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# Estimation of light lamb carcass composition by in vivo real-time ultrasonography at four anatomical locations[1]

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**ABSTRACT:** The objectives of this study were to study the relationship between in vivo ultrasound measurements and cold carcass measurements at 4 anatomical points of the backbone, and to establish regression equations to estimate carcass composition within the cold carcass weight range for Ternasco lambs (8 to 12.5 kg) by using ultrasonic measurements taken at a single location. Measurements of subcutaneous fat and skin thickness and of muscle depth and width were taken over the 10th to 11th and 12th to 13th thoracic vertebrae and the 1st to 2nd and 3rd to 4th lumbar vertebrae. These measurements were taken at 2 and 4 cm from the nearest end of the LM to the backbone and at 1/3 of the LM width with the probe perpendicular to and parallel to the backbone. The left sides of the carcasses were dissected into muscle, fat, and bone. Body weight (22.6 kg) and cold carcass weight (10.8 kg) were representative of Ternasco light lambs. Muscle depth measured at 2 cm, 4 cm, and 1/3 of LM width remained regular, with slight ups and downs along the spine. All the pairs of in vivo ultrasound and cold carcass measurements were significantly different ($P < 0.05$) and had small correlations. All the ultrasound measurements of muscle depth at any location or at any distance to the backbone were less than their equivalent cold carcass measurements, with differences ranging from 0.8 to 5.9 mm. Differences between ultrasound fat thickness + interface (US_FDGI) and cold carcass fat thickness were less than differences between ultrasound fat thickness and cold carcass fat thickness, ranging from $-0.9$ to $-1.0$ mm for the former and from $-2.1$ to $-0.5$ mm for the latter. The small differences in absolute values between US_FDGI and cold carcass fat thickness suggest that US_FDGI is the best measure of the real fatness level of the lambs. The best prediction equations for muscle, bone, and fat were developed with in vivo ultrasound data measured at the 1st to 2nd lumbar vertebrae perpendicularly to the backbone, but they had limited predictive value. To predict the muscle content of carcass, BW and muscle depth were included, and they explained 59% of variation. Fifty-one percent of total fat was predicted by BW and fat thickness, whereas only 17% of the variation in bone was predicted by 2 fat-related variables. The BW of lambs was an important predictor to improve regression equations but ultrasound measurements were the most important variables when a narrow range of BW was used.

**Key words:** carcass composition, fat thickness, muscle depth, prediction, regression, ultrasound

## INTRODUCTION

Lamb meat consumers in the Mediterranean area demand lean carcasses with less fat (Font i Furnols et al., 2006). In some areas of Spain, consumers specifically demand Ternasco, which is lamb slaughtered within a narrow range of cold carcass weight (8 to 12.5 kg; BOE, 2006).

Real-time ultrasonography can be used in live animals to provide quick, objective information to predict body composition with the aim of satisfying market demands. This is a noninvasive technology that provides objective and accurate live animal evaluations (Stouffer, 2004) and allows carcass quality to be assessed without damaging the product.

Previous studies in Spanish sheep breeds suggest the usefulness of ultrasound fat thickness for predicting carcass composition (Delfa et al., 1996b; Fernández et al., 1998; Mendizabal et al., 2003). Several studies have

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been published in which new anatomical locations for measuring muscle depth and fat thickness were evaluated to predict the tissue composition of the ovine carcass. Some reports have proposed multiple points along the vertebral column, from the 6th thoracic vertebra (Mahgoub, 1998) to the 3rd coccygeous vertebra (Leymaster et al., 1985), and diverse measures of muscle depth and fat thickness in different anatomical sites have been assessed in different studies (Moody et al., 1965; Kempster et al., 1982a; Teixeira and Delfa, 1997; Cadavez et al., 1999a, 2000).

Regression equations are usually developed by combining many different ultrasonic measurements and, in general, they provide good predictions. However, the usefulness of regression equations that take into account many on-farm measurements is questionable because of the time-consuming nature of the data collection that is necessary.

The objectives were to study the relationship between in vivo ultrasound measurements and cold carcass measurements at 4 anatomical points of the backbone of the lamb and to establish regression equations to estimate carcass composition within the BW range for Ternasco lambs by using ultrasonic measurements taken at a single location.

## MATERIALS AND METHODS

All procedures were conducted according to the guidelines of Council Directive 86/609/EEC (European Communities, 1986) on the protection of animals used for experimental and other scientific purposes.

### Animal Management

This experiment was conducted at the experimental facilities of Centro de Investigación y Tecnología Agroalimentaria de Aragón (**CITA**) in Zaragoza (Spain). The experiment involved 129 single, spring-born male lambs of the Churra Tensina and Rasa Aragonesa sheep breeds.

### Ultrasound Measurements

Ultrasonic measurements of fat thickness and muscle LM depth were taken the day before slaughter by using an Aloka SSD-900 instrument with a with a multifrequency electronic linear array probe of 7.5 MHz (5 to 10 MHz) with a 62-mm width (UST 5710-7.5, Aloka Spain, Madrid, Spain). Measurements were recorded on the left side in all animals by the same operator, measuring over the skin without clipping the fleece (Brown et al., 2000). Even though the presence of the fleece had an impact on the ultrasound, this was overcome by combing the hair until a completely clean skin surface was achieved. An acoustic gel was used to allow a better contact surface between the probe and the skin of the animal. Animals were immobilized and held manu-
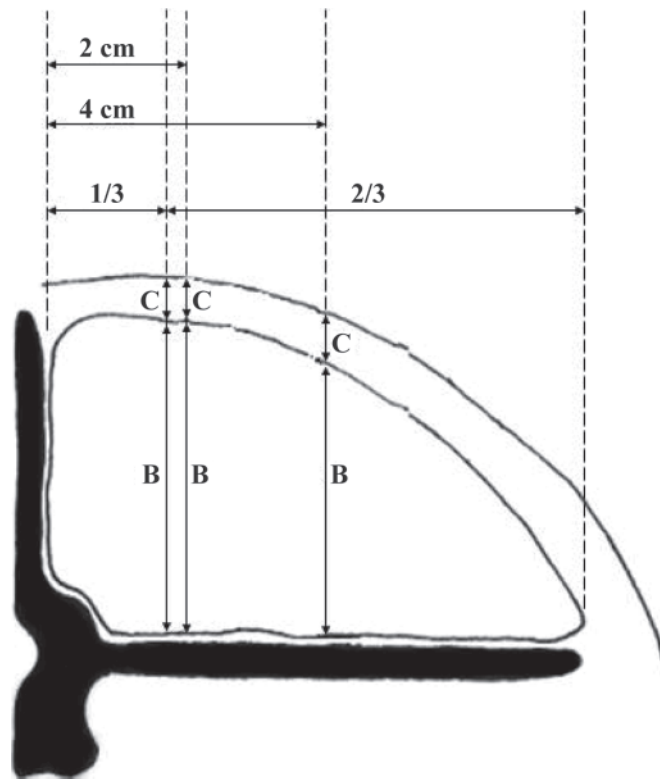


**Figure 1.** Fat thickness (C) and muscle depth (B) measured at 2 and 4 cm, and 1/3 of the LM width.

ally, avoiding any abnormal situation that would have stressed the animal.

