In vivo estimation of sheep carcass composition using real-time ultrasound with two probes of 5 and 7.5 MHz and image analysis¹

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ABSTRACT: Ultrasonic measurements were taken on 46 sheep using a real-time ultrasound machine equipped with 2 probes (5 and 7.5 MHz). Measurements of subcutaneous fat thickness (SC) and muscle LM depth (MD) and area (MA) were taken at 2 locations: over the 13th thoracic vertebra (SC13, MD13, and MA13, respectively) and at the interval between the third and fourth lumbar vertebrae (SC34, MD34, and MA34, respectively). Fat thickness was also measured over the third sternebra of the sternum. The relationship between carcass and in vivo ultrasound measurements was high for all the measurements (r^2 between 0.54 and 0.96, $P < 0.01$). Concerning MD and SC, the 7.5 MHz probe estimates were consistently more precise than the 5-MHz estimates (r^2 increased between 0.09 and 0.13), but the reverse occurred with the MA estimates, although to a lesser extent. Estimates of carcass composition for muscle, subcutaneous fat, intermuscular fat, internal fat, and total fat based on BW explained a large amount of variation in muscle (87%), subcutaneous fat (85%), intermuscular fat (79%), internal fat (74%), and total fat (87%). In most cases (55 of

70) the introduction of one ultrasound measurement in addition to BW in the multiple regression equations further improved the explanation of variation for weight of carcass tissues, internal fat, and total fat. For carcass muscle estimation, the ultrasound measurements of muscle provided an increase of r^2 between 0.05 and 0.10 ($P < 0.01$). The SC13 and SC34 gave the best improvements in estimating subcutaneous fat, intermuscular fat, internal fat, and total fat (r^2 increased between 0.05 and 0.17; $P < 0.01$). Prediction of the proportions of the carcass components (internal and total fat from BW) was clearly lower than the prediction of the absolute amounts of these traits. Inclusion of one or more ultrasound measurements in addition to BW increased the predictive ability of the equations. Both probes were useful to estimate carcass muscle depth and area and fat depth, but the 7.5-MHz probe showed a greater ability to estimate depth. For all traits, the stepwise procedure demonstrated that the best fit was obtained with BW and one or more ultrasound measurement with the 7.5-MHz probe.

Key words: carcass composition, frequency probe, sheep, ultrasound

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INTRODUCTION

Although ultrasound technology has been used for evaluating meat animals for over 40 yr, only in the last 10 yr has its use become widespread. This is primarily due to the technological development of real-time (RT), linear array, ultrasonic transducers and scanners in

the medical field. Among the objective methods suitable for use in sheep, computed tomography, and magnetic resonance imaging have been pointed out as very accurate (Fuller et al., 1994), but the high cost of the technology limits their application in animal science. Therefore, RT ultrasound appears to be the most promising technique for use in animal science in the near future. Real-time ultrasound is frequently used to monitor differences in lean and fat growth (Hopkins et al., 1993; Silva et al., 2005). For such purpose, accurate measurements are an important goal to achieve to identify small variations in tissue depth.

A large number of factors can influence accuracy, precision, and repeatability of RT ultrasound measure-

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ments. Most studies have focused on the effects of animal, technician, and equipment (McLaren et al., 1991; Perkins et al., 1992; Herring et al., 1994). Among these factors, image analysis and probe frequency are recognized as important. In recent years, efforts have been focused on automated image analysis systems (Glasbey et al., 1996; Szabo et al., 1999), which improve the image analysis and reduce the effects attributable to operator and image acquisition. However, little information is available about the effect of probe frequency on prediction of carcass composition, despite the knowledge that the ability of sound waves to penetrate tissue and image resolution are dependent on and inversely related to the frequency of probe (Williams, 2002).

The study herein reported was undertaken to compare 2 ultrasonic probes (5 and 7.5 MHz) for predicting lamb carcass composition using *in vivo* ultrasound.

