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Evaluation of ultrasound scanning to predict carcass composition of Austrian meat sheep

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ABSTRACT

Aims of the study were to evaluate the routine ultrasound scanning plus subjective muscle scoring system for meat sheep in Austria in terms of (1) their ability to predict carcass quality and composition, (2) the repeatability of ultrasound scanning and (3) a comparison of three anatomical scanning sites. Lambs of six breeds ($n = 189$; mean bodyweight 39 kg) were scored for the muscling of their shoulder, back and hindquarter and were scanned with an ultrasound device for back fat and *longissimus dorsi* muscle depth lateral of the spine at 10th/11th (US1) and 13th (US2) thoracic vertebrae as well as at 3rd/4th (US3) lumbar vertebrae. Each ultrasound picture was taken twice within a few minutes to check on within operator repeatability. After slaughter the carcasses were classified according to the EUROP system and back fat and muscle depth were measured on a carcass cross section, and 36 carcasses were dissected to lean meat, fat and bone to evaluate carcass composition. Relationships between carcass and dissection traits and routine performance testing traits (live weight, fat and muscle depth at US3) were evaluated based on partial regression coefficients additionally considering breed, sex (carcass traits only) and birth type as fixed effects. Further, fat and muscle depth at scan sites US1 and US2 were fitted alternatively and Pearson's correlation coefficients were calculated. Correlations between ultrasonic and carcass measures ranged from $r = 0.60$ (muscle depth at US1 and EUROP conformation class) to $r = 0.84$ (muscle depth at US1 and muscle depth at carcass). Repeatabilities for muscle and backfat thickness ranged from 0.90 to 0.95. The results support the usefulness of the currently routine ultrasound scans as relatively easy method to predict carcass composition in live lambs of different breeds. Muscle scans are valuable to estimate amount of carcass lean and EUROP conformation class, but fat scans have greater power to predict the fattiness of the carcass as well as lean percentage. Subjective muscle scoring of live animals seems to be mainly influenced by the fattiness of the animal. The comparison of three anatomical scanning sites did not give definite results. US1 seems to be favourable for estimating muscle depth, for the prediction of lean and in terms of repeatability whereas US2 and US3 had small advantages in scanning fat depth and in the prediction of EUROP classification and carcass fat.

1. Introduction

Producing lamb meat is the main economic activity in Austrian sheep farming. Consumer demand for lean meat has made selection for leaner animals necessary. Since the

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Table 1
Number of animals per breed and sex.

Breed	Male	Female	Total
Merinoland	20	20	40
Bergschaf	20	20	40
Suffolk	13	19	32
Jura	16	15	31
Texel	15	15	30
Schwarzköpfiges Fleischschaf	15	1	16
Total	99	90	189

year 2000, ultrasound scanning has been routinely used for performance testing of sheep of meat focused breeds in Austria. Herd book animals both male and female are obligatorily scanned for back fat and *longissiumus dorsi* depth and additionally get subjective scores for the muscularity of their shoulder, back and hindquarter. Even though methods to predict carcass quality of lambs were already examined (Delfa et al., 1995, 1996; Hopkins et al., 2008; Leeds et al., 2008; Stanford et al., 1998, 2001), most other studies analysed quite homogeneous animal groups, of the same breed and from the same feeding background, often of similar age and weight. Aim of the present study was to analyse the particular situation of routine performance testing of meat sheep in Austria, where quite heterogeneous animals of different breeds from different farms are examined with the same methods. The study is not intended to compare different breeds or animals, but rather to evaluate the methods under routine conditions. Additionally, the literature is not concordant about the optimal anatomical position for scanning lambs (Ripoll et al., 2009; Theriault et al., 2009). In detail, the aims of this study were to evaluate

(1) how accurate the current ultrasound scanning and scoring systems predict the carcass composition of lambs taking further effects like breed and sex into account,
(2) the repeatability of ultrasound scanning as test-retest reliability and
(3) if three different scan sites vary in prediction of carcass composition and or repeatability.