The measurements, taken perpendicularly to the dorsal midline, were as follows: LM width (**US_A**); LM depth (**US_MD**); skin thickness + subcutaneous fat thickness + interfaces (**US_FD**); subcutaneous fat thickness + interfaces (**US_FDGI**); subcutaneous fat thickness (**US_FDG**); and skin thickness (**US_FSK**). These measurements were made at 2 and 4 cm from the nearest end of the LM to the backbone (Delfa et al., 1996a), and at 1/3 of the LM width (Delfa et al., 2007; Figure 1). With the probe parallel (Figure 2) to the dorsal midline, the following were also measured: LM depth (**US_MDP**); skin thickness + subcutaneous fat thickness + interfaces (**US_FDP**); subcutaneous fat thickness + interfaces (**US_FDGIP**); subcutaneous fat thickness (**US_FDGP**); and skin thickness (**US_SKP**) at 1/3 of the total length of the transverse apophysis from the dorsal midline (Delfa, 2004). All these measurements were taken at the 10th to 11th (**10–11T**) and 12th to 13th (**12–13T)** thoracic vertebrae and at the 1st to 2nd (**1–2L**) and 3rd to 4th (**3–4L**) lumbar vertebrae.

Ultrasound frequency was adjusted for each tissue to achieve a clear image by using high frequencies (8 to 10 MHz) for superficial measures (fat) and low frequencies (7 MHz) for muscle depth. Ultrasound measures were obtained directly from the screen of the B-mode of the instrument.
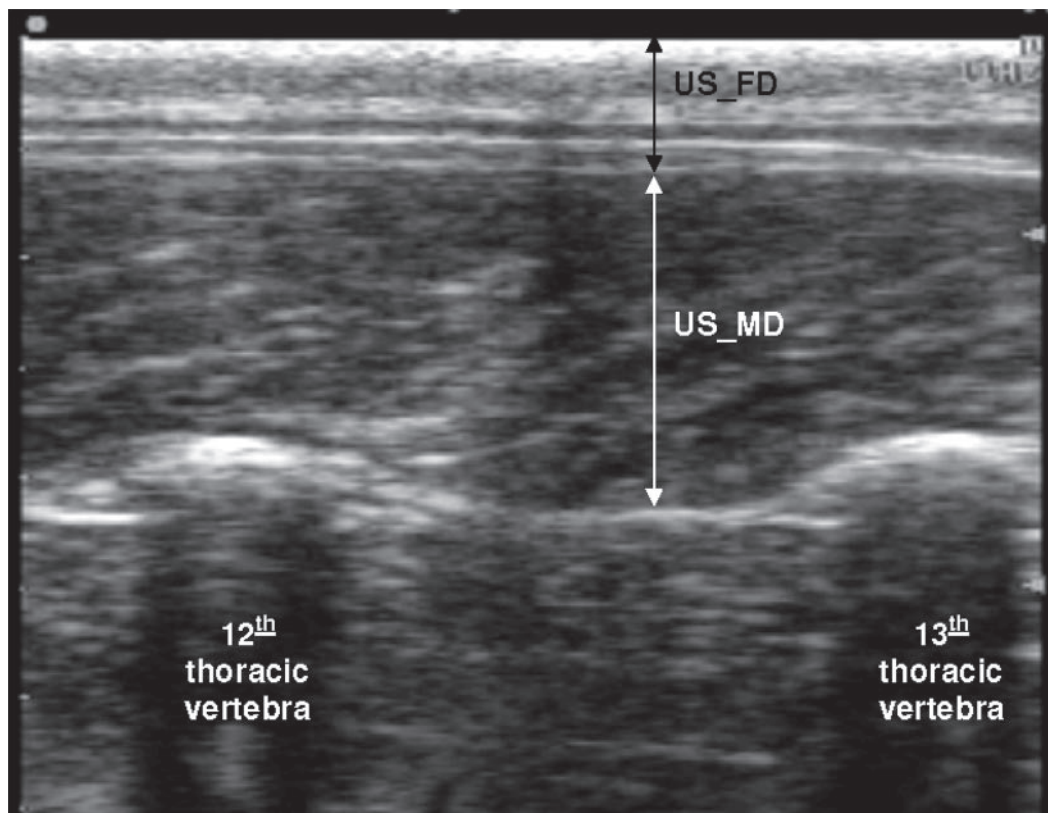
**Figure 2.** Ultrasound image at the 12th to 13th thoracic vertebrae with the probe parallel to the backbone. US_MD = LM depth; US_FD = skin thickness + subcutaneous fat thickness + interfaces.

### Slaughter Procedure, Carcass Measurements, and Carcass Composition

When lambs reached 22 to 24 kg of BW, they were weighed and slaughtered without fasting, according the European Union laws, at the CITA experimental slaughterhouse. Standard commercial procedures were used, with special care taken to avoid fat and muscle depth alterations when the skin was removed. Carcasses were hung by the Achilles tendon and were chilled for 24 h at 4°C.

Cold carcass measurements were taken on the left half carcass. Carcasses were cut off at 10–11T, 12–13T, 1–2L, and 3–4L. The LM width (**CC_A**) and depth (**CC_MD**), and subcutaneous fat thickness (**CC_FD**) were measured with a ruler in millimeters at the cranial side of the section. The CC_MD and CC_FD were measured at 2 and 4 cm from the nearest end of the LM to the backbone, and at 1/3 of the LM width (Delfa et al., 2007). The left side of the 129 carcasses was completely dissected with a scalpel into muscle, subcutaneous fat, intramuscular fat, and bone + remainder, which included the major blood vessels, ligaments, tendons, and thick connective tissue associated with muscles (Colomer-Rocher et al., 1988).