MATERIALS AND METHODS

Animals and Management

This experiment was conducted in accordance with principles and guidelines outlined in Guidelines for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 1999).

The experimental group consisted of 37 female sheep of the native Churra da Terra Quente breed (44.8 ± 2.27 kg) and 9 intact male lambs (Ile de France $\times$ Churra da Terra Quente; 27.0 ± 3.03 kg). All sheep were kept under the same management conditions. The sheep were fed according to the NRC (1985) recommendations. Before ultrasound measurements and subsequent slaughter, the sheep were shorn, deprived of food for 24 h, and weighed. Just before slaughter, the sheep were scanned with an Aloka SSD 500V real-time scanner (Tokyo, Japan) using 2 linear probes, one of 7.5 MHz (UST-5512U-7.5, 38 mm, Aloka) and another of 5.0 MHz (UST-588U-5, 64 mm, Aloka). At each measurement site, the wool was clipped close to the skin and shaved. A gel was used as a coupling medium. For ultrasound scanning, sheep were individually restrained in a crate to minimize movements and to ensure they were standing in a normal position.

Ultrasound Measurements

Probes were placed perpendicular to the backbone, over the 13th thoracic vertebra, between the third and the fourth lumbar vertebrae, and over the third sternebra of the sternum. Measurements of subcutaneous fat (SC) at these sites represented 3 fat depths: **SC13**, **SC34**, and **SCst**, respectively. The depth (**MD**) and the area (**MA**) of the LM were measured over the 13th thoracic vertebra and at the interval between the third and fourth lumbar vertebrae, yielding 2 muscle depths and 2 muscle areas: **MD13**, **MD34**, **MA13**, and **MA34**, respectively.

Image Analysis

Once a satisfactory image had been obtained at each site, it was captured on a video printer (SSZ-303E, Aloka). Then, the images were digitized and amplified 1.5 times, and measurements were calculated by image analysis with National Institutes of Health (NIH) 1.57 software (<http://rsb.info.nih.gov/nih-image/>; last accessed on 15 August, 2006). Scanning and interpretation of the scans were always done by the same technician, who had extensive experience with ultrasound technology and image interpretation, and anatomical knowledge of sheep.

Slaughter Procedure, Carcass Composition, and Carcass Measurements

After being stunned with a captive-bolt gun, the sheep were slaughtered by severing the carotid arteries. The fore and the hind limbs (feet) were then separated at the radiocarpal and tarsometatarsal articulations, respectively. The pelt, head, and all internal organs were removed, and the carcass was weighed. Internal fat depots (mesenteric, omental, kidney, and pelvic fat) were carefully obtained and weighed. The carcass was stored at 4°C for 24 h, reweighed, split along the vertebral column with a band saw, and each side was weighed. The left half of the carcass was entirely dissected into muscle, subcutaneous fat, intermuscular fat, and bone using the standard method described by Fisher and DeBoer (1994).

A segment of the thoracic/lumbar region (13th thoracic vertebra, first, second, and third lumbar vertebrae) and a segment of the sternum region (first, second, third, and fourth sternebrae) were removed from the right half of the carcass to take carcass measurements equivalent to those taken *in vivo*. For this purpose, a digital camera (Coolpix 900, Nikon, Tokyo, Japan) was used to capture an image of the carcass at the same transverse planes at which the ultrasound measurements were taken, and all measurements were obtained after image analysis with the NIH 1.57 software mentioned above.

