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In vivo estimation of goat carcass composition and body fat partition by real-time ultrasonography

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ABSTRACT: The accuracy of ultrasound measurements to assess goat carcass composition and the partition of body fat depots was evaluated. An ultrasound machine with a 5-MHz probe and image analysis was used to assess in vivo fat thickness and muscle depth in 56 Spanish Celtiberica adult goats, in lumbar and breast body regions. The goats were slaughtered and the weight of body fat depots recorded. Measurements corresponding to the in vivo ultrasound fat thickness and muscle depth were taken on carcasses. The left sides of carcasses were completely dissected into their components. The best relationships (r = 0.94, $P < 0.01$) between in vivo and carcass measurements of fat thickness were obtained when measurements were taken at the sternum, and the best anatomical point was located between the third and fourth sternebrae. The best correlation coefficients (r = 0.84) for muscle depth were found for measurements taken between the third and the fourth lumbar vertebrae at 2 cm from the middle of the vertebral column. Body weight and ultrasound measurements were used to fit the best multiple regression equations to predict carcass composition and the partition of body fat depots. All equations, with the exception of those for muscle quantity, omental, and total body fat depot amounts, were computed after performing a logarithmic transformation. Body weight in association with the ultrasound measurement taken at largest LM muscle depth, between the first and second lumbar vertebrae accounted for 90% of the muscle weight. Body weight was the first variable admitted into the prediction models of muscle, mesenteric fat, and total body fat and accounted for 82, 67, and 79% of the variation in tissue weights, respectively. The ultrasound measurement of fat thickness taken at the third sternebra was the first variable admitted into the prediction models for intermuscular fat, kidney and pelvic fat, and total carcass fat and accounted for by 73, 75, 71, and 79% of the variation in the weight of these fat depots, respectively. The ultrasound measurements taken in the breast region, particularly at the third and fourth sternebrae, were the most suitable for assessing fat thickness. The results of this experiment suggest that BW associated with some in vivo ultrasonic fat measurements allow the accurate prediction of goat carcass composition and body fat depots.

Key words: body fat, carcass composition, goat, ultrasound

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INTRODUCTION

Real-time ultrasonography (**RTU**) is a noninvasive technique that has been used to predict carcass composition and quality, avoiding damage of the product and, consequently, reduction of carcass price.

Initially, the use of RTU in small ruminants showed limited potential. The initial cost of equipment, the presence of wool, and the small thickness of the dorsal fat layer compared with other species (e.g., pigs) were the principal limitations for the usage of ultrasound to predict body or carcass composition. In fact, studies carried out on sheep by Hamby et al. (1986) and Edwards et al. (1989) were not promising. In goats the first studies of the use of RTU to predict carcass or body composition were published in 1995, by Delfa et al. (1995a) and Stanford et al. (1995). According to Stouffer (2004) the ultrasound technique will play an important role in animal science by routinely providing accurate and objective live-animal and carcass evaluations. Accuracy is an important characteristic of ultrasound technique and recently, studies on sheep by Silva et al. (2006) and Teixeira et al. (2006) indicate that the amounts of muscle, subcutaneous fat, intermuscular fat, and total fat can be accurately predicted using ultrasound.

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Figure 1. Ultrasound measurement procedure in sternum region.

Ultrasound tissue evaluations are usually based on the measurement of fat thickness and muscle depth. Teixeira et al. (1995) have shown that goats have a lesser fat deposition on the back compared with the breast bone, where the greater amount of fat allowed taking more accurate subcutaneous fat measurements. As result of the evident lack of subcutaneous fat on goats' backs, Delfa et al. (1996, 2000) suggested that the sternum region is the most useful and accurate part of the body on which to assess fat thickness in goats.

The objectives of this study were 1) to compare several carcass fat thickness measurements taken in the lumbar and breast regions with the corresponding ultrasound measurements evaluated in live animals; 2) to study the accuracy of ultrasound measurements to predict carcass composition and to estimate body fat partition using the ultrasound fat thicknesses measurements as predictors.

MATERIALS AND METHODS

All procedures involving animals were approved by the Spanish Instituto Nacional de Investigación y Tecnología Agrária y Alimentaria and the Servicio de Investigación Agroalimentaria de la Diputación General de Aragon.