2. Materials and methods

2.1. Animals

In total 189 slaughter lambs were bought from 34 different Austrian farms and transported to the Agricultural Research and Education Centre Raumberg-Gumpenstein in Styria, Austria. They were pure bred animals of the six main breeds for lamb production in Austria: Merinoland, Tiroler Bergschaf (Tyrolean Mountain Sheep), Suffolk, Jura, Texel and Schwarzköpfiges Fleischschaf (Blackheaded Meatsheep). Sexes were almost equally distributed, except for Schwarzköpfiges Fleischschaf, where 15 males, but only one suitable female lamb was available for the trial. Table 1 shows the number of animals per breed and sex.

The lambs were on average 4 months old (min 81 days, max 263 days) and represented the normal slaughter weight in Austria of about 39 kg (Table 2).

2.2. Measures on live animals including ultrasound

The live animals were weighed (without prior restriction of feed and water) and given subjective scores (1 = worst to 9 = best) for muscling of shoulder, back and hindquarter. Subsequently back fat and *longissimus* *dorsi* muscle thickness were scanned with an ultrasound device (Mindray DP-6900 Vet, 5 mHz). Ultrasound pictures were taken laterally of the spine (right side) on three different anatomical sites: (1) in the area of 10th/11th thoracic vertebrae (= US1); (2) around 13th thoracic vertebrae (last rib) (= US2); and (3) at 3rd/4th lumbar vertebrae (= US3). US3 is the site used routinely for performance testing for meat sheep in Austria. Fig. 1 is an example of an ultrasound picture at site 2.

Table 2
Descriptive statistics (mean, standard deviations, minimum and maximum values).

	Mean	SD	Min	Max
Measurements on live animals (n = 189)				
Live weight (kg)	38.8	4.7	29.4	51.6
Average daily gain (g/d)	317	76	161	536
Muscling scores (1–9; 9 = best)				
Shoulder	6.2	0.8	5	8
Back	6.3	0.8	5	8
Hindquarter	6.2	0.8	4	9
Ultrasound scanning at three anatomical sites[a] (n = 189)				
MusUS1 (mm)	20.5	3.2	12.8	28.4
MusUS2 (mm)	20.4	3.1	12.5	28.7
MusUS3 (mm)	19.5	3.3	12.1	26.0
FatUS1(mm)	5.5	1.0	3.4	10.1
FatUS2 (mm)	6.0	1.2	3.8	10.2
FatUS3 (mm)	6.9	1.7	3.4	12.6
Carcass traits (n = 189)				
Cold carcass weight (kg)	18.4	2.6	12.6	26.2
Dressing percent	48.4	0.3	39.5	56.5
EUROP conformation class[b]	3.0	0.8	1	5
EUROP fat class[c]	2.3	0.8	1	4
MusC (mm)	29.2	4.6	18.0	42.3
FatC (mm)	2.9	1.6	0.3	8.5
Dissection of right carcass halves (n = 36)				
Lean meat (kg)	5.1	0.8	3.8	6.5
Lean meat %	57.7	4.9	49.3	68.6
Fat (kg)	1.8	0.6	0.8	3.6
Fat %	19.4	4.9	10.8	30.8
Bone (kg)	2.0	0.3	1.5	2.8
Bone %	22.6	2.7	17.8	28.5

[a] US1 measured in the area of 10th/11th thoracic vertebrae; US2 measured around 13th thoracic vertebrae (last rib); US3 measured at 3rd/4th lumbar vertebrae
[b] 5 = E (most muscular), 4 = *U*, 3 = *R*, 2 = O, 1 = *P* (poorly muscled)
[c] 1 = leanest, 5 = fattest

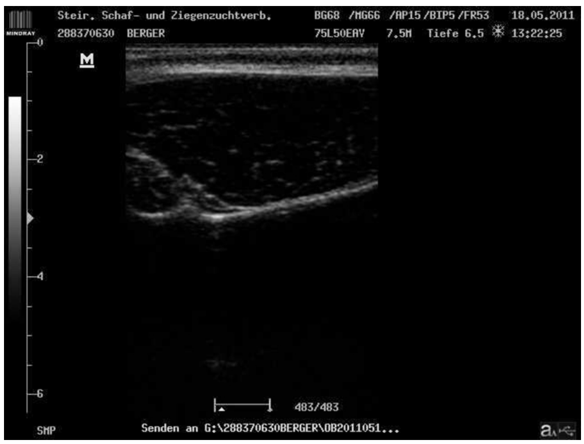

Fig. 1. Ultrasound picture at 13th thoracic vertebra (US2), same animal pictured as in Fig. 2.

