported for ULMA, UBFT, and UBWT (CV = 9.8, CV = 15.3, and CV = 16.9% in that study, respectively).

Accuracy of Carcass Trait Prediction

Correlation. Within-technician correlations between live (first day) and carcass measurements are shown in Table 5. Again, correlations differed more among measurements than between technicians. Correlations for

Table 5. Within-technician (A or B) correlation, prediction bias, SE of prediction (SEP), and CV associated with traits measured both in live animals and carcasses[1,2]

	Correlation[3]		Prediction bias[4]		SEP[5]		CV,[6] %	
Live variable	A	B	A	B	A	B	A	B
BCS, 1 to 9	0.60***	0.62***						
UBFT, cm	0.90***	0.91***	–0.17*	–0.15*	0.22	0.22	28.6	28.6
ULMA, cm^2	0.79***	0.78***	–0.96	–0.11	7.93	8.19	10.6	11.0
UBWT, cm	0.94***	0.94***	–0.65*	–0.42*	0.59	0.57	15.8	15.3
UIMF, %	0.77***	0.74***						

[1]UBFT = ultrasound backfat thickness; ULMA = ultrasound LM area; UBWT = ultrasound body wall thickness; UIMF = ultrasound intramuscular fat.

[2]Calculated using only live animal measurements collected on the first day.

[3]Simple correlation between ultrasound and carcass measurements. Correlations for BCS, UBFT, ULMA, UBWT, and UIMF are with carcass backfat thickness (CBFT), CBFT, carcass LM area, carcass body wall thickness, and carcass marbling score, respectively.

[4]Calculated by subtracting the carcass measurement from the ultrasound measurement.

[5] $SEP_j = \left[\sum_i^n \left(y_{U_{ij}} - \mu_{PB_j} - y_{C_i}\right)^2 / (n-1)\right]^{1/2}$, in which $y_{U_{ij}}$ is the ultrasound measurement for a trait on the ith of n cows by the jth technician, and y_{C_i} was the carcass measurement for that trait on the ith cow. Means did not differ between technicians ($P > 0.70$).

[6]SEP relative to the mean carcass measurement for the trait.

*Bias differs from 0 ($P < 0.05$); ***Correlation differs from 0 ($P < 0.0001$).

fat measurements were high, with $r \geq 0.90$ for UBFT and UBWT. Correlations were slightly less for UIMF and ULMA ($r = 0.74$ to 0.79). This result was to be expected for UIMF, as CMS was a related but not analogous measure. The modest relationship between ULMA and CLMA is possibly explained by area measurements being 2 dimensional as compared to 1 dimensional. Bilateral asymmetry could also be a source of error since carcass measurements reflect the average of both sides. This is more likely, since the correlation between repeated measurements of ULMA was high ($r = 0.86$ to 0.94; Table 4). However, although predictions from the carcass imaging software used both sides, independent values were not available to assess asymmetry. The correlations of 0.60 and 0.62 between BCS and CBFT are not surprising since the traits differ, including the fact that BCS considers both muscling and fatness.

Our accuracy correlations for cows were greater than those reported by Bullock et al. (1991) for UBFT ($r = 0.79$) but less for ULMA ($r = 0.90$). Our results were similar to those of Miller et al. (2004) for UBFT and UIMF ($r = 0.85$ and $r = 0.69$, respectively) and considerably greater than that reported for ULMA ($r = 0.49$). A difference in methods between these studies is that we used predicted rather than actual carcass measurements. Still, our predictions were derived from imaging software that has been shown to be useful to the beef industry for standard measurements and in-line grading of steer carcasses (Shackelford et al., 2003).

Both technicians in our study met UGC guidelines for prediction correlations of UBFT ($r \geq 0.90$) but were slightly below certification standards for ULMA and UIMF ($r \geq 0.85$ and $r \geq 0.85$, respectively; Tess, 2012). These comparisons are for reference only; the UGC guidelines are not intended to certify cow scan technicians. For UGC certification, UIMF measurements would instead be compared to the UIMF measurement of a reference technician rather than to CMS and typically for yearling seed stock. The greater amount of connective tissue expected in mature cows also may have introduced error in our UIMF predictions.

Prediction Bias. Mean values for the differences between ultrasound and carcass measurements (prediction bias) are reported for the 2 technicians in Table 5. Both technicians underestimated carcass measurements with ultrasound for all traits, as indicated by consistently negative values for prediction bias. Of the 3 traits for which both ultrasound and carcass measurements existed, prediction bias for both backfat and body wall thickness differed from 0 ($P < 0.05$). The composition of mature animals differs from young animals, with mean values for traits often larger. This may increase prediction bias. In addition, the carcass measurements were based on prediction equations developed for steer carcasses rather than cows. Carcass fat measurements may have been predicted in part by relationships with other traits that applied only in young animals. Differences in muscle shape between cows and steers may have introduced error to carcass measurements and/or to ultrasound interpretation by technicians accustomed to young beef cattle images. Still, our prediction bias nearly met the UGC's guidelines for UBFT absolute bias (0.17 and $0.15 \geq 0.13$ cm) and was within the acceptable range for ULMA (0.96 and $0.11 \leq 6.45$ cm^2).