### Statistical Analysis

Differences between in vivo ultrasound measurements and their respective cold carcass measurements were analyzed by a paired-samples $t$-test and their relationship was analyzed by linear correlation. Carcass composition was estimated by in vivo ultrasound data by a stepwise regression procedure using BW and ultrasound measurements as independent variables. The following options were tested: untransformed variables, independent variables on a logarithmic scale, dependent variables on a logarithmic scale, and both independent and dependent variables on a logarithmic scale (Teixeira et al., 2006). The accuracy of the estimates was evaluated by adjusted $R^2$ and residual SD (**RSD**). All statistics were calculated by using the SAS statistical package (SAS Institute Inc., Cary, NC).

### RESULTS AND DISCUSSION

Means, minimum, maximum, and SD of the BW, carcass weight, and carcass components are shown in Table 1. The BW and cold carcass weight used in this work were representative of Ternasco light lambs (Joy et al., 2008). The SD in this study was greater than that reported by Delfa et al. (1995), who predicted the carcass composition from in vivo ultrasound measurements in light lambs with a similar BW and carcass composition.

Means and SD of in vivo ultrasound measurements in each anatomical location are shown in Table 2. The LM increased in width (US_A) from 43.0 to 46.8 mm from the cranial to the caudal side, with a constant in-

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**Table 1.** Means, minimum, maximum, and SD of the BW, cold carcass weight (CCW), and left half carcass components (in kg)

| Item | Mean | Minimum | Maximum | SD |
|------|------|---------|---------|-----|
| BW | 22.6 | 19.9 | 26.8 | 1.05 |
| CCW | 10.8 | 8.7 | 13.3 | 0.86 |
| Meat | 2.99 | 2.29 | 3.49 | 0.225 |
| Fat | 1.07 | 0.59 | 1.87 | 0.233 |
| Bone | 1.03 | 0.81 | 1.29 | 0.099 |

crease. The greatest variation was 3 mm from 10–11T to 12–13T, whereas from 12–13T to 3–4L, width muscle increased almost linearly. Fernández et al. (1998) found a similar tendency in 25-kg Manchego breed lambs, although the LM width at 12–13T was slightly greater than the present results.

The US_MD2, US_MD4, and US_MD1/3 [perpendicular (MD) and parallel (MDP)] remained regular, with slight ups and downs along the spine. At the 4 anatomical locations, US_MD had an increase of 0.5 to 1.4 mm from US_MD1/3 and US_MDP1/3 to US_MD2, and decreased from US_MD2 to US_MD4 from

4.1 to 4.5 mm. From the medial to the lateral direction, muscle depth increased slightly from 1/3 LM width to 2 cm, and showed a clear decrease toward the lateral side of the LM from 2 to 4 cm (US_MD1/3 < US_MD2 > US_MD4). Delfa et al. (1995) found similar US_MD and US_FD values in Rasa Aragonesa and Roya Bilbilitana breeds slaughtered at BW similar to those in the present study, whereas Fernández et al. (1998) reported greater muscle depths than those in our study.

The US_FD measurement (skin thickness + subcutaneous fat thickness + interfaces) was always greater in 10–11T than in the rest of the locations studied,

**Table 2.** Means and SD of in vivo ultrasound and cold carcass measurements at 4 anatomical locations[1]

| Item[2] | 10–11T | | 12–13T | | 1–2L | | 3–4L | |
|---------|--------|-----|--------|-----|------|-----|------|-----|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| US_A | 43.0 | 7.52 | 46.1 | 6.34 | 46.5 | 7.24 | 46.8 | 7.16 |
| CC_A | 45.5 | 3.13 | 46.4 | 3.67 | 48.3 | 6.03 | 54.7 | 7.02 |
| US_MD2 | 18.0 | 1.94 | 17.8 | 2.06 | 18.1 | 2.02 | 18.1 | 2.06 |
| CC_MD2 | 21.1 | 2.90 | 22.7 | 2.99 | 22.7 | 2.24 | 21.2 | 2.4 |
| US_FD2 | 4.3 | 0.97 | 3.5 | 0.64 | 3.4 | 0.61 | 3.6 | 0.64 |
| CC_FD2 | 3.0 | 1.27 | 1.15 | 0.67 | 1.4 | 0.86 | 1.6 | 1.00 |
| US_FDG2 | 1.2 | 0.78 | 0.5 | 0.36 | 0.5 | 0.34 | 0.6 | 0.39 |
| US_FDGI2 | 2.5 | 0.86 | 1.7 | 0.55 | 1.7 | 0.55 | 1.8 | 0.65 |
| US_SK2 | 1.8 | 0.39 | 1.7 | 0.40 | 1.7 | 0.45 | 1.7 | 0.41 |
| US_MD4 | 13.7 | 2.47 | 13.7 | 2.25 | 14.0 | 2.67 | 13.6 | 2.35 |
| CC_MD4 | 14.5 | 2.47 | 16.7 | 2.92 | 19.4 | 2.46 | 16.2 | 2.78 |
| US_FD4 | 4.7 | 1.25 | 3.6 | 0.74 | 3.8 | 1.26 | 3.8 | 0.79 |
| CC_FD4 | 3.2 | 1.38 | 1.1 | 0.68 | 1.4 | 0.86 | 2.8 | 1.66 |
| US_FDG4 | 1.4 | 1.00 | 0.5 | 0.42 | 0.6 | 0.47 | 0.8 | 1.37 |
| US_FDGI4 | 2.8 | 1.15 | 1.8 | 0.61 | 1.8 | 0.60 | 2.0 | 0.67 |
| US_SK4 | 1.8 | 0.43 | 1.7 | 0.49 | 1.8 | 0.54 | 1.8 | 0.50 |
| US_MD1/3 | 17.4 | 1.85 | 17.0 | 1.74 | 17.6 | 1.77 | 16.8 | 2.3 |
| CC_MD1/3 | 21.5 | 2.66 | 22.8 | 2.84 | 22.8 | 2.11 | 21.9 | 2.39 |
| US_FD1/3 | 4.3 | 0.94 | 3.6 | 0.67 | 3.5 | 0.65 | 3.6 | 0.64 |
| CC_FD1/3 | 2.8 | 1.18 | 1.3 | 0.69 | 1.5 | 0.87 | 1.5 | 1.07 |
| US_FDG1/3 | 1.2 | 0.71 | 0.6 | 0.43 | 0.6 | 0.38 | 0.6 | 0.40 |
| US_FDGI1/3 | 2.5 | 0.81 | 1.8 | 0.57 | 1.7 | 0.59 | 1.8 | 0.67 |
| US_SK1/3 | 1.9 | 0.45 | 1.8 | 0.47 | 1.8 | 0.47 | 1.8 | 0.46 |
| US_MDP | 17.0 | 1.07 | 16.5 | 2.53 | 17.6 | 1.77 | 16.9 | 2.02 |
| US_FDP | 5.3 | 1.41 | 4.3 | 0.87 | 4.5 | 0.93 | 4.8 | 1.12 |
| US_FDGP | 1.6 | 1.06 | 0.7 | 0.50 | 0.8 | 0.48 | 1.0 | 0.69 |
| US_FDGIP | 3.1 | 1.24 | 2.2 | 0.74 | 2.3 | 0.73 | 2.6 | 0.97 |
| US_SKP | 2.2 | 0.58 | 2.1 | 0.58 | 2.2 | 0.69 | 2.2 | 0.66 |