Animals and Experimental Procedures

A total of 56 adult goats of Blanca Celtiberica Spanish breed (age 6 ± 2 yr) were selected from the experimental flock of the Agricultural Research Centre (CITA, Zaragoza, Spain) according their BCS ranging 1.5 to 4.5 (on a 5-point scale; Russel et al., 1969) and with a BW of 57 ± 13 kg.

The ultrasound images were evaluated before slaughter using a Toshiba Sonolayer ultrasound (SAC-32B, Toshiba Corp., Otawara, Japan) with a 5-MHz probe (veterinary model). To obtain the ultrasound images, the animals were immobilized and were held manually avoiding any abnormal situation that could stress the animal. When the ultrasound images were taken at the breast bone, goats were restrained in dorsal recumbency on a surgical table (Figure 1). Ultrasound images were recorded for all animals using the same technique by the same operator measuring over the skin without shearing or clipping the hair. An acoustic gel was used to allow a better contact surface between the probe and the skin of the animal. Although there is an effect in the ultrasound caused by the presence of hair, this problem was reduced by combing the hair to achieve a completely clean skin surface as shown in Figure 1. This procedure was more suitable than shearing the animal, which would damage the skin and reduce the commercial value of the animal.

Ultrasound Measurements

The fat thickness and LM depth were taken in a perpendicular position to the dorsal midline at the level of the largest depth of muscle LM between the first and second (**UL1–2FD**, lumbar subcutaneous fat depth; **UL1–2MD**, lumbar muscle depth), the third and fourth (**UL3–4FD**, lumbar subcutaneous fat depth; **UL3–4MD**, lumbar muscle depth), the fifth and sixth (**UL5–6FD**, lumbar subcutaneous fat depth; **UL5–6MD**, lumbar muscle depth) lumbar vertebrae and along the second (**US2FD**, sternum fat depth), the third (**US3FD**, sternum fat depth), the fourth (**US4FD**, sternum fat depth), and the fifth (**US5FD**, sternum fat depth) sternebrae of the breast bone (Figure 2). The procedure for interpreting images described by Teixeira et al. (2006) for lambs was adopted in this study. Briefly, the procedure was as follows. When an acceptable image of the anatomical points was obtained, it was recorded, video printed, digitized, and transferred to a computer for subsequent laboratory processing. Measurements were then performed by image analysis using the National Institute of Health 1.57 software (http://rsb.info.nih.gov/nih-image/) to help the operator interpret the image and identify the anatomical points to take measurements using the same technique in all scanned animals. All the images were scanned, interpreted, and the measurements taken by the same operator.

Slaughter Procedure, Carcass Measurements, and Carcass Composition

Goats were slaughtered after a 24-h fast under the same conditions and in accordance with the European