Statistical Analysis

All data for carcass muscle, subcutaneous fat, intermuscular fat, internal fat, and total fat weights, and their respective proportions relative to empty BW (**EBW**), were estimated by simple regression equations using BW and also by multiple regression using BW and ultrasound measurements. All regression analyses were performed with PROC REG (SAS Inst. Inc., Cary, NC) to determine which independent variables best predicted carcass composition. The regression equations were evaluated by using the coefficient of determination and the residual SD. The best regression equations were obtained using a stepwise procedure. The best models were selected based on the coefficient of determination, optimizing Mallows Cp statistics, and the resid-

Table 1. Body weight, empty BW (EBW), carcass tissues, internal fat, total fat, and proportion of carcass tissues, internal fat, and total fat (n = 46)

Weights and proportions	Mean	SD	CV, %
BW, kg	41.4	14.9	36.0
Empty BW, kg	36.2	12.8	35.4
Carcass composition, kg			
Muscle	12.3	4.8	39.1
Subcutaneous fat	2.21	1.61	72.9
Intermuscular fat	2.04	1.17	57.5
Bone	3.58	1.19	33.3
Internal fat depots, kg			
Mesenteric fat	0.42	0.23	55.3
Omental fat	0.53	0.33	61.0
KKCF ¹	0.35	0.22	61.1
Internal fat, ² kg	1.30	0.75	57.6
Total fat, ³ kg	5.54	3.44	62.0
Proportion of carcass tissues, g·kg of EBW ⁻¹			
Muscle	337.9	28.0	8.3
Subcutaneous fat	54.5	23.8	43.6
Intermuscular fat	53.7	14.1	26.3
Bone	100.0	11.7	11.7
Internal fat, g·kg of EBW ⁻¹	33.7	11.0	32.8
Total fat, g·kg of EBW ⁻¹	141.9	43.8	30.9

¹KKCF = Kidney knob and channel fat (kidney and pelvic fat, respectively).

²Internal fat = mesenteric + omental + KKCF.

³Total fat = internal fat + subcutaneous fat + intermuscular fat.

ual SD (MacNeil, 1983). The carcass and ultrasound measurements were analyzed by ANOVA, and differences among specific means were determined using Fisher's LSD test with a predetermined significance level of $P < 0.05$.

RESULTS AND DISCUSSION

Means, SD, and CV of BW, EBW, carcass tissues, internal fat, total fat, and proportions of carcass tissues, internal fat, and total fat are shown in Table 1. Carcass composition varied considerably: muscle weight varied between 5.1 and 25.1 kg and subcutaneous fat between 0.36 and 7.1 kg (data not shown). This variation was expected because it mainly reflects variation of BW (18 to 79 kg). Also, as expected, fat depots were the components that exhibited more variation, given the variation in BW and the fact that fat is the most variable tissue in terms of proportion of body composition. Means and SD of ultrasound and carcass measurements are presented in Table 2. Ultrasound measurements in vivo with both probes and carcass measurements were not different ($P > 0.05$) for muscle and SCst measurements. A small difference was observed between SC13 and SC34 carcass measurements, which were higher ($P < 0.05$) with 7.5 MHz and closer to the observed values in carcass than those obtained with the 5-MHz probe. This finding is in agreement with results previously obtained by this team (Silva et al., 2005). Carcass mea-

surements of all variables were not different ($P > 0.05$) from those obtained in vivo with the 7.5-MHz probe.

Relationship Between Ultrasonic and the Corresponding Carcass Measurements

The r^2 and the residual SD of the simple regression equations obtained between ultrasound and the corresponding carcass measurements are summarized in Table 3. The potential of ultrasound measurements in vivo as predictors of measurements made in carcass was high for all subcutaneous fat and muscle measurements (r^2 between 0.54 and 0.98; $P < 0.01$). However, the potential of SCst ultrasound measurements (r^2 0.54 and 0.63 for 5- and 7.5-MHz probes) was clearly below the other measurements. Silva et al. (2005) also observed that the potential of this variable was low to predict body chemical composition. In all but 2 cases (MA13 and MA34), the prediction ability of the 7.5-MHz probe was better than that of the 5 MHz.