[1]10–11T = 10th to 11th thoracic vertebrae; 12–13T = 12th to 13th thoracic vertebrae; 1–2L = 1st to 2nd lumbar vertebrae; 3–4L = 3rd to 4th lumbar vertebrae.

[2]All the variables were measured in millimeters. A, MD, FD, FDG, and FDGI were measured perpendicularly to the backbone at 2 cm, 4 cm, or 1/3 of the LM width. US_A = ultrasound LM width; CC_A = carcass LM width; US_MD = ultrasound muscle depth; CC_MD = carcass muscle depth at 2 cm, 4 cm, or 1/3 of the LM width; US_FD = ultrasound skin + subcutaneous fat + interface thickness; CC_FD = carcass subcutaneous fat thickness at 2 cm, 4 cm, or 1/3 of the LM width; US_FDG = ultrasound subcutaneous fat thickness; US_FDGI = ultrasound subcutaneous fat + interface thickness; US_SK = ultrasound skin thickness; US_MDP = ultrasound muscle depth in parallel; US_FDP = ultrasound skin + subcutaneous fat + interface thickness in parallel; US_FDGP = ultrasound subcutaneous fat thickness in parallel; US_FDGIP = ultrasound subcutaneous fat + interface thickness in parallel; US_SKP = ultrasound skin thickness in parallel.

regardless of the distance to the backbone, with differences of between 0.7 and 1.1 mm. In all locations, we observed that the further from the backbone the measurement was taken, the greater the US_FD value was. Thus, US_FD4 had a greater value than US_FD2, and US_FD2 was greater than US_FD1/3. The US_FD values ranged from 3.4 mm (US_FD2 at 1–2L) to 5.3 mm (US_FDP 1/3 at 10–11T). Teixeira et al. (2006) measured US_FD in 36-kg Churra Galega Bragançana male lambs at the greatest depth of the muscle (corresponding to the 2 cm from the backbone measurement of the present study), and at 12–13T reported US_FD values similar to those of the present study (3.6 mm) and greater ones when the location was at 3–4L (4.2 mm).

The US_FDG measurement showed the same tendency as US_FD, with differences of 0.5 to 0.7 mm at 10–11T and at the rest of the locations. Skin thickness revealed similar values in all locations and at all distances to the backbone (1.7 to 1.8 mm), except when it was measured parallel to the backbone (2.1 to 2.2 mm). Brown et al. (2000), working in Merino sheep, found skin thicknesses from 1.6 to 2.6 mm throughout 1 yr and reported that real-time ultrasound could measure skin thickness and that it offered many potential advantages over the caliper technique.

### *Relationships Between Ultrasound Measurements and the Corresponding Carcass Measurements*

The literature has usually reported the precision of measurements by means of correlation coefficients between real and ultrasound measurements, essentially looking for prediction equations of any tissue, but differences between them (bias) have not often been reported. Ultrasound accuracy is important to fix the optimal finishing periods of lambs or to choose males for selection schemes (Stanford et al., 2001). The differences between in vivo ultrasound measurements and their equivalent cold carcass measurements and the relationships between them are shown in Table 3. Except for US_FDG4 measured at 3–4L, the pairs of in vivo ultrasound and cold carcass measurements were significantly different ($P < 0.05$) and had small correlations. Any ultrasound measurements of muscle depth at any location or at any distance to the backbone were less than their equivalent measurements on cold carcasses, with differences from 0.8 mm for US_MD4 at 10–11T to 5.9 mm for US_MD1/3 at 12–13T. This underestimation of ultrasound measurements is in agreement with the results of Fernández et al. (1998), although these researchers reported greater differences than the ones observed in muscle depth in the present study of 25-kg lambs measured at 12–13T and 2–4L.

When ultrasound measurements were perpendicular to the backbone, differences between US_FDGI and CC_FD were closer to zero than differences between ultrasound fat thickness without interface (US_FDG)

and CC_FD (Table 3), ranging from −0.9 to 0.6 mm for the former and from −2.1 to −0.5 mm for the latter. In addition, the US_FDG revealed a slight underestimation in relation to carcass measurements. In relation to this, Fernández et al. (1997, 1998) observed differences from 0.3 to 0.6 mm in Manchego, Merino, and Ile de France × Merino lambs slaughtered between 22 and 28 kg of BW. These underestimations could be produced by pressure exerted by technicians or operators on tissues below the probe (Purchas and Beach, 1981; McEwan et al., 1989). Nevertheless, these narrow differences proved that ultrasound techniques provided accurate measurements. Hence, the results suggest that US_FDGI measured parallel to the backbone was the most accurate measurement of the real fatness level of lambs. The US_FDGI measured perpendicularly had a greater correlation with CC_FD than the US_FDGI measured parallel to the backbone.

All the correlations of fat thickness measured perpendicular to and parallel to the backbone at the 4 locations were highly significant ($P < 0.001$), with the exception of fat thickness at 4 cm at 3–4L. In general, greater correlations were found at 10–11T and 1–2L. The literature showed differences between studies. Cadavez et al. (1999b) and Fernández et al. (1998) observed greater correlations between ultrasonic and carcass measurements taken at 12–13T than those taken at 1–2L or 3–4L, which were similar to those reported in this study. Teixeira et al. (2006) and Delfa et al. (1991) found correlations at 12–13T and 3–4L similar to those observed in the present study. In general, the correlations found were not great. The small variability in the BW and carcass weight could be responsible for this. Silva et al. (2006) found greater correlations for muscle (r = 0.75–0.88) and fat depth (r = 0.83–0.96) when using males and females of 2 breeds with BW ranging from 27 to 45 kg.