Fig. 2. Carcass cross section behind last rib (equivalent to site US2), example of a very lean animal (same animal as in Fig. 1).

To check on within operator repeatability, each ultrasound picture was taken twice within a few minutes. In total six ultrasound pictures (two pictures of three sites) were available for each animal. The pictures were stored on a computer and later the program Messen Version 1.0 (Guggenberger, 2003) was used to obtain the measurements. Back fat and muscle depth (FatUS1-3, MusUS1-3) were measured twice on each picture: At the thickest point of *longissimus dorsi* and 2 cm lateral. Both measures are averaged for further use. All muscling scores, ultrasound pictures and measurements on the pictures were taken by the same experienced examiner.

2.3. Carcass evaluation

At maximum 48 h after the in vivo examination all animals were slaughtered according to EU regulations (Council Directive 93/119/EC of 22 December 1993 on the protection of animals at the time of slaughter or killing). After three to seven days of cooled hanging the carcasses were weighed and classified according to the EUROP system (Commission Regulations (EEC) No 2137/92 and No 461/93). Europe conformation class (ECC) ranges from 1 to 5 (with 5 meaning “E”, best score), and Europe fat class (EFC) ranges from 1 to 5 (with 1 meaning leanest). After classification, carcasses were cut transversely in half caudal of the last rib. Standardised digital pictures were taken of the cross section of the caudal half (for an example see Fig. 2). The computer program PicEdCora Version 9.15 (Jomesa Meßsysteme GmbH, Ismaning, Germany) was used to measure back fat thickness and *longissimus dorsi* thickness on these pictures (similar to the measurements on the ultrasound pictures). Slaughter and carcass classification were in all cases performed by the same professional butcher.

2.4. Dissection

Six male carcasses per breed (in total 36 carcasses) were further examined for their composition. These carcasses were cut in half along the spine. The right carcass half was further dissected to divide lean meat from bone and fat (including connective tissue). All components were weighed. Lean meat percentage (Lean %) was calculated by dividing lean meat kg by the weight of the right carcass half in kg, expressed as relative proportion. Fat and bone percentage (Fat %, Bone %) were calculated accordingly.

2.5. Statistical analysis

All statistical analyses were done with the software package SAS 9.2 (SAS Inst. Inc., Cary, NC). Relationships between routine performance testing traits and carcass traits were tested by *proc glm* and the following model:

$$Y_{ijkl} = m + \text{breed}_i + \text{sex}_j + \text{birth type}_k + b_1(\text{MusUS3}) + b_2(\text{FatUS}_3) + b_3(\text{LW}) + \varepsilon_{ijkl} \quad (1)$$

where Y_{ijkl} is the individual observation, μ the overall mean, breed$_i$ the fixed effect of breed i (i = 1–5, (1) Merinoland, (2) Tiroler Bergschaf, (3) Suffolk, (4) Jura, (5) Texel), sex$_j$ the fixed effect of sex j (j = 2, (1) = male, (2) = female), birth type$_k$ the fixed effect of birth type k (k = 2, (1) = single, (2) = multiple), b_1–b_3 regression coefficients, MusUS3 the continuous effect of muscle depth at scanning site 3 in mm, FatUS3 the continuous effect of fat depth at scanning site 3 in mm, LW the continuous effect of live weight and ε_{ijkl} the random residual. The breed Schwarzköpfiges Fleischschaf was not considered for this analysis as only one female animal was recorded. For the dissection traits the same model except the effect sex was applied (model [2]). Interactions between breed and birth type (carcass and dissection traits), breed and sex and sex and birth type (carcass traits only) were tested but not found to be significant and thus discarded. To analyse different scan sites, muscle and fat depth of US1 and US2 were fitted as covariates alternatively to MusUS3 and FatUS3.

In order to allow conclusions with regard to the predictive ability of routine performance traits, *proc glmselect* with stepwise selection method and Schwarz Bayesian Information Criterion (Cohen, 2006) were run for both models.

Data were expressed as least squares (LS) means and mean standard errors. Pearson’s correlations were obtained with SAS *proc corr*.