A number of authors reported less satisfactory results when ultrasonic measurements in vivo were used with the same purpose presented here (McEwan et al., 1989; McLaren et al., 1991; Hopkins et al., 1993). The lack of adequate resolution power of the equipment used by these authors was probably the main reason behind the discrepancies. The resolution power of the equipment is a key issue as discussed, among others, by Young et al. (1992). Of course it will be especially important when the depth of the tissues is low as is the case with subcutaneous fat in sheep or, even more, in goats. In addition, use of 1.5 times image magnification and image analysis by specific software (resolution 0.2 mm), which clearly identified the skin-fat-muscle interfaces, allowed the measurements of a thin fat depth. This may also explain better correlations for subcutaneous fat and muscle depth with the 7.5-MHz probe because it provided a clear and larger image of superficial structures (subcutaneous fat and LM muscle) than the 5-MHz probe (Figure 1).

The fact that the prediction ability of MA13 and MA34 from the measurements done with the 5-MHz probe was higher than the one observed with 7.5 MHz may be explained by the difficulty in identifying the lateral boundaries of the LM muscle with the 7.5-MHz probe (Figure 1), particularly with heavier animals. In addition, the greater length of the 5-MHz probe may have contributed to better prediction ability of this probe as observed by Stouffer (2004) in cattle.

Estimation of Carcass Composition, Internal Fat, and Total Fat from BW and In Vivo Ultrasound Measurements

Estimation of carcass composition of muscle, subcutaneous fat and intermuscular fat tissues, internal fat, and total fat was achieved by simple regressions with BW and multiple regressions with BW and in vivo ultra-

Table 2. In vivo measurements and carcass measurements (n = 46)

Item ¹		Probe				Carcass	
		5 MHz		7.5 MHz			
		Mean	SD	Mean	SD	Mean	SD
Fat measurement	SC13, mm	2.98 ^a	1.35	3.11 ^b	1.21	3.14 ^b	1.65
	SC34, mm	3.12 ^a	1.25	3.15 ^b	1.22	3.18 ^b	1.53
	SCst, mm	8.2 ^a	3.1	7.6 ^a	2.1	7.5 ^a	2.4
Muscle measurement	MD13, mm	26.4 ^a	5.2	26.1 ^a	5.0	28.3 ^a	7.9
	MD34, mm	26.5 ^a	5.5	27.3 ^a	6.2	28.1 ^a	5.2
	MA13, cm ²	16.0 ^a	4.0	15.6 ^a	3.9	15.9 ^a	4.9
	MA34, cm ²	16.7 ^a	3.6	17.0 ^a	5.9	16.1 ^a	4.6

^{a,b}Within a row, means without a common superscript letter differ ($P < 0.05$).

¹Ultrasound and carcass measurements: SC13 = subcutaneous fat depth over the 13th thoracic vertebra; SC34 = subcutaneous fat depth between the third and the fourth lumbar vertebrae; SCst = subcutaneous fat depth at the third sternebra of the breast bone; MD13 = muscle depth over the 13th thoracic vertebra; MD34 = muscle depth between the third and the fourth lumbar vertebrae; MA13 = muscle area over the 13th thoracic vertebra; and MA34 = muscle area between the third and the fourth lumbar vertebrae.

Table 3. Coefficients of determination (r^2) and residual SD (rsd) for simple linear regression between in vivo ultrasound measurements (independent variable) and carcass measurements (dependent variable)

Item ¹		Probe			
		5 MHz		7.5 MHz	
		r^2	rsd	r^2	rsd
Fat measurement	SC13, mm	0.835**	0.81	0.940**	0.77
	SC34, mm	0.854**	0.95	0.957**	0.86
	SCst, mm	0.539**	1.65	0.628**	1.42
Muscle measurement	MD13, mm	0.749**	4.09	0.874**	3.22
	MD34, m	0.763**	2.66	0.878**	2.27
	MA13, cm ²	0.895**	1.18	0.873**	1.26
	MA34, cm ²	0.902**	1.14	0.894**	1.19

¹Ultrasound measurements: SC13 = subcutaneous fat depth over the 13th thoracic vertebra; SC34 = subcutaneous fat depth between the third and the fourth lumbar vertebrae; SCst = subcutaneous fat depth at the third sternebra of the breast bone; MD13 = muscle depth over the 13th thoracic vertebra; MD34 = muscle depth between the third and the fourth lumbar vertebrae; MA13 = muscle area over the 13th thoracic vertebra; and MA34 = muscle area between the third and the fourth lumbar vertebra.