### *Prediction Models*

In vivo ultrasound measurements were used as independent variables in linear multiple regressions to predict carcass muscle, fat, and bone as dependent variables. Logarithmic transformations were applied to both the dependent and independent variables and also were included in the regressions.

To compare the prediction equations developed, adjusted $R^2$ and RSD statistics were taken into account. Although RSD is generally considered better than $R^2$ for comparing regressions (Kempster et al., 1982b), $R^2$ is widely used (as in this study) when RSD values are not reported in the literature.

Determination coefficients and RSD of regressions (data not shown) revealed slight differences, depending on the anatomical location and mathematical transformation (absolute vs. logarithmic), but there were more regressions with greater $R^2$ and smaller RSD when using measurements taken at 1–2L than when using measurements taken at other anatomical locations. Re-

**Table 3.** Differences (mm) between in vivo ultrasound measurements and cold carcass measurements in the same location (in vivo cold carcass)[1] and correlations among them

| | 10–11T | | | | | 12–13T | | | | |
| | t-test | | | Correlation | | t-test | | | Correlation | |
| Item[2] | Difference | SEM | P-value[3] | r | P-value | Difference | SEM | P-value | r | P-value |
|---|---|---|---|---|---|---|---|---|---|---|
| US_MD2-CC_MD2 | −3.1 | 0.25 | *** | 0.42 | *** | −4.9 | 0.27 | *** | 0.32 | *** |
| US_MD4-CC_MD4 | −0.8 | 0.27 | 0.004 | 0.29 | *** | −3.0 | 0.29 | *** | 0.25 | 0.005 |
| US_MD1/3-CC_MD1/3 | −4.2 | 0.26 | *** | 0.23 | 0.011 | −5.9 | 0.25 | *** | 0.32 | *** |
| US_FD2-CC_FD2 | 1.4 | 0.09 | *** | 0.63 | *** | 2.3 | 0.05 | *** | 0.67 | *** |
| US_FDG2-CC_FD2 | −1.7 | 0.09 | *** | 0.60 | *** | −0.6 | 0.05 | *** | 0.64 | *** |
| US_FDGI2-CC_FD2 | −0.5 | 0.09 | *** | 0.64 | *** | 0.6 | 0.04 | *** | 0.67 | *** |
| US_FD4-CC_FD2 | 1.5 | 0.10 | *** | 0.60 | *** | 2.5 | 0.06 | *** | 0.56 | *** |
| US_FDG4-CC_FD4 | −1.7 | 0.10 | *** | 0.57 | *** | −0.5 | 0.05 | *** | 0.57 | *** |
| US_FDGI4-CC_FD4 | −0.4 | 0.10 | *** | 0.62 | *** | 0.4 | 0.06 | *** | 0.62 | *** |
| US_FD1/3-CC_FD1/3 | 1.6 | 0.09 | *** | 0.58 | *** | 2.4 | 0.05 | *** | 0.64 | *** |
| US_FDG1/3-CC_FD1/3 | −1.6 | 0.08 | *** | 0.66 | *** | −0.7 | 0.05 | *** | 0.64 | *** |
| US_FDGI1/3-CC_FD1/3 | −0.3 | 0.08 | *** | 0.64 | *** | 0.5 | 0.05 | *** | 0.61 | *** |
| US_FDP-CC_FD1/3 | 2.5 | 0.12 | *** | 0.42 | *** | 3.0 | 0.08 | *** | 0.38 | *** |
| US_FDGP-CC_FD1/3 | −1.2 | 0.10 | *** | 0.46 | *** | −0.6 | 0.06 | *** | 0.28 | 0.001 |
| US_FDGIP-CC_FD1/3 | 0.3 | 0.12 | 0.015 | 0.42 | *** | 0.9 | 0.08 | *** | 0.26 | 0.003 |

| | 1–2L | | | | | 3–4L | | | | |
| | t-test | | | Correlation | | t-test | | | Correlation | |
| | Difference | SEM | P-value | r | P-value | Difference | SEM | P-value | r | P-value |
|---|---|---|---|---|---|---|---|---|---|---|
| US_MD2-CC_MD2 | −4.5 | 0.22 | *** | 0.34 | *** | −3.2 | 0.22 | *** | 0.41 | *** |
| US_MD4-CC_MD4 | −5.4 | 0.28 | *** | 0.24 | 0.006 | −2.6 | 0.28 | *** | 0.25 | 0.005 |
| US_MD1/3-CC_MD1/3 | −5.2 | 0.22 | *** | 0.25 | 0.005 | −5.1 | 0.27 | *** | 0.20 | 0.028 |
| US_FD2-CC_FD2 | 2.1 | 0.06 | *** | 0.61 | *** | 2.0 | 0.08 | *** | 0.50 | *** |
| US_FDG2-CC_FD2 | −0.8 | 0.06 | *** | 0.60 | *** | −1.0 | 0.08 | *** | 0.53 | *** |
| US_FDGI2-CC_FD2 | 0.4 | 0.06 | *** | 0.68 | *** | 0.2 | 0.07 | 0.001 | 0.57 | *** |
| US_FD4-CC_FD2 | 2.3 | 0.12 | *** | 0.30 | 0.001 | 1.0 | 0.13 | *** | 0.45 | *** |
| US_FDG4-CC_FD4 | −0.8 | 0.06 | *** | 0.54 | *** | −2.1 | 0.19 | *** | 0.05 | ns |
| US_FDGI4-CC_FD4 | 0.7 | 0.06 | *** | 0.54 | *** | −0.9 | 0.12 | *** | 0.58 | *** |
| US_FD1/3-CC_FD1/3 | 2.0 | 0.06 | *** | 0.62 | *** | 2.1 | 0.08 | *** | 0.59 | *** |
| US_FDG1/3-CC_FD1/3 | −0.9 | 0.06 | *** | 0.65 | *** | −0.9 | 0.07 | *** | 0.70 | *** |
| US_FDGI1/3-CC_FD1/3 | 0.3 | 0.06 | *** | 0.68 | *** | 0.3 | 0.07 | *** | 0.67 | *** |
| US_FDP-CC_FD1/3 | 3.0 | 0.09 | *** | 0.39 | *** | 3.2 | 0.11 | *** | 0.34 | *** |
| US_FDGP-CC_FD1/3 | −0.6 | 0.06 | *** | 0.66 | *** | −0.5 | 0.08 | *** | 0.50 | *** |
| US_FDGIP-CC_FD1/3 | 0.8 | 0.07 | *** | 0.49 | *** | 1.0 | 0.10 | *** | 0.32 | *** |

[1]10–11T = 10th to 11th thoracic vertebrae; 12–13T = 12th to 13th thoracic vertebrae; 1–2L = 1st to 2nd lumbar vertebrae; 3–4L = 3rd to 4th lumbar vertebrae.