Standard Error of Prediction. Standard errors of prediction between analogous ultrasound and carcass measurements are shown for both technicians in Table 5. The 2 technicians were similar in prediction accuracy for all 3 traits ($P > 0.05$). Neither technician met the requirements for UBFT or ULMA SEP in young animals

Table 6. Random animal and residual variation and respective SE for scan differences and prediction errors after accounting for fixed effect of technician[1]

	Full data[2]				Reduced data[3]			
	Animal		Residual		Animal		Residual	
Variable	Estimate[4]	SE	Estimate	SE	Estimate[4]	SE	Estimate	SE
Scan differences[5]								
BCS,[2] score	0.513*** (50.4%)	0.123	0.505***	0.077	0.504*** (49.5%)	0.140	0.514***	0.089
UBFT, cm^2	0.000 (1.4%)	0.001	0.008***	0.001	0.001* (23.6%)	0.001	0.004***	0.001
ULMA, cm^4	1.043 (3.5%)	3.184	28.468***	4.340	3.690 (15.7%)	2.930	19.823***	3.451
UBWT, cm^2	0.018 (12.2%)	0.016	0.131***	0.020	0.015 (12.2%)	0.015	0.109***	0.019
URFD, cm^2	0.002 (11.4%)	0.002	0.018***	0.003	0.003* (23.6%)	0.002	0.009***	0.002
URMD, cm^2	0.044 (7.3%)	0.068	0.568***	0.088	0.112 (20.7%)	0.070	0.429***	0.076
UIMF, %^{2}	0.025 (9.0%)	0.030	0.252***	0.038	0.013 (4.9%)	0.032	0.248***	0.043
Prediction errors[6]								
UBFT, cm^2	0.041*** (87.2%)	0.007	0.006***	0.001	0.033*** (93.2%)	0.006	0.002***	0.000
ULMA, cm^4	48.897*** (75.2%)	8.823	16.112***	2.472	40.309*** (73.1%)	8.473	14.846***	2.604
UBWT, cm^2	0.276*** (81.7%)	0.047	0.062***	0.009	0.151*** (75.5%)	0.031	0.049***	0.009

[1]UBFT = ultrasound backfat thickness; ULMA = ultrasound LM area; UBWT = ultrasound body wall thickness; URFD = ultrasound rump fat depth; URMD = ultrasound rump muscle depth; UIMF = ultrasound intramuscular fat.

[2]Includes scans on all animals (n = 86) by both technicians.

[3]Excludes animals with average BCS <4 or >7 (20 cows were removed).

[4]Percentage of total variance accounted for by animal effects is shown in parentheses.

[5]Calculated by subtracting the first day measurement from the second.

[6]Calculated by subtracting the carcass measurement from the first ultrasound measurement.

*P < 0.05; ***P < 0.0001.

published by the UGC (Tess, 2012). However, it is important to note that UGC guidelines (Tess, 2012) base accuracy statistics on reference ultrasound measurements collected by technicians rather than on carcass data as done in this study. When scaled to the mean carcass measurement for the trait within technician, the SEP was greatest for UBFT (CV = 28.6%) and least for ULMA (CV = 10.6 to 11.0%). Our CV for UBFT and ULMA were slightly greater than those reported in lambs by Emenheiser et al. (2010) and slightly less than the CV for UBWT in that study (CV = 22.4, CV = 9.9, and CV = 16.4% for UBFT, ULMA, and UBWT, respectively).

Technician and Animal Variation

Precision of Live Animal Measurements. When considering variation in scan differences in the full data due to technician and animal, errors due to technician were negligible (P > 0.29). For all traits except UIMF (3.1%), random technician effects accounted for <1% of the total phenotypic variation in scan differences. When the data were reduced to lessen variation in BCS, very little (<3.9%) of the variation in scan differences for any trait was still explained by technician (P > 0.29).

The remaining variation in scan differences, after accounting for technician effects, was partitioned into animal and residual components. For ultrasound traits, the animal effect accounted for between 1.4 and 12.2% of that remaining variation (Table 6; P > 0.13). Only for BCS was a substantial amount of the difference in measurements between days explained by animal after accounting for technician (50.4%; P < 0.0001). Therefore, only for BCS evaluations was the pattern of change across days consistent among animals.