To evaluate repeatability, a general linear model (*proc glm*) was chosen with repeated measurement as dependent variable (y) and animal as predictor (x) to generate mean square errors (MSE) of variance and random error. According to Essl (1987) repeatability of two repeated measurements was calculated as

$$r = \frac{\sigma^2(t)}{\sigma^2(t) + \sigma^2(\varepsilon)} \text{ with}$$

$$\sigma^2(t) = \text{variance of difference between measurements} = \frac{MSE(t/\mu) - MSE(\varepsilon)}{2} \text{ and}$$

$$\sigma^2(\varepsilon) = \text{variance of random error} = MSE(\varepsilon).$$

3. Results and discussion

3.1. General

Table 2 gives details on the descriptive statistics on the 189 lambs under study. Average daily gain was calculated by dividing the animal’s live weight by its age in days, without knowing its birth weight. Live weight ranged from 29 to 52 kg, with a mean of 39 kg. Lambs were supposed to represent the desired weight range for slaughter lambs in Austria of 35–45 kg, but like in routine performance testing a few animals were slightly lighter or heavier. Mean average daily gain was 317 g/d. The wide range 161–536 g/d reflects different breeds but also the different feeding and housing systems on the home farms (from pasture based to concentrate based). Muscling scores for shoulder, back and hindquarter averaged 6. As often with subjective scores the maximum range of the scale (from 1 to 9) was not fully utilised: The scores for shoulder and back ranged from 5 to 8. The hindquarter scores showed more variation with a range from 4 to 9.

Dressing percentage was calculated as ratio of hot carcass weight to live weight. It was in a normal range of about 40–57%, with a mean of 48%. Scoring the carcasses according to the EUROP system used most of the scale: Europe conformation class (ECC) and Europe fat class (EFC) ranged from 1 to 5 and from 1 to 4, respectively. The carcasses were on average moderately muscular (mean ECC 3.0 = ‘*R*’) and rather lean (mean EFC 2.3).

Muscle and back fat thickness measured with ultrasound are well distributed and show similar values for the three sites (US1, US2 and US3), see Table 2. The *longissimus*

Table 3
LS Means for fixed effects, estimates for partial regression coefficients for routine performance testing traits (MusUS3, FatUS3 and live weight), their level of significance and the residual standard deviations (RSD) for carcass traits and model [1] as well as RSD for the same model but fitting US measurements of alternative sites (US1, US2) ($N = 173$).

Effect		Traits Cold carcass weight (kg)		Dressing percent (%)		ECC[4]		EFC[4]		MusC (mm)		FatC (mm)	
Levels of significance, LS Means													
Breed	JU[1]	**[2,3]	18.25^{ab}	*	47.90^{ab}	***	2.76^{a}	***	2.17^{ab}	***	29.14^{b}	***	3.34^{c}
	ML		17.80^{a}		47.50^{a}		2.72^{a}		2.26^{b}		28.82^{b}		2.86^{bc}
	SU		18.06^{a}		48.02^{ab}		2.89^{a}		2.21^{ab}		30.06^{b}		2.43^{ab}
	TB		18.60^{b}		48.70^{ab}		2.88^{a}		2.63^{c}		25.67^{a}		3.39^{c}
	TE		18.37^{ab}		49.42^{b}		3.57^{b}		1.86^{a}		31.82^{c}		1.88^{a}
Sex	male	**	18.00	ns	47.98	ns	2.89	**	2.11	ns	29.06	**	2.51
	female		18.43		48.63		3.03		2.35		29.14		3.04
Birth type	single	ns	18.19	ns	48.35	ns	2.87	ns	2.20	ns	28.73	ns	2.70
	multiple		18.24		48.26		3.04		2.25		29.47		2.86
Levels of significance, Estimates													
MusUS3 (mm)		***	0.265	***	0.567	***	0.092	**	0.058	***	0.545	**	0.119
FatUS3 (mm)		***	0.242	***	0.824	ns	0.055	***	0.279	***	0.621	***	0.603
Live weight (kg)		***	0.394	***	−0.192	***	0.043	*	0.020	***	0.164	ns	−0.015
RSD (US3)[5]		0.90		2.29		0.57		0.47		2.29		0.98	
Alternative US sites													
RSD (US1)		0.88		2.20		0.59		0.53		2.05		1.06	
RSD (US2)		0.89		2.13		0.57		0.49		2.11		0.99	