** $P < 0.01$.

Figure 1. Images over the 13th vertebra showing the measurements taken on the LM (MA = muscle area; MD = muscle depth) and the subcutaneous fat depth (SC) with the 5-MHz probe (left image) and with the 7.5-MHz probe (right image).

Table 4. Estimation of carcass composition of muscle (M), subcutaneous fat (SF), intermuscular fat (IF), internal fat, and total fat by use of BW or BW plus in vivo ultrasound measurements

Probe	Tissue		BW		BW plus in vivo ultrasound measurement ¹						
					SC13	SC34	MD13	MD34	MA13	MA34	SCst
5 MHz	M, kg	r ²	0.870**	Increase ²	0.04*	0.04*	0.07**	0.06**	0.10**	0.09**	0.01 ^{ns}
		rsd ³	2.47		1.84	1.92	1.45	1.53	0.99	1.07	2.39
	SF, kg	r ²	0.852**	Increase	0.07**	0.05**	0.02*	0.003 ^{ns}	0.001 ^{ns}	0.02*	0.002 ^{ns}
		rsd	0.63		0.46	0.50	0.59	0.62	0.63	0.58	0.63
	IF, kg	r ²	0.792**	Increase	0.05**	0.06**	0.02*	0.02*	0.02*	0.04**	0.01 ^{ns}
		rsd	0.56		0.45	0.44	0.51	0.52	0.52	0.47	0.62
	Internal fat, kg	r ²	0.736**	Increase	0.11**	0.10**	0.00 ^{ns}	0.02*	0.02*	0.01 ^{ns}	0.00 ^{ns}
		rsd	0.37		0.24	0.27	0.37	0.30	0.30	0.31	0.31
	Total fat, kg	r ²	0.866**	Increase	0.08**	0.06**	0.04**	0.03*	0.03*	0.02*	0.03*
		rsd	0.75		0.51	0.59	0.67	0.70	0.70	0.72	0.69
	M, kg	r ²	0.870**	Increase	0.08**	0.07**	0.10**	0.10**	0.06**	0.05**	0.01 ^{ns}
		rsd	2.47		1.30	1.38	0.91	0.85	1.61	1.69	2.31
7.5 MHz	SF, kg	r ²	0.852**	Increase	0.10**	0.09**	0.01 ^{ns}	0.001 ^{ns}	0.02*	0.005 ^{ns}	0.01 ^{ns}
		rsd	0.63		0.36	0.41	0.61	0.63	0.60	0.62	0.60
	IF, kg	r ²	0.792**	Increase	0.13**	0.12**	0.05**	0.06**	0.02*	0.04**	0.02*
		rsd	0.56		0.33	0.36	0.45	0.44	0.51	0.46	0.51
	Internal fat, kg	r ²	0.736**	Increase	0.13**	0.17**	0.00 ^{ns}	0.04**	0.00 ^{ns}	0.06**	0.02*
		rsd	0.37		0.24	0.24	0.31	0.29	0.31	0.29	0.29
	Total fat, kg	r ²	0.866**	Increase	0.09**	0.12**	0.02*	0.02*	0.02*	0.03*	0.04
		rsd	0.75		0.43	0.26	0.70	0.72	0.71	0.69	0.67

¹Ultrasound measurements: SC13 = subcutaneous fat depth over the 13th thoracic vertebra; SC34 = subcutaneous fat depth between the third and the fourth lumbar vertebrae; SCst = subcutaneous fat depth at the third sternebra of the breast bone; MD13 = muscle depth over the 13th thoracic vertebra; MD34 = muscle depth between the third and the fourth lumbar vertebrae; MA13 = muscle area over the 13th thoracic vertebra; and MA34 = muscle area between the third and the fourth lumbar vertebrae.