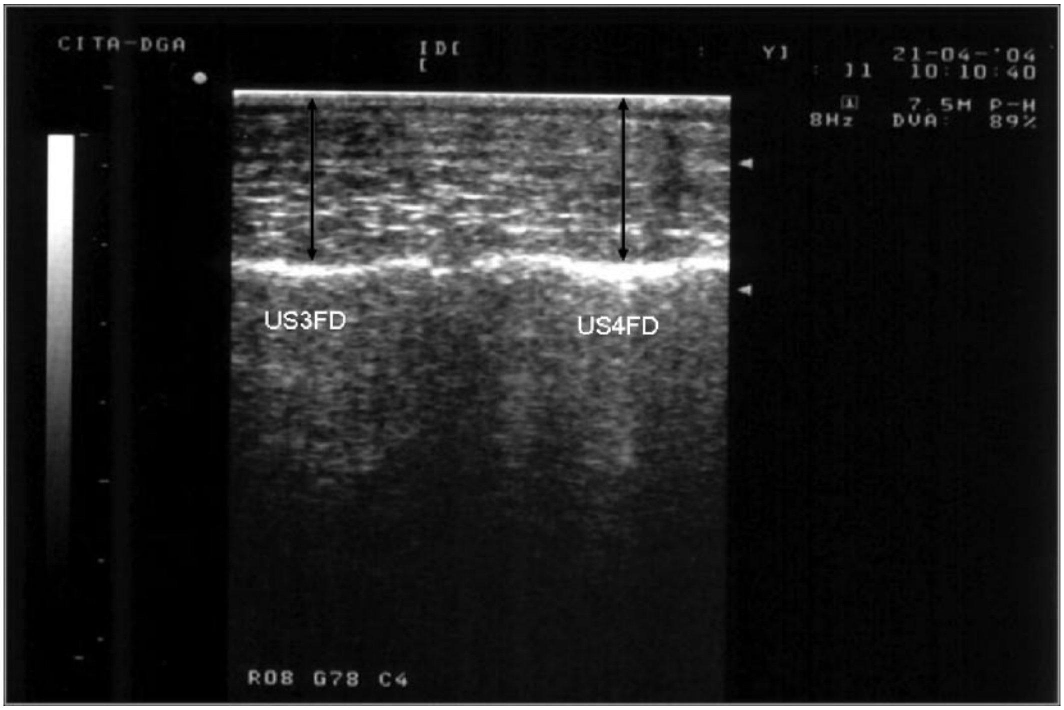

Figure 2. Ultrasound fat thickness measurement in sternum region at the third and fourth sternebrae (US3FD and US4FD, respectively).

laws of ethics and welfare, at the CITA experimental slaughterhouse. Omental, mesenteric, kidney, and pelvic fat depots were removed, weighed, and recorded separately. Carcasses were cooled at 4°C for 24 h. The process of handling and cooling carcasses affects the carcass measurements, and the relationship between the carcass and ultrasound measurements should be carefully interpreted.

Fat depth measurements at the sternum were carried out with a sharpened steel rule on the intact carcass. These measurements were taken along the second (**CSFD2**), third (**CSFD3**), and fourth (**CSFD4**) sternebrae and between the second and third (**CSFD2–3**), third and fourth (**CSFD3–4**), and fourth and fifth (**CSFD4–5**) sternebrae. The rest of anatomical points measured were obtained after carefully halving the carcass with a caliper at 2 cm, 4 cm, and one-third from the dorsal midline between first and second (**CL1–2FD2**, **CL1–2FD4**, and **CL1–2FD1/3** for fat thickness; **CL1–2MD2**, **CL1–2MD4**, and **CL1–2MD1/3** for muscle depth), the third and fourth (**CL3–4FD2**, **CL3–4FD4**, and **CL3–4FD1/3** for fat thickness; **CL3–4MD2**, **CL3–4MD4**, and **CL3–4MD1/3** for muscle depth), the fifth and sixth (**CL5–6FD2**, **CL5–6FD4**, and **CL5–6FD1/3** for fat thickness; **CL5–6MD2**, **CL5–6MD4**, and **CL5–6MD1/3** for muscle depth) of lumbar vertebrae (Figure 3).

The left side of each carcass was completely dissected with a scalpel into muscle, bone, subcutaneous fat, intermuscular fat, and remainder (major blood vessels, ligaments, tendons, and thick connective tissue associated with muscles).

Statistical Procedure

The relationship between in vivo measurements of fat thickness and muscle depth and the same carcass measurements was analyzed by linear correlation (Steel and Torrie, 1980). To estimate carcass composition and body fat partition, the data were analyzed

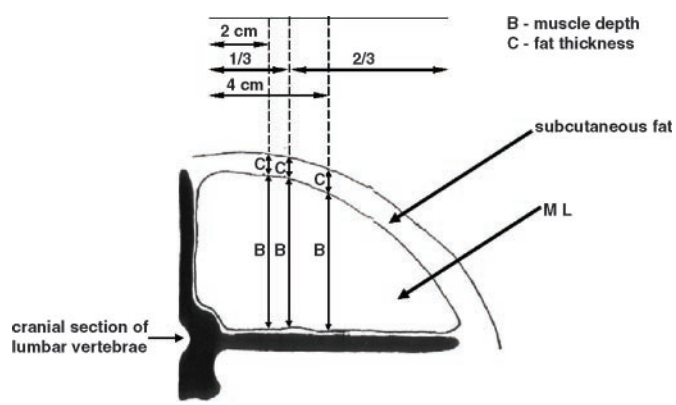

Figure 3. Schematic representation of carcass measurements taken in lumbar vertebra at 2 cm, 4 cm, and one-third from the dorsal midline. M L = longissimus dorsi muscle.