[1] JU = Jura, ML = Merinoland, SU = Suffolk, TB = Tiroler Bergschaf, TE = Texel.
[2] ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$, ns not significantly different from zero ($P \geq 0.05$).
[3] Different letters indicate significant differences between levels ($P < 0.05$) based on a Tukey–Kramer test.
[4] Europe conformation class (ECC), 1–5, $E = 5$, $P = 1$; Europe fat class (EFC), 1–5, 1 = leanest.
[5] US1 measured in the area of 10th/11th thoracic vertebrae; US2 measured around 13th thoracic vertebrae (last rib); US3 measured at 3rd/4th lumbar vertebrae.

dorsi got slightly thinner the more caudal the measurement, from 20.5 mm at US1 to 19.5 mm at US3, and back fat got thicker (5.5–6.9 mm). Nevertheless, the ultrasound values for muscle depth were clearly smaller than the values measured on carcasses (mean MusC 29.2 mm). This underestimation of ultrasound muscle measurements is in agreement with literature results (Emenheiser et al., 2010; Esquivelzeta et al., 2012; Fernández et al., 1998; Ripoll et al., 2009, 2010). On the contrary, ultrasound back fat was generally thicker than measured on carcasses (FatC 2.9 mm). This can be explained, because the carcasses are cleared of skin and layers of fat attached to it. In ultrasound scanning all tissue above the muscle (including skin) is considered fat. Additional, current studies concluded that ultrasound measurements overestimate back fat thickness in lean animals with less than 10 mm of back fat (Leeds et al., 2008; Theriault et al., 2009), like most of the lambs in the present study.

In total 36 carcass halves were manually separated in lean meat, fat and bone. On average the dissected carcass halves contained 58% lean meat, 19% fat (including connective tissue) and 23% bone (Table 2). As expected the ranges for content of lean (49–69%) and fat (11–31%) were wider than for bone (18–29%).

3.2. Relationship between in vivo routine performance testing traits and carcass traits

In Table 3, LS Means for fixed effects, estimates for the continuous effects, levels of significance as well as residual standard deviations (RSD) are shown for routine performance testing traits at US3 and carcass traits. As only one female Schwarzköpfiges Fleischschaf was recorded, this breed was discarded from analysis in order to be able to fit the effect sex in the model. Hence, only 173 records were utilised.

Breed affected all traits significantly. Texel, a specialised meat breed, had the highest dressing percentage, ECC and muscle depth and the lowest EFC and fat depth. Tiroler Bergschaf, an alpine landsheep breed without routine meat performance testing, was found to have the highest carcass weights but more fat and less muscle than other breeds. Sex only had a significant effect on cold carcass weight, EFC and fat depth while birth type did not significantly affect any of the traits analysed. In a recent study by Simeonov et al. (2014), females also had slightly higher carcass weights and dressing percentage. However, neither sex nor birth type significantly affected those slaughter traits.

The routine ultrasound performance testing traits, MusUS3 and FatUS3 showed a positive relationship to carcass traits which were significantly different from zero for all traits but FatUS3 and ECC ($P = 0.16$). Contrary to raw data, for which the simple linear regression coefficient of MusC on MusUS3 was $b = 1.12$ (data not shown) und thus MusC was underestimated (see above), the partial regression coefficient dropped to 0.545 (Table 3). With $b = 0.731$ (data not shown) and $b = 0.603$ for the simple linear and partial regression coefficients of FatC on FatUS3, respectively, the difference was smaller for the fat depth measurement.

In preceding analyses, stepwise procedures were performed. When only fitting MusUS3 for the analyses of the traits MusC and ECC, R^2 defined as the proportion of the total variance explained by the model was 0.64 and 0.40, respectively. Including all other effects, R^2 increased to 0.77

Table 4
LS Means for fixed effects, estimates for regression coefficients for routine performance testing traits (MusUS3, FatUS3 and live weight), their level of significance and the residual standard deviations (RSD) for dissection traits and model [2] as well as RSD for the same model but fitting US measurements of alternative sites (US1, US2) ($N = 36$).