[2]All the variables were measured in millimeters. MD, FD, FDG, and FDGI were measured perpendicularly to the backbone at 2 cm, 4 cm, or 1/3 of the LM width. US_MD = ultrasound muscle depth; CC_MD = carcass muscle depth at 2 cm, 4 cm, or 1/3 of the LM width; US_FD = ultrasound skin + subcutaneous fat + interface thickness; CC_FD = carcass subcutaneous fat thickness at 2 cm, 4 cm, or 1/3 of the LM width; US_FDG = ultrasound subcutaneous fat thickness; US_FDGI = ultrasound subcutaneous fat + interface thickness; US_MDP = ultrasound muscle depth in parallel; US_FDP = ultrasound skin + subcutaneous fat + interface thickness in parallel; US_FDGP = ultrasound subcutaneous fat thickness in parallel; US_FDGIP = ultrasound subcutaneous fat + interface thickness in parallel.

[3]NS, not significant; ***P < 0.001.

gression equations with variables without logarithmic transformations had greater $R^2$ and smaller RSD (Table 4) than equations with variables with logarithmic transformations (data not shown). Nevertheless, the best prediction equation for fat was the equation with both dependent and independent variables previously transformed into logarithms. In this sense, Teixeira et al. (1989, 1995, 2006), working with ewes and goats, concluded that variables transformed into logarithms gave better regression equations, which suggests that the fat depots had a logarithmic relationship with BW.

Teixeira et al. (2006) reported an $R^2$ of 0.85 when using both dependent and independent variables previously transformed into logarithms. This greater $R^2$ value was due to the wider BW range used by Teixeira et al. (2006), whereas in the present results, the BW range was narrow.

Ultrasound measurements taken at 1–2L have been used by Stanford et al. (2001) and Mendizabal et al. (2003). Stanford et al. (1995) reported that fat thickness taken at the first lumbar vertebra was the best variable for predicting saleable meat yield. In addition,

**Table 4.** Multiple regression equations[1] using BW and in vivo ultrasound measurements at the 1st to 2nd lumbar vertebrae for predicting tissue carcass composition (g)

| Dependent variable | Independent variable[2] | a | b | sb | $R^2$ | RSD |
|---|---|---|---|---|---|---|
| Muscle | US_MD1/3 | −114.91 | 43.14 | 6.86 | 0.45 | 166.92 |
|  | BW |  | 82.84 | 13.36 | 0.59 | 144.46 |
| Log fat | Log US_FD2 | 0.27 | 0.27 | 0.09 | 0.32 | 0.073 |
|  | Log BW |  | 1.72 | 0.28 | 0.51 | 0.062 |
| Bone | US_FDGI1/3 | 798.36 | 71.04 | 17.91 | 0.13 | 90.12 |
|  | US_FDG2 |  | −58.74 | 29.11 | 0.17 | 88.20 |

[1]a = intercept; b = regression coefficients; sb = SE of b; $R^2$ = adjusted coefficient of determination; RSD = residual SD.

[2]US_MD1/3 = muscle depth at 1/3 measured perpendicularly; US_FD2 = fat thickness at 2 cm; US_FD22 = ultrasound subcutaneous fat thickness at 2 cm; US_FDGI1/3 = ultrasound subcutaneous fat + interface thickness at 1/3.

this location is used in several countries in programs for genetic improvement, such as in Denmark (Jensen, 1990), Finland, and Norway (Puntilla and Nylaner, 1993). However, the literature is not conclusive concerning the optimal anatomical position for predicting carcass composition. Bruwer et al. (1987), Jones et al. (1982), and Teixeira et al. (2006) considered that ultrasound fat depth at the 13th thoracic vertebra gave the best prediction of carcass composition. For ultrasound measurements at 3–4L, Junkuszew and Ringdorfer (2005) reported $R^2$ of 0.67, 0.62, and 0.58 for muscle, fat, and bone, respectively. Delfa et al. (1991, 1996a) and Stanford et al. (1995) concluded that lumbar fat thickness measurements assessed ultrasonically in live animals were the best predictors of total carcass muscle.

To predict muscle content of the carcass, 2 positive variables were included in the equation. The US_MD1/3 measurement was the first variable admitted, and it accounted for 45% of the variation in muscle tissue weight. Admission of BW by the model increased precision by 14% (to 59%). For the prediction of fat, BW was admitted after US_FD2, and both variables explained 51% of the total variability. Carcass bone was poorly predicted with 2 fat-related variables. Fat thickness measurements were included inconsistently in bone regression equations, relating bone positively to US_FDGI1/3 and negatively to US_FDG2.

The prediction equations obtained in the present study showed smaller $R^2$ than expected, in accordance with the ultrasound literature. Although the very thin subcutaneous fat layer of light lambs used in the present study limited the potential of ultrasound to provide accurate measurements (Teixeira et al., 2006), it is probably the narrow range of BW that was responsible for these results. This would be in accordance with the results of Delfa et al. (1995, 1996a), who used in vivo and carcass ultrasound on the same kinds of animals, with carcasses weighing between 8.5 and 11.5 kg. Delfa et al. (2007) used lambs slaughtered at 22.4 kg, with a SD of 0.96, but despite the narrower range of BW than was considered in our study, these authors achieved

$R^2$ of 0.70, 0.81, and 0.51 for muscle, subcutaneous fat, and bone, respectively. These improvements were based on the inclusion of more than 2 variables from 4 anatomical points, whereas in our study, the variables used were limited to 1 anatomical location. It may be useful to use image analysis systems when narrow and low ranges of BW are used. As reported by Silva et al. (2005), measurements carried out directly on ultrasound monitors had a low accuracy (±1 mm) compared with those of the image analysis system (±0.1 mm). Thus, ultrasound measurements are capable of detecting differences in tissue thickness among animals that have low values for this trait.