Table 1. Means, SE, and CV (%) of body fat depots and half-carcass composition

Variable	Mean	SE	CV
BW, kg	57.1	1.5	19.8
HCW, kg	27.7	1.1	29.3
Body fat depots, g			
Omental	3,038.7	291.6	71.8
Mesenteric	1,748.1	113.7	48.7
Kidney	1,478.8	148.6	75.3
Pelvic	269.6	24.9	69.2
Half carcass composition, g			
Subcutaneous fat	1,130.8	136.2	90.1
Intermuscular fat	1,423.0	104.9	55.2
Bone + remainder	2,009.0	32.4	12.1
Muscle	7,870.8	230.4	21.8

by a stepwise regression procedure using, as independent variables, BW and the ultrasound measurements in the following sequence: untransformed variables, dependent variables on a logarithmic scale, and independent variables on a logarithmic scale. The best regression equations were obtained by using a stepwise procedure. The best models were selected based on the coefficient of determination, optimizing the Mallow's Cp statistics and the residual SD.

All statistics were calculated using the JMP-SAS statistical package (SAS Inst. Inc., Cary, NC).

RESULTS AND DISCUSSION

The means and SE of body fat depots and half-carcass tissue composition are shown in Table 1. The means, SE, and CV of the ultrasound and carcass measurements are shown in Table 2. All variables present a large range of variation in BW and fat deposition, suggesting that we have worked with an animal sample representative of the Spanish Blanca Celtibérica goat breed. The high CV observed, particularly for fat measurements and fat depots, was due to the large variation in BW and to the fact that the fat tissue presents large variations.

The means of ultrasound fat measurements revealed a slight overestimation in relation to carcass measurements, which is a tendency also found by Delfa et al. (2000) and Corral-de-Mesta et al. (2004) working with Celtibérica and Spanish goats, respectively. A possible reason for this overestimation could be the difficulty in measuring fat thickness in goats because of the low content of fat over the loin and the impact of handling and cooling on carcass measurements. This trend was also found in young lambs by Delfa et al. (1995b) and Teixeira et al. (2006).

Relationship Between Ultrasound and Carcass Measurements

The correlation coefficients between carcass and ultrasound measurements are shown in Table 3. The best relationships (r = 0.94) were obtained between the measurements taken at the sternum specifically at the third and the fourth sternebrae, in accordance with the results of Delfa et al. (1998, 1999). In fact, Delfa et al. (2000) have suggested the sternum region as the most useful part of the body to assess subcutaneous fat in goats. Unlike the lumbar region, where goats have a lower fat deposition, the breast bone shows a considerably deeper amount of subcutaneous fat that is suitable for taking fat measurements (Teixeira et al., 1995).

The best correlation coefficients (r = 0.84) for muscle depth were found for measurements taken between the third and fourth lumbar vertebrae 2 cm from the middle of vertebral column, in accordance with the results reported by Delfa et al. (1996) also working with several Spanish goat breeds. The coefficients found in the present study were greater than the results found by Stanford et al. (1995) for Alpine goats and than those found by Corral-de-Mesta et al. (2004) for Spanish goats. Stanford et al. (1995) and Corral-de-Mesta et al. (2004) found the best relationships when the measurements were taken between the 12th and 13th rib with a 3.5- or 5.0-MHz probe, respectively, as opposed to the lumbar region. The different results between authors could be explained by the different type of ultrasound equipments and the probes used. A 5- or 7.5-MHz probe has a short wavelength with low tissue penetration and high resolution, which is better for measuring tissues in sheep and goats compared with the 3.5-MHz probe with deep penetration normally used in beef cattle carcass imaging. In fact, the choice of frequency and resolution (usually from 1 to 15 MHz) is a compromise between penetration and resolution (Swatland, 1995). Working with lambs and using probes of 5 and 7.5 MHz, Teixeira et al. (2006) found the best carcass composition estimations when the ultrasound fat thickness measurements were taken with the 7.5-MHz probe. Similar results were also found in sheep carcass composition estimations by Silva et al. (2006) for fat thickness measurements but the 5-MHz probe provided better results to assess the LM area. The present study had greater correlation coefficients than those found for sheep by Teixeira et al. (2006) but lower than those obtained by Silva et al. (2006). This difference may be due to the different species used in the present study. Furthermore, there are differences that can be explained by the different ultrasonic measurement procedures utilized. In the present study, hair was not sheared and clipped because it takes time and is not compatible with the normal procedure in a commercial abattoir. However, in other studies, hair and wool were sheared and clipped (Silva et al., 2005, 2006).