²Increase by inclusion of ultrasound measurement compared with BW alone.

³rsd = Residual SD.

* $P < 0.05$; ** $P < 0.01$; ^{ns}not significant, $P > 0.05$.

sound measurements as independent variables obtained with the 5- and the 7.5-MHz probes. The r^2 and the residual SD of the regression obtained are presented in Table 4.

Results show that BW alone can explain a large amount of the variation of the dependent variables (range of r^2 : 0.74 to 0.87). However, in most cases (55 of 70), ultrasonic measurements provided a significant improvement in precision when added to BW irrespective of probe frequency. This was particularly evident with the SC13 and SC34 measurements to predict the amount of fat tissues in carcass, internal fat, and total fat (r^2 increase between 0.05 and 0.17; $P < 0.01$).

Body weight was also a powerful estimator of the muscle amount in carcass ($r^2 = 0.87\%$). As occurred with fat, the prediction was improved when ultrasound measurements were included in the regression equations in addition to BW (R^2 increase between 0.04; $P < 0.05$ and 0.10; $P < 0.01$). As observed by others (Leymaster et al., 1985; Delfa et al., 1995), sternum measurements (SCst) gave very small improvements in the prediction ability of the multiple regressions irrespective of probe frequency, and in 5 of 10 cases, this improvement was not significant.

When more than one ultrasound measurement was used in addition to BW in multiple regressions equations, only in intermuscular fat and internal fat estimation was a significant improvement found (R^2 increased by 0.07 and 0.05, respectively). A similar improvement

was observed with the 7.5-MHz probe for internal fat (0.04 points). In all other cases, the improvements were negligible over BW plus in vivo ultrasound measurements that elicit the best response shown in Table 4.

Other authors have found that BW is a very useful variable to predict carcass composition when used in multiple regressions. This is consistent with previous observations in cattle (Williams et al., 1997; Greiner et al., 2003). Silva et al. (2005) also found that most of the variation in the amount of protein in empty body and carcass weight of sheep was explained by BW, particularly the amount of protein ($r^2 = 97.5$ and 96.8% for empty body and carcass protein, respectively). This is an expected finding because, within a breed and sex, BW is the main determinant of the amount of fat and muscle tissues. In addition, the range in BW of the sheep used in the current study was very large (18 to 79 kg).

Estimation of Proportion of Carcass Tissues, Internal Fat, and Total Fat from BW and Ultrasound Measurements

The r^2 and the residual SD of the proportions (g/kg of EBW) of carcass tissues, internal fat, and total fat accounted for by BW and BW plus in vivo ultrasound measurements are given in Table 5.

The predictions of all these traits based on BW and BW plus ultrasound measurements showed r^2 values

Table 5. Estimation of the proportion (g/kg of empty BW, EBW) of muscle (M), subcutaneous fat (SF), intermuscular fat (IF), internal fat, and total fat by use of BW or BW plus in vivo ultrasound measurements