The BW variable is the most important measurement for predicting muscle weight (Shelton et al., 1977; Jones et al., 1982; Kempster et al., 1982a; Fortin and Shrestha, 1986; Silva et al., 2007), and the inclusion of ultrasound measurements normally provides only a little improvement in the accuracy of the prediction (Leymaster et al., 1985). However, the present results showed that narrow ranges of BW did not offer much as a predictor of the carcass composition of Ternasco lambs because many factors affect the rate and onset of fattening in meat animals, in agreement with Delfa et al. (1995), Berg et al. (1996), and Puntilla (1986).

In conclusion, fat thickness including the interface measured perpendicularly to the backbone was the most precise and accurate measurement and could be recommended to ascertain the real level of fatness of light lambs. The best prediction equations for muscle, bone, and fat were developed with in vivo ultrasound data measured at 1–2L, but they had limited predictive value. Unlike in most of the references, ultrasound measurements were the most important predictors when a narrow range of BW was used. Regression equations may be improved by increasing the range of BW.

## LITERATURE CITED

Berg, E. P., M. K. Neary, J. C. Forrest, D. L. Thomas, and R. G. Kauffman. 1996. Assessment of lamb carcass composition from

live animal measurement of bioelectrical impedance or ultrasonic tissue depths. J. Anim. Sci. 74:2672–2678.

BOE. 2006. Orden APA/2696/2006, de 28 de julio, por la que se ratifica la modificación del Reglamento de la Indicación Geográfica Protegida "Ternsco de Aragón." Boletín Oficial del Estado 200:30928–30929.

Brown, D. J., M. L. Wolcott, and B. J. Crook. 2000. The measurement of skin thickness in Merino sheep using real time ultrasound. Wool Technol. Sheep Breed. 48:269–276.

Bruwer, G. G., R. T. Naudé, M. M. du Toit, A. Cloete, and W. A. Vosloo. 1987. An evaluation of the lamb and mutton carcase grading system in the Republic of South Africa.2.The use of fat measurements as predictors of carcase composition. S. Afr. J. Anim. Sci. 17:85–89.

Cadavez, V., A. Teixeira, and R. Delfa. 1999a. Utilización de ultrasonidos junto con el peso vivo y el peso de la canal caliente para la estimación del peso de las piezas de carnicería en corderos de la raza Churra Galega Bragançana: Comparación de sondas de 5 y 7.5 MHz. Pages 425–432 in Producción Ovina y Caprina. Sociedad Española de Ovinotecnia y Caprinotecnia (SEOC), Soria, Spain.

Cadavez, V., A. Teixeira, R. Delfa, and S. Matos. 2000. Prediction of carcass composition in vivo by slaughter weight and ultrasound measurements in Churro Galego Bragançano local breed lambs. Page 296 in Book of Abstracts No. 6 of 51th Annu. Meet. Eur. Assoc. Anim. Prod., The Hague, the Netherlands. Wageningen Pers, Wageningen, the Netherlands.

Cadavez, V., A. Teixeira, R. Delfa, and E. Pereira. 1999b. Precisión de los ultrasonidos (sondas de 5 y 7,5 MHz) en la determinación del espesor de la grasa subcutánea y de la profundidad del *M. longissimus dorsi* in vivo y en la canal. Informaciones Tecnicas Economicas Agraria (ITEA) 20(I):119–121.

Colomer-Rocher, F., R. Delfa, and I. Sierra. 1988. Método normalizado para el estudio de los caracteres cuantitativos y cualitativos de las canales ovinas producidas en el área mediterránea, según los sistemas de producción. Pages 7–30 in Les carcasses d'agneux et de chevreaux méditerranéens. Rapport EUR 11479 FR, Saragossa, Spain.

Delfa, R. 2004. Los ultrasonidos como predictores del reparto del tejido adiposo y de la composición tisular de la canal en cabras adultas. PhD Thesis. Universidad de Zaragoza, Spain.

Delfa, R., C. Gonzalez, and A. Teixeira. 1996a. Use of cold carcass weight and fat depth measurements to predict carcass composition of Rasa Aragonesa lamb. Small Rumin. Res. 20:267–274.

Delfa, R., C. Gonzalez, E. Vijil, A. Teixeira, M. Tor, and C. Gosalvez. 1996b. Ultrasonic measurements for predicting carcass quality and body fat depots in Ternasco de Aragon-Spain. Page 272 in Sheep and Goat Production, Proc. 47th Annu. Meet. Eur. Assoc. Anim. Prod., Lillehammer, Norway. Book of Abstracts No. 2. Wageningen Pers, Wageningen, the Netherlands.

Delfa, R., M. Joy, A. Sanz, B. Panea, J. Alvarez-Rodriguez, P. Albertí, and A. Teixeira. 2007. In vivo ultrasonic measurements and live weight for predicting carcass quality in Churra Tensina mountain breed lambs. Pages 189–193 in Evaluation of carcass and meat quality in cattle and sheep. Eur. Assoc. Anim. Prod. Publ. No. 123. Wageningen Pers, Wageningen, the Netherlands.

Delfa, R., A. Teixeira, I. Blasco, and F. Colomer-Rocher 1991. Ultrasonic estimates of fat thickness, C measurement and longissimus dorsi depth in Rasa Aragonesa ewes with same body condition score. Options Méditerranéennes. Série A 13:25–30.

Delfa, R., A. Teixeira, C. Gonzalez, and I. Blasco. 1995. Ultrasonic estimates of fat thickness and longissimus dorsi muscle depth for predicting carcass composition of live Aragon lambs. Small Rumin. Res. 16:159–164.

European Communities. 1986. Council Directive 86/609/EEC of 24 November 1986 on the approximation of laws, regulations and administrative provisions of the Member States regarding the protection of animals used for experimental and other scientific purposes. Off. J. L 358:1–29.

Fernández, C., L. Gallego, and A. Quintanilla. 1997. Lamb fat thickness and longissimus muscle area measured by a computerized ultrasonic system. Small Rumin. Res. 26:277–282.

Fernández, C., A. García, H. Vergara, and L. Gallego. 1998. Using ultrasound to determine fat thickness and *longissimus dorsi* area on Manchego lambs of different live weight. Small Rumin. Res. 27:159–165.