Effect		Traits Lean meat (kg)		Fat (kg)		Bone (kg)		Lean Meat %		Fat %		Bone %	
Levels of significance, LS Means													
Breed	JU[1]	*[2,3]	4.99^{ab}	ns	1.83^{a}	***	1.75^{a}	***	58.58^{ab}	ns	20.35^{a}	***	20.69^{a}
	ML		5.05^{ab}		1.69^{a}		1.94^{ab}		58.33^{ab}		19.08^{a}		22.33^{a}
	SK		5.37^{ab}		1.93^{a}		2.07^{b}		57.21^{ab}		20.20^{a}		22.13^{a}
	SU		4.92^{a}		2.08^{a}		2.06^{b}		54.80^{ab}		21.75^{a}		23.09^{ab}
	TB		5.15^{ab}		1.81^{a}		2.46^{c}		54.82^{a}		18.83^{a}		26.05^{b}
	TE		5.75^{b}		1.57^{a}		1.94^{ab}		62.34^{b}		16.29^{a}		20.98^{a}
Birth type	Single	ns	18.19	ns	1.91	ns	2.09	ns	57.66	ns	19.51	ns	22.43
	Multiple		18.24		1.73		1.98		57.70		19.33		22.67
Levels of significance, Estimates													
MusUS3 (mm)		ns	0.090	ns	0.004	ns	0.002	ns	0.414	ns	−0.137	ns	−0.269
FatUS3 (mm)		*	−0.192	**	0.177	ns	−0.045	**	−1.722	***	2.028	ns	−0.320
Live weight (kg)		***	0.134	***	0.055	***	0.044	ns	−0.032	ns	0.144	ns	−0.096
RSD (US3)[4]		0.36		0.26		0.14		2.66		2.56		1.44	
Alternative US sites													
RSD (US1)		0.35		0.25		0.13		2.77		2.46		1.36	
RSD (US2)		0.37		0.26		0.14		2.75		2.56		1.30	

[1] JU = Jura, ML = Merinoland, SK = Schwarzkopf, SU = Suffolk, TB = Tiroler Bergschaf, TE = Texel
[2] ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$, ns not significantly different from zero ($P \geq 0.05$)
[3] Different letters indicate significant differences between levels ($P < 0.05$) based on a Tukey–Kramer test
[4] US1 measured in the area of 10th/11th thoracic vertebrae; US2 measured around 13th thoracic vertebrae (last rib); US3 measured at 3rd/4th lumbar vertebrae

and 0.52. Thus, a large proportion of the variation can be explained by the ultrasound measurement of muscle depth. Likewise, when FatUS3 was fitted as the only effect, the R^2 values for FatC and EFC were 0.59 and 0.61 and increased to 0.66 and 0.68 for the full model.

As expected, carcass weight increased with increasing live weight ($P < 0.001$); the same was found for MusC ($P < 0.001$), ECC ($P < 0.001$) and EFC ($P < 0.05$). A large proportion of carcass weight variation (73%) was explained by fitting live weight as covariate only. When MusUS3 and FatUS3 were also fitted, this value was increased to 87% and further to 88% when additionally considering the fixed effects in the model.

Dressing percentage decreased with increasing live weight ($P < 0.001$). However, when fitting live weight as independent variable only, less than 1% of the dressing percentage's variation could be explained. These results are in agreement with findings in Awassi sheep (Orman et al., 2008). FatC was not significantly affected by LGUS when all other effects were also included in the model.

While FatUS3 was selected for the prediction of all carcass traits when applying *proc glmselect*, MusUS3 and live weight were not selected for FatC and EFC.

3.3. *Relationship between in vivo routine performance testing traits and dissection traits*

LS Means for the fixed effects, estimates for the continuous effects, levels of significance as well as RSDs are presented for routine performance testing traits at US3 and dissection traits (Table 4). In accordance to Junkuszew and Ringdorfer (2005) comparing Texel, Merinoland and Suffolk sheep, Texel had the highest amount of lean ($P < 0.05$) and lowest amount of fat ($P > 0.05$). Similarly, highest lean percentage and lowest fat percentage were observed for this breed. Generally, breed did not significantly affect traits related to fat. As for the carcass traits, birth type was not found to have a significant effect on any of the dissection traits. Simeonov et al. (2014) also could not detect significant differences between singles and twins for internal fat kg and fattiness.