When animal (after accounting for technician) effects were evaluated in the reduced data where cows with average BCS <4 or >7 had been removed, the results were similar for BCS, UBWT, and UIMF as in the full data (Table 6). However, the animal component increased substantially for UBFT, ULMA, URFD, and URMD (23.6 vs. 1.4%, 15.7 vs. 3.5%, 23.6 vs. 11.4%, and 20.7 vs. 7.3%, respectively). Furthermore, animal defined significant variation in scan differences for UBFT (P = 0.03) and URFD (P = 0.03). These results suggest that for fat traits particularly, when cows are comparatively more uniform in BCS, measurement precision is even more sensitive to animal differences. It is likely, however, that these results partly reflect the lower overall variation in the reduced data set.

Accuracy of Carcass Trait Prediction. Technician also defined trivial variation in prediction errors in both the full and reduced data for most traits (P > 0.24). Although still not significant, technician explained 6.7 and 12.7% of the variation in body wall thickness prediction errors in the full and reduced data, respectively.

Animal effects were considerably more important for explaining prediction errors than scan differences

(Table 6). For backfat, LM, and body wall prediction errors, animal effects accounted for 87.2, 75.2, and 81.7% of the variation remaining, respectively, after accounting for technician effects ($P < 0.0001$). This result indicates that large individual animal effects on prediction accuracy were present and were consistent between technicians. These animal effects likely reflect unique differences in amounts, shapes, or distributions of tissues among animals.

When investigating prediction errors using the reduced data set (Table 6), the animal component remained highly significant ($P < 0.0001$). Animal accounted for 93.2, 73.1, and 75.5% of the variation remaining in prediction error for backfat, LM, and body wall, respectively, in the reduced data. These results further substantiate that animal differences are highly influential on typical UGC validation statistics for ultrasound of cows, even when variation in BCS is restricted to levels commonly encountered in practice.

Conclusions

Our results indicate that experienced ultrasound technicians can precisely and accurately measure traits indicative of composition in mature beef cows. Both technicians were highly repeatable in their assessment of the commonly measured ultrasound traits. The objective ultrasound measurements were more repeatable than subjective BCS and were more predictive of carcass measurements. Ultrasound therefore provides more reliable and more trait-specific assessment of cow composition than a less direct measure such as BCS.

Accuracy of carcass trait prediction was similar between the 2 technicians in this study. Repeatability estimates for the carcass imaging software were previously shown to be very high (>0.97) for traits used in our analysis (Shackelford et al., 2003). Innate discrepancy between ultrasound and carcass measurements appears to exist that is not attributable to error in repeatability of either measure. Furthermore, prediction accuracy is more sensitive to differences among animals than between experienced technicians; in excess of 73% of the total variation in prediction errors for all traits was associated with animal effects. Such was the case with both a broader and narrower range of cow BCS.

Implications

There are 3 main contexts in which the precision and accuracy of composition estimation are important: 1) certification of ultrasound technicians, 2) pricing of live animals based on carcass merit, and 3) genetic evaluation of composition traits. The technicians in our study mostly met the UGC criteria for technician certification. However, repeatability and, especially, prediction errors overwhelmingly reflected differences among animals rather than between technicians. This implies that UGC guidelines may not be sufficiently stringent when variation in fatness among animals scanned for a certification event is not standardized.

In practice, mature cows are not commonly scanned, and the variation in fatness among the same animals at younger ages would be anticipated to be less. Still, investigation of between-animal effects on UGC statistics is likely warranted in yearling seed stock to ensure that certification requirements for technicians are sufficiently and consistently rigorous.

Given the extent of prediction bias, the pricing of cow carcasses on direct carcass measurements is not likely improved by live animal ultrasound. Such is particularly the case given the relatively narrow range of cow carcass grades and prices and the costs associated with implementing ultrasound technologies. However, if the spread of cow carcass value was greater and/or ascribed in the live animal, the high repeatability of ultrasound indicates it could contribute to delineating differences in carcass composition and value and could assist in management decisions before marketing.

In genetic evaluation of composition traits, the current beef industry structure again focuses on younger animals. With the fit of contemporary group effects in BLUP evaluations, the batch effect of individual technicians is absorbed. Therefore, in the context of genetic evaluation, the ability of a technician to consistently rank animals is more important than lack of measurement bias. Despite discrepancy between ultrasound and carcass measurements in our study, the high repeatability of ultrasound indicates it would be suitable for incorporation into genetic evaluation of composition in cows, if such was deemed valuable. Among the most promising applications of ultrasound in cows is its potential for more precise adjustment of mature cow weights to a constant endpoint for mature size EPD calculations.

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