Estimation of Carcass Composition and Body Fat

The best equations for predicting carcass composition and body fat depots are shown in Table 4. The equations were developed by multiple linear regression

Table 2. Means, SE, and CV (%) of ultrasound and carcass measurements

Measurement	Mean	SE	CV
Ultrasound measurement,[1] mm			
UL1–2FD	3.62	0.20	59.1
UL3–4FD	3.39	0.23	50.7
UL5–6FD	3.49	0.25	53.8
US2FD	29.34	1.26	32.2
US3FD	28.09	1.00	26.7
US4FD	26.55	0.99	28.0
US5FD	25.15	0.95	28.3
UL1–2MD	19.46	0.69	26.5
UL3–4MD	18.88	0.73	28.9
UL5–6MD	18.25	0.70	28.7
Carcass measurement,[2] mm			
CL1–2FD2	1.14	0.15	95.7
CL1–2FD1/3	1.29	0.19	107.3
CL1–2 FD4	1.50	0.21	104.5
CL3–4FD2	1.74	0.27	113.8
CL3–4FD1/3	3.12	0.45	107.2
CL2–4FD4	3.33	0.47	103.8
CL5–6FD2	1.89	0.30	116.3
CL5–6FD1/3	3.89	0.54	101.6
CL5–6FD4	4.18	0.64	111.9
CSFD2	25.19	1.24	36.7
CSFD2–3	24.57	1.15	35.0
CSFD3	25.30	0.98	28.9
CSFD3–4	22.59	0.92	30.4
CSFD4	22.07	0.90	30.6
CSFD4–5	19.82	0.85	32.2
CL1–2MD2	29.05	0.75	18.9
CL1–2MD1/3	26.51	0.77	21.4
CL1–2MD4	22.12	0.85	28.3
CL3–4MD2	27.45	0.69	18.5
CL3–4 MD1/3	23.48	0.68	21.4
CL3–4MD4	18.93	0.69	26.5
CL5–6MD2	28.15	0.71	18.6
CL5–6MD1/3	24.94	0.67	19.9
CL5–6MD4	22.38	0.61	19.9

[1]Ultrasound measurements: UL1–2FD = lumbar subcutaneous fat depth between first and second vertebrae; UL3–4FD = lumbar subcutaneous fat depth between third and fourth vertebrae; UL5–6FD = lumbar subcutaneous fat depth between fifth and sixth vertebrae; US2FD = sternum fat depth at second sternebra; US3FD = sternum fat depth at third sternebra; US4FD = sternum fat depth at fourth sternebra; US5FD = sternum fat depth at fifth sternebra; UL1–2MD = lumbar muscle depth between first and second vertebrae; UL3–4MD = lumbar muscle depth between third and fourth vertebrae; UL5–6MD = lumbar muscle depth between fifth and sixth vertebrae.

[2]Carcass measurements: CL1–2FD2, CL1–2FD1/3, and CL1–2FD4 = lumbar fat depth between first and second vertebrae at 2 cm, 1/3, and 4 cm of dorsal middle line; CL3–4FD2, CL3–4FD1/3, and CL2–4FD4 = lumbar fat depth between third and fourth vertebrae at 2 cm, 1/3, and 4 cm of dorsal middle line; CL5–6FD2, CL5–6FD1/3, and CL5–6FD4 = lumbar fat depth between third and fourth vertebrae at 2 cm, 1/3, and 4 cm of dorsal middle line; CSFD2 = carcass sternum fat depth at second sternebra; CSFD2–3 = carcass sternum fat depth between second and third sternebrae; CSFD3 = carcass sternum fat depth at third sternebra; CSFD3–4 = carcass sternum fat depth between third and fourth sternebrae; CSFD 4 = carcass sternum fat depth at fourth sternebra; CSFD 4–5 = carcass sternum fat depth between fourth and fifth sternebrae; CL1–2MD2, CL1–2MD1/3, and CL1–2MD4 = lumbar muscle depth between first and second vertebrae at 2 cm, 1/3, and 4 cm of dorsal middle line; CL3–4MD2, CL3–4MD1/3, and CL3–4MD4 = lumbar muscle depth between third and fourth vertebrae at 2 cm, 1/3, and 4 cm of dorsal middle line; CL5–6MD2, CL5–6MD1/3, and CL5–6MD4 = lumbar muscle depth between fifth and sixth vertebrae at 2 cm, 1/3, and 4 cm of dorsal middle line.