While MusUS3 seems to be a good predictor for carcass traits (Table 3), the prediction for amount or percentage of dissection traits is weaker (Table 4). However, the positive relationship to lean meat kg was close to being significant ($P = 0.053$). Similar results were also found for MusUS1 and MusUS2 (data not shown). Nevertheless, based on *proc glmselect*, muscle depth was not among the selected predictors for lean kg or lean percentage. Ultrasound muscle scans show positive correlations to lean and fat kg ($r = 0.58$–0.68 and $r = 0.39$–0.40, respectively), but correlations to lean or fat percentage are not significantly different from zero ($P > 0.05$; Table 5). Animals with higher muscle depth are

Table 5
Correlation coefficients (Pearson r) of muscle (Mus) and back fat (Fat) thickness measured with ultrasound (US) or on carcass (C) with EUROP conformation (ECC) and fat class (EFC) and carcass composition (amount and percentage of lean or fat).

	ECC	EFC	Lean kg	Lean%	Fat kg	Fat%
MusUS1	0.60	0.28	0.68	0.15ns	0.40	0.22ns
MusUS2	0.61	0.32	0.58	0.11ns	0.40	0.27ns
MusUS3	0.62	0.32	0.63	0.14ns	0.39	0.22ns
MusC	0.62	0.35	0.73	0.14ns	0.49	0.32ns
FatUS1	0.26	0.66	0.16ns	−0.62	0.79	0.81
FatUS2	0.31	0.74	0.38	−0.56	0.86	0.81
FatUS3	0.32	0.78	0.29ns	−0.60	0.84	0.81
FatC	0.22	0.69	0.10ns	−0.69	0.81	0.85

ns = not significantly different from zero ($P > 0.05$).

Table 6
Correlation coefficients (Pearson *r*) of muscle (Mus) or back fat thickness (Fat) measured with ultrasound at three scan sites (US1-3) on live animals and measured on carcasses (C).

	MusC	MusUS1	MusUS2
MusUS1	0.84		
MusUS2	0.82[a]	0.88	
MusUS3	0.79	0.82	0.86
	FatC	FatUS1	FatUS2
FatUS1	0.71		
FatUS2	0.76[a]	0.85	
FatUS3	0.76	0.81	0.88

[a] Measured on same anatomical site

generally the heavier ones, with more fat and bone, too. This is confirmed by the estimates for live weight in Table 4: increasing live weight is related to higher amounts of lean meat, fat and bone while no significant relationship was observed for the percentage traits. Consistently, when *proc glmselect* was applied, live weight was selected for predicting lean and fat kg but not for the prediction of lean and fat percentage.

In contrast to muscle depth, lower fat depth is significantly related to a higher amount of lean and lean meat percentage but also to higher amount of fat and fat percentage (Tables 4 and 5). Hence, fat scans are good predictors of carcass lean. This result is widely reported in ultrasound studies (Bergen et al., 2003; Delfa et al., 1995, 1996; Ripoll et al., 2009). Animals with thinner back fat have a higher percentage of lean; they are generally the leaner ones, but with regard to ECC not necessarily the more muscular ones (Tables 4 and 5).

3.4. Ultrasound – comparison of three anatomical scan sites

Correlations of ultrasound measures at all sites with carcass measures are shown in Table 6. For muscle depth the correlation coefficients are significant ($P < 0.001$) and between $r = 0.79$ (MusUS3) and 0.84 (MusUS1). MusUS2 was measured anatomically at the same spot as MusC, but its correlation to MusC is not higher but similar to the correlations at the other sites ($r = 0.82$). In accordance to the correlations in Table 6, the lowest RSD value for MusC was found when replacing the routine US site (US3) by US1 (Table 3). The muscle depth measurements of all three sites are highly correlated with each other ($r = 0.82–0.88$).

Fat depth shows smaller correlations between ultrasound and carcass measurement than muscle depth ($P < 0.001$; Table 3). They range between $r = 0.71$ (FatUS1) and $r = 0.76$ (FatUS2 and FatUS3). This is probably due to the removal of skin from carcasses and overestimated fat depth with ultrasound (see above) and is in accordance with current literature results (Esquivelzeta et al., 2012). Similar to muscle depth, the scan site equal to carcass cross section (US2) did not show better correlations with carcass measures and all scan sites were highly correlated within each other ($r = 0.81–0.88$). However, the routinely evaluated US site US3 resulted in the best prediction (with lowest RSD) for FatC (Table 3). Correlations of ultrasound scans with their corresponding carcass measurements are higher than in a similar study reported by Junkuszew and Ringdorfer (2005).