			BW plus in vivo ultrasound measurement ¹								
Probe	Tissue	BW		SC13	SC34	MD13	MD34	MA13	MA34	SCst	
5 MHz	M, g·kg of EBW ⁻¹	r ²	0.373**	Increase ²	0.09*	0.005 ^{ns}	0.26**	0.28**	0.37**	0.46**	0.05 ^{ns}
		rsd ³	22.69		20.72	23.31	18.44	18.15	16.06	15.17	21.13
	SF, g·kg of EBW ⁻¹	r ²	0.663**	Increase	0.05**	0.04**	0.02 ^{ns}	0.005**	0.08**	0.001 ^{ns}	0.03*
		rsd	14.07		12.99	13.29	13.74	13.09	12.34	14.05	13.41
	IF, g·kg of EBW ⁻¹	r ²	0.292*	Increase	0.25**	0.19**	0.20**	0.25**	0.001 ^{ns}	0.06 ^{ns}	0.02 ^{ns}
		rsd	12.16		9.78	10.45	10.29	9.75	12.03	11.68	12.03
	Internal fat, g·kg pf EBW ⁻¹	r ²	0.436**	Increase	0.01 ^{ns}	0.001 ^{ns}	0.003 ^{ns}	0.08**	0.06**	0.02*	0.20**
		rsd	8.47		8.47	8.46	8.43	7.87	8.04	8.36	6.85
	Total fat, g·kg of EBW ⁻¹	r ²	0.603**	Increase	0.06**	0.04**	0.06**	0.07**	0.05**	0.007 ^{ns}	0.09**
		rsd	17.14		15.88	16.42	15.87	15.70	16.17	17.04	15.22
7.5 MHz	M, g·kg of EBW ⁻¹	r ²	0.373**	Increase	0.11**	0.19**	0.31**	0.33**	0.12**	0.19**	0.009 ^{ns}
		rsd	22.69		20.46	18.62	17.30	16.66	19.64	18.58	22.62
	SF, g·kg of EBW ⁻¹	r ²	0.663**	Increase	0.10**	0.19**	0.06**	0.09**	0.002 ^{ns}	0.02 ^{ns}	0.10**
		rsd	14.07		11.83	9.29	12.85	12.15	13.95	13.75	11.74
	IF, g·kg of EBW ⁻¹	r ²	0.292*	Increase	0.35**	0.39**	0.32**	0.29**	0.06 ^{ns}	0.02 ^{ns}	0.001 ^{ns}
		rsd	12.16		8.64	8.28	9.01	9.38	11.68	11.98	12.16
	Internal fat, g·kg of EBW ⁻¹	r ²	0.436**	Increase	0.23**	0.10**	0.02*	0.009 ^{ns}	0.006 ^{ns}	0.06**	0.23**
		rsd	8.47		6.71	7.67	8.36	8.38	8.41	7.98	6.05
	Total fat, g·kg of EBW ⁻¹	r ²	0.603**	Increase	0.19**	0.22**	0.01 ^{ns}	0.03*	0.004 ^{ns}	0.01 ^{ns}	0.14**
		rsd	17.14		12.75	11.55	16.99	16.63	17.09	17.00	14.01

¹Ultrasound measurements: SC13 = subcutaneous fat depth over the 13th thoracic vertebra; SC34 = subcutaneous fat depth between the third and the fourth lumbar vertebrae; SCst = subcutaneous fat depth at the third sternbra of the breast bone; MD13 = muscle depth over the 13th thoracic vertebra; MD34 = muscle depth between the third and the fourth lumbar vertebrae; MA13 = muscle area over the 13th thoracic vertebra; and MA34 = muscle area between the third and the fourth lumbar vertebrae.

²Increase by inclusion of ultrasound measurement compared with BW alone.

³rsd = Residual SD.

* $P < 0.05$; ** $P < 0.01$; ^{ns}not significant, $P > 0.05$.

clearly lower and residual SD values higher than those observed for absolute weights (Table 4). Conversion of weights to proportions removes most of the variation caused by the differences in BW among animals and, hence, makes the explanation of the variation in the proportion of each tissue more difficult. This observation has been previously reported by Shelton et al. (1977) and Fortin (1980). Still, as observed for tissue weight, BW alone explained an important part of the variation in tissue proportions (r^2 between 0.292; $P < 0.05$ and 0.663; $P < 0.01$).