Table 3. Correlation coefficients between carcass and ultrasound measurements

Carcass measurement[1]	Ultrasound measurement[2]	r
CL1–2FD2	UL1–2FD	0.63**
CL1–2FD1/3	UL1–2FD	0.68**
CL1–2 FD4	UL1–2FD	0.69**
CL3–4FD2	UL3–4FD	0.70**
CL3–4FD1/3	UL3–4FD	0.63**
CL2–4FD4	UL3–4FD	0.69**
CL5–6FD2	UL5–6FD	0.47**
CL5–6FD1/3	UL5–6FD	0.74**
CL5–6FD4	UL5–6FD	0.71**
CSFD2	US2FD	0.92**
CSFD2–3	US2FD	0.89**
CSFD2–3	US3FD	0.91**
CSFD3	US3FD	0.94**
CSFD3–4	US3FD	0.91**
CSFD3–4	US4FD	0.91**
CSFD4	US4FD	0.94**
CSFD4–5	US4FD	0.93**
CSFD4–5	US5FD	0.92**
CL1–2MD2	UL1–2MD	0.83**
CL1–2MD1/3	UL1–2MD	0.81**
CL1–2MD4	UL1–2MD	0.67**
CL3–4MD2	UL3–4MD	0.84**
CL3–4MD1/3	UL3–4MD	0.80**
CL3–4MD4	UL3–4MD	0.60**
CL5–6 MD2	UL5–6MD	0.47**
CL5–6 MD1/3	UL5–6MD	0.34**
CL5–6 MD4	UL5–6MD	0.21[NS]

[1]Carcass measurements: CL1–2FD2, CL1–2FD1/3, and CL1–2FD4 = lumbar fat depth between first and second vertebrae at 2 cm, 1/3, and 4 cm of dorsal middle line; CL3–4FD2, CL3–4FD1/3, and CL2–4FD4 = lumbar fat depth between third and fourth vertebrae at 2 cm, 1/3, and 4 cm of dorsal middle line; CL5–6FD2, CL5–6FD1/3, and CL5–6FD4 = lumbar fat depth between third and fourth vertebrae at 2 cm, 1/3, and 4 cm of dorsal middle line; CSFD2 = carcass sternum fat depth at second sternebra; CSFD2–3 = carcass sternum fat depth between second and third sternebrae; CSFD3 = carcass sternum fat depth at third sternebra; CSFD3–4 = carcass sternum fat depth between third and fourth sternebrae; CSFD 4 = carcass sternum fat depth at fourth sternebra; CSFD 4–5 = carcass sternum fat depth between fourth and fifth sternebrae; CL1–2MD2, CL1–2MD1/3, and CL1–2MD4 = lumbar muscle depth between first and second vertebrae at 2 cm, 1/3, and 4 cm of dorsal middle line; CL3–4MD2, CL3–4MD1/3, and CL3–4MD4 = lumbar muscle depth between third and fourth vertebrae at 2 cm, 1/3, and 4 cm of dorsal middle line; CL5–6MD2, CL5–6MD1/3, and CL5–6MD4 = lumbar muscle depth between fifth and sixth vertebrae at 2 cm, 1/3, and 4 cm of dorsal middle line.

[2]Ultrasound measurements: UL1–2FD = lumbar subcutaneous fat depth between first and second vertebrae; UL3–4FD = lumbar subcutaneous fat depth between third and fourth vertebrae; UL5–6FD = lumbar subcutaneous fat depth between fifth and sixth vertebrae; US2FD = sternum fat depth at second sternebra; US3FD = sternum fat depth at third sternebra; US4FD = sternum fat depth at fourth sternebra; US5FD = sternum fat depth at fifth sternebra; UL1–2MD = lumbar muscle depth between first and second vertebrae; UL3–4MD = lumbar muscle depth between third and fourth vertebrae; UL5–6MD = lumbar muscle depth between fifth and sixth vertebrae.