Correlations of ultrasound and carcass measurements with ECC and EFC as well as carcass composition are detailed in Table 5. In general, correlations with carcass composition (lean and fat kg and %) were similar for carcasses' back fat and muscle depth and the respective ultrasound measures. All ultrasound muscle measurements were positively correlated to ECC ($r = 0.60–0.62$, $P < 0.001$), as well as to EFC, but on a lower level ($r = 0.28–0.32$, $P < 0.01$). The correlations of MusUS1, MusUS2 and MusUS3 to lean kg were positive ($r = 0.58–0.68$; $P < 0.001$) as well. All correlations of ultrasound fat with carcass fat measures (EFC, fat kg and fat percentage) were also positive ($P < 0.001$; $r = 0.66–0.86$).

Comparing the correlations, but also the RSD values of models [1] and [2] (Tables 3–5), none of the scanning sites is clearly favourable over the others: US1 has a small advantage in predicting amount of lean, US2 and US3 tend to be the better sites to predict EEC, EFC and fat kg.

Likewise, literature is not concordant about the optimal anatomical position of scanning lambs. In two similar trials Ripoll et al. (2009, 2010) compared four anatomical scan sites. In the first study using only light lambs (20–27 kg body weight) they found 10th/11th thoracic vertebrae (equivalent to US1) to have the greatest correlations with carcass measurements but better prediction equations for predicting tissue carcass composition using measurements at 1st/2nd lumbar vertebrae (Ripoll et al., 2009). In their second study using lambs with a wider range of body weight (9–37 kg), 10th/11th vertebrae showed the smallest correlations and no optimal site could be suggested (Ripoll et al., 2010). Fernández et al. (1998) and Hopkins et al. (2008) reported advantages of scanning at 12/13th thoracic vertebrae (comparable to US2), which is easiest palpable for the operator next to the last rib. Other authors showed advantages at 3rd/4th lumbar vertebrae, equivalent to US3 (Delfa et al., 1996; Silva et al., 2006; Teixeira et al., 2006). Theriault et al. (2009) found the site 12th/13th thoracic vertebrae better for measuring fat depth but 3rd/4th lumbar vertebrae better measuring for muscle depth.

Table 7
Correlation coefficients (Pearson *r*) and repeatability for two repeated measurements of muscle (Mus) and back fat (Fat) thickness measured with ultrasound at three scan sites (US1-3).

	Correlation coefficient *r*	Repeatability
MusUS1	0.95	0.95
MusUS2	0.91	0.89
MusUS3	0.90	0.87
FatUS1	0.93	0.99
FatUS2	0.95	0.91
FatUS3	0.94	0.92

3.5. Repeatability of ultrasound scanning

Table 7 lists the correlation coefficients of two repeated ultrasound measurements of muscle and back fat depth at three scan sites. All correlations were high (≥ 0.90) but never equal to 1, indicating a small but constant within

Table 8
Correlation coefficients (Pearson *r*) of EUROP conformation (ECC) and fat class (EFC) and carcass composition (amount and percentage of lean, fat and bone).

	EFC	Lean kg	Lean %	Fat kg	Fat %	Bone kg	Bone %
Lean kg	0.22ns						
Lean %	−0.70	0.24ns					
Fat kg	0.87	0.41	−0.72				
Fat %	0.88	0.08ns	−0.84	0.93			
Bone kg	0.37	0.43	−0.51	0.50	0.32ns		
Bone %	−0.31ns	−0.55	−0.28ns	−0.38	−0.27ns	0.37	
ECC	0.38	0.76	−0.07ns	0.61	0.39	0.36	−0.56

ns = not significantly different from zero ($P > 0.05$).

Table 9
Correlation coefficients (Pearson *r*) of muscling scores for shoulder, back and hindquarter to EUROP conformation (ECC) and fat class (EFC), carcass components and carcass muscle depth (MusC) as well as ultrasonic muscle (MusUS3) and fat depth (FatUS3).

	ECC	EFC	Lean kg	Fat kg	Bone kg	MusC	MusUS3	FatUS3