Font i Furnols, M., R. San Julián, L. Guerrero, C. Sañudo, M. M. Campo, J. L. Olleta, M. A. Oliver, V. Cañeque, I. Álvarez, M. T. Díaz, W. Branscheid, M. Wicke, G. R. Nute, and F. Montossi. 2006. Acceptability of lamb meat from different producing systems and ageing time to German, Spanish, and British consumers. Meat Sci. 72:545–554.

Fortin, A., and J. N. B. Shrestha. 1986. In vivo estimation of carcass meat by ultrasound in ram lambs slaughtered at average live weight of 37 kg. Anim. Prod. 46:469–475.

Jensen, N. E. 1990. Performance tests of ram lambs 1990. Page 44 in Rep. 684. Natl. Inst. Anim. Sci., Copenhagen, Denmark.

Jones, S. D. M., J. S. Walton, J. W. Wilton, and J. E. Szkotnicki. 1982. The use of urea dilution and ultrasonic backfat thickness to predict the carcass composition of live lambs and cattle. Can. J. Anim. Sci. 62:371–379.

Joy, M., J. Álvarez-Rodríguez, R. Revilla, R. Delfa, and G. Ripoll. 2008. Ewe metabolic performance and lamb carcass traits in pasture and concentrate-based production systems in Churra Tensina breed. Small Rumin. Res. 75:24–35.

Junkuszew, A., and F. Ringdorfer. 2005. Computer tomography and ultrasound measurement as methods for the prediction of the body composition of lambs. Small Rumin. Res. 56:121–125.

Kempster, A. J., D. Arnall, J. C. Alliston, and J. D. Barker. 1982a. An evaluation of two ultrasonic machines (Scanogram and Danscanner) for predicting the body composition of live sheep. Anim. Prod. 34:249–255.

Kempster, T., A. Cuthberston, and G. Harrington. 1982b. Carcase evaluation in livestock breeding, production and marketing. Granada Publishing Limited, London, UK.

Leymaster, K. A., H. J. Mersmann, and T. G. Jenkins. 1985. Prediction of the chemical composition of sheep by use of ultrasound. J. Anim. Sci. 61:165–172.

Mahgoub, O. 1998. Ultrasonic scanning measurements of the *longissimus thoracis et lumborum* muscle to predict carcass muscle content in sheep. Meat Sci. 48:41–48.

McEwan, J. C., J. N. Clarke, M. A. Knowler, and M. Wheeler. 1989. Ultrasonic fat depths in Romney lambs and hoggets from lines selected for different production traits. Proc. N. Z. Soc. Anim. Prod. 49:113–119.

Mendizabal, J. A., R. Delfa, A. Arana, P. Eguinoa, C. Gonzalez, T. Treacher, and A. Purroy. 2003. Estimating fat reserves in Rasa Aragonesa ewes: A comparison of different methods. Can. J. Anim. Sci. 83:695–701.

Moody, W. G., S. E. Zobrisky, C. V. Ross, and H. D. Naumann. 1965. Ultrasonic estimates of fat thickness and longissimus dorsi area in lambs. J. Anim. Sci. 24:364–367.

Puntilla, M. L. 1986. Experiences using ultrasound scanner for evaluation of body composition in young Finnsheep rams. Page 25 in Proc 37th Annu. Meet.. Eur. Assoc. Anim. Prod., Budapest, Hungary.

Puntilla, M. L., and A. Nylaner. 1993. Possibilities to predict body composition in young Finnsheep rams. Page 87 in Proc. 43rd Annu. Meet. Eur. Assoc. Anim. Prod., Madrid, Spain.

Purchas, R. W., and A. D. Beach. 1981. Between-operator repeatability of fat depth measurements mad on live sheep and lambs with an ultrasonic probe. N. Z. J. Exp. Agric. 9:213–220.

Shelton, M., G. C. Smith, and F. Orts. 1977. Predicting carcass cutability of Rambouillet rams using live animal traits. J. Anim. Sci. 55:333–337.

Silva, S. R., J. J. Afonso, V. A. Santos, A. Monteiro, C. M. Guedes, J. M. T. Azevedo, and A. Dias-da-Silva. 2006. In vivo estimation of sheep carcass composition using real-time ultrasound with two probes of 5 and 7.5 MHz and image analysis. J. Anim. Sci. 84:3433–3439.

Silva, S. R., M. J. Gomes, A. Dias-da-Silva, L. F. Gil, and J. M. Azevedo. 2005. Estimation in vivo of the body and carcass chemical composition of growing lambs by real-time ultrasonography. J. Anim. Sci. 83:350–357.

Silva, S. R., C. M. Guedes, V. A. Santos, A. L. Lourenco, J. M. T. Azevedo, and A. Dias-Da-Silva. 2007. Sheep carcass composition estimated from *longissimus thoracis et lumborum* muscle volume measured by in vivo real-time ultrasonography. Meat Sci. 76:708–714.

Stanford, K., D. R. C. Bailey, S. D. M. Jones, M. A. Price, and R. A. Kemp. 2001. Ultrasound measurement of longissimus dimensions and backfat in growing lambs: Effects of age, weight and sex. Small Rumin. Res. 42:189–195.

Stanford, K., I. Clark, and S. D. M. Jones. 1995. Use of ultrasound in prediction of carcass characteristics in lambs. Can. J. Anim. Sci. 75:185–189.

Stouffer, J. R. 2004. History of ultrasound in animal science. J. Ultrasound Med. 23:577–584.

Teixeira, A., and R. Delfa. 1997. The use of ultrasonic measurements assessed with two probes in live lambs for prediction the carcass composition. Page 295 in Proc. 48th Annu. Meet. Eur. Assoc. Anim. Prod., Vienna, Austria. Book of Abstracts No. 3. Wageningen Pers, Wageningen, the Netherlands.

Teixeira, A., R. Delfa, and F. Colomer-Rocher. 1989. Relationships between fat depots and body condition score or tail fatness in the Rasa Aragonesa breed. Anim. Prod. 49:275–280.

Teixeira, A., R. Delfa, C. Gonzalez, L. Gosalvez, and M. Tor. 1995. Use of three joints as predictors of carcass and body fat depots in Blanca Celtibérica goats. Options Méditerranéennes, Série A 27:121–131.

Teixeira, A., S. Matos, S. Rodrigues, R. Delfa, and V. Cadavez. 2006. In vivo estimation of lamb carcass composition by real-time ultrasonography. Meat Sci. 74:289–295.

**References**

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