**$P < 0.01$; NS = not significant.

using BW and ultrasound measurements as independent variables. With the exception of muscle quantity, omental, and total body fat depots, all the equations were computed after a logarithmic transformation. This confirms the suggestion that the goat fat depots

Table 4. Multiple regression equations using BW and ultrasound measurements for predicting carcass composition (g) and body fat depots (g)[1]

Dependent variable	Independent variable[2]	a	b	SB	Cp	R^2	RSD
Muscle	BW	−234.34	95.71	8.81	45.76	0.82	730.78
	UL1–2MD		134.48	19.33	1.09	0.90	533.28
Subcutaneous fat*	US4FD*	−5.02	1.85	0.20	53.04	0.80	0.46
	UL5–6FD*		0.43	0.10	14.22	0.88	0.36
	BW*		1.28	0.33	4.45	0.91	0.32
Intermuscular fat*	US3FD*	−1.09	0.95	0.13	57.13	0.73	0.30
	BW*		1.23	0.22	9.31	0.86	0.22
	UL5–6FD*		0.33	0.09	7.55	0.87	0.21
	UL3–4FD*		−0.24	0.11	4.57	0.89	0.20
Kidney*	US3FD*	−5.37	1.68	0.22	37.35	0.75	0.48
	BW*		1.43	0.37	5.00	0.85	0.38
	UL5–6FD*		0.35	0.11	4.00	0.87	0.35
Pelvic*	US3FD*	−2.34	2.12	0.19	3.84	0.71	0.41
Total carcass fat*	US3FD*	−1.59	1.35	0.15	77.27	0.79	0.35
	BW*		1.18	0.24	18.92	0.89	0.26
	UL5–6FD*		0.29	0.07	8.47	0.92	0.22
Omental	US3FD*	−5,381.00	130.70	19.30	49.541	0.77	1,052.03
	UL5–6FD*		366.20	65.60	3.95	0.86	818.56
	BW*		60.70	12.50	0.08	0.91	685.70
Mesenteric*	BW*	0.10	1.17	0.26	23.55	0.67	0.31
	US3FD*		0.71	0.16	1.45	0.78	0.26
	UL5–6FD*		0.17	0.08	0.51	0.80	0.25
Total body fat	BW	−19,175.16	292.73	38.48	108.96	0.79	3,614.70
	US3FD		565.99	127.04	35.32	0.89	2,644.30
	UL5–6FD		1,131.43	211.40	14.16	0.92	2,308.82

[1]Variables marked with an asterisk (*) are on a logarithmic scale; a = intercept; b = regression coefficients; SB = standard error of b; Cp = Mallow's statistic; R^2 = coefficient of determination; RSD = residual standard deviation.

[2]UL1–2MD = lumbar muscle depth between first and second vertebrae; US4FD = sternum fat depth at fourth sternebra; UL5–6FD = lumbar subcutaneous fat depth between fifth and sixth vertebrae; UL3–4FD = lumbar subcutaneous fat depth between third and fourth vertebrae; US3FD = sternum fat depth at third sternebra.

have a logarithmic relationship with BW, as described by Teixeira et al. (1995), who were also working with Blanca Celtibérica goats. All of the equations have high R^2 values and all of them were significant at the $P < 0.001$ level. Body weight was the first variable admitted in the models of muscle, mesenteric fat, and total body fat predictions and accounted for 82, 67, and 79% of the variation in tissues weights, respectively. In relation to total body fat, the inclusion in the model of prediction of 2 ultrasonic measurements taken in the sternum and lumbar regions improved the accuracy of the estimation by 13% and allowed a decrease in residual standard deviation of 36%.

For muscle prediction equations, the inclusion of BW as the first independent variable has been observed by several authors in other species such as sheep (Silva et al., 2005, 2006; Teixeira et al., 2006). The admission of the ultrasound measurement UL1–2MD by the model increases the precision of muscle prediction by 8% and considerably reduces the error of estimation.