In the large majority of the cases (14 of 16) subcutaneous fat measurements obtained on thoracic and lumbar positions improved the estimation ability of fat traits (r^2 increase over BW alone as estimator: 0.04 to 0.39 points) irrespective of probe frequency. However, estimation of carcass fat depots was stronger with the 7.5-MHz probe. In 18 of 32 cases, estimation of the proportions of fat tissues in carcass was improved by ultrasound muscle measurements. These measurements accounted for an increase in r^2 from 12 to 46 percentage points ($P < 0.01$) in predicting muscle proportion, the improvement being apparently higher and more consistent with the 5-MHz probe. Similar findings were observed when ultrasound muscle area measurements done with this probe were used to predict carcass muscle (Table 4).

Table 6 presents the best prediction equations generated by stepwise procedure for weights and proportions

of muscle, subcutaneous fat, intermuscular fat, internal fat and total fat in carcass using BW and ultrasound measurements. For all traits, the best fit was obtained with BW and one or more 7.5-MHz probe ultrasound measurement. Amounts of muscle, subcutaneous fat, intermuscular fat, internal fat, and total fat are accurately ($R^2 > 0.92$, $P < 0.01$) predicted. As expected, the accuracy was lower for tissue proportions (R^2 range 0.68 to 0.89, $P < 0.01$). For tissue amounts and proportions, the stepwise procedure was consistent in selecting BW and subcutaneous fat measurements for the equations. Ultrasound measurements showed high ability to estimate the composition of sheep carcass. The prediction ability of the 7.5-MHz probe was consistently better than the 5-MHz probe to estimate depth measurements, whereas the reverse occurred in estimating area measurements, although to a lower extent. Therefore, 7.5-MHz probes are potentially more useful in monitoring changes in muscle and fat depth measurements, particularly in lean lambs, where subcutaneous fat depth variation is low. It can be expected that the potential to measure LM area will increase with probe length. Although BW explained a very high proportion of total variation in the absolute amounts of the estimated traits, the inclusion of one ultrasonic measurement in multiple regression equations significantly improved the estimation of these independent variables in 55 of 70 cases irrespective of probe frequency.

Table 6. Multiple regression equations for predicting weights and proportions (g/kg of empty BW, EBW) of muscle (M) subcutaneous fat (SF), intermuscular fat (IF), internal fat, and total fat of carcass by using BW and ultrasound measurements

Tissue	Cp ¹	R ²	rsd ²	Intercept	Coefficients of the equation's variables ³					
					BW	SC13	SC34	SCst	MD13	MA13
M, kg	3.15	0.990	0.48	-8.3	0.10	0.42			0.585	
SF, kg	14.31	0.977	0.25	-1.9	0.021	0.30	0.77			
IF, kg	5.23	0.922	0.33	-0.95	0.030	0.60				
Internal fat, kg	12.92	0.931	0.20	-0.93	0.011		0.28	0.049		
Total fat, kg	6.98	0.986	0.24	-1.9	0.039	0.25	1.00			
M, g·kg of EBW ⁻¹	6.21	0.837	12.7	148.9	-5.7		14.4		10.4	7.1
SF, g·kg of EBW ⁻¹	7.87	0.886	8.0	-9.5	-0.46		16.7	1.7		
IF, g·kg of EBW ⁻¹	4.43	0.682	8.3	33.8	-0.57		14.3			
Internal fat, g·kg of EBW ⁻¹	9.66	0.726	6.1	-0.45	-0.09			2.0		
Total fat, g·kg of EBW ⁻¹	3.32	0.869	9.7	16.0	-0.77		19.8	2.3		

¹Cp = Mallows statistic.²rsd = Residual SD.³SC13 = Subcutaneous fat depth over the 13th thoracic vertebra; SC34 = subcutaneous fat depth between the third and the fourth lumbar vertebrae; SCst = subcutaneous fat depth at the third sternbra of the breast bone; MD13 = muscle depth over the 13th thoracic vertebra; and MA13 = muscle area over the 13th thoracic vertebra.

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