The ultrasonic measurement taken on the fourth sternebra (US4FD) was the first independent variable admitted in the model of prediction of subcutaneous fat and explains 80% of the variation. The ultrasound measurement taken on the third sternebra (US3FD) was the first variable admitted in the models of prediction of omental, intermuscular, kidney and pelvic fats, and total carcass fat and accounted for 77, 73, 75, 71, and 79% of the variation in the weight of fat depots, respectively. All of these values were greater than the coefficients found by Stanford et al. (1995) and Corral-de-Mesta et al. (2004) for Alpine and Spanish goats, respectively. As in other species, the tendency was to take the ultrasonic fat thickness measurements on the LM between the 12th and 13th ribs, and the LM depth and area at the same point (Williams 2002; Greiner et al., 2003). However, Bruwer et al. (1987) used the measurement between the third and fourth lumbar vertebrae as a predictor of carcass composition in a study of the lamb and mutton carcass grading system in South Africa. Moreover, previous studies on some Mediterranean sheep breeds (Delfa et al., 1995b; Teixeira and Delfa, 1997; Silva et al., 2006; Teixeira et al., 2006) have shown the usefulness of ultrasound measurements taken between the third and fourth lumbar vertebrae to predict carcass composition, and have suggested that ultrasound fat thickness measurements with BW could be good predictors of carcass and body composition. The present results also suggest that the ultrasonic measurements taken between the third and fourth sternebrae are the most suitable for assessing fat, confirming that fat thickness measurements taken at the breast bone could be useful in the prediction of carcass and body composition of goats.

As previously mentioned, BW was the other important independent variable in the models that explained between 10 and 13% more of the total amount of those fat depots. In some cases, the models admitted a third variable, the measurement taken between the fifth and sixth lumbar vertebrae (UL5–6FD), which accounted for only a further 1 or 3% of the total variation in the weight of total carcass fat, kidney fat, and intermuscular fat, but reduced the errors of the prediction equations.

The prediction equation for intermuscular fat was the only model admitting 4 independent variables in this order: US3FD, LW, UL5–6FD, and UL3–4FD accounting for 89% of the total variance. Even though the increase of 2 percentage points in the determination coefficient accounted for the fourth variable entered in the model was significant, the prediction equation with 4 independent variables was not practical enough to work, especially in the field or abattoir, where tasks need to be executed rapidly.

The variation in the most important body fat depots such as omental and mesenteric fat, shown in Table 4, was also explained for US3FD in association with BW and UL5–6FD measurements. Generally, prediction equations of body fat from ultrasonic measurements in live goats were better than expected and better than those previously reported and discussed. In fact, 91 and 80% of the variation of the omental and mesenteric fat depot weights were explained by prediction equations.

Swatland (1995) reported that one of the problems in predicting meat yield from fatness is to find a simple yet reliable measure of carcass fatness. According to Swatland (1995), we found that all our estimated equations included BW, which is one of the simplest variables to obtain. The other measurement often admitted in the models was US3FD. Both of the aforementioned independent variables explain 89% of the variation of total carcass fat and total body fat. If a third variable was admitted in the model, it was always UL5–6FD, the ultrasound lumbar measurement that explains more of the variation explained in association with BW plus the ultrasound sternum measurement US3FD. Overall, it would seem that the prediction equations calculated are acceptable, consistent, and probably adequate for standardized serial order work in on-line carcass classification and evaluation.

Under the experimental conditions of this study, the ultrasound measurements allowed us to obtain good, in vivo predictions of goat carcass composition and to assess main body fat partitioning. For goats, the ultrasonic fat depth measurements taken at the third and fourth sternebrae of the breast bone in association with BW were the most appropriate predictors, improving the determination coefficients and reducing the residual standard deviation of the prediction equations. Ultrasound equipment is an important tool that provides good accuracy; moreover, it is not expensive and is relatively easy and rapid to operate. The recent advances in RTU made the use of this technology available to all the meat industry from the producer to the operator at the abattoir. As a noninvasive method, ultrasound is also appropriate for live estimation of fat and muscle deposition and body composition in goats; to evaluate and estimate carcass quality and composition; and to evaluate growth and predict the optimal time of slaughter. Further research is needed to explain changes in body and carcass composition during growth, particularly in young animals and under different physiological conditions such as lactation, and according to the different kinds of preferred carcasses for different goat meat consumer markets.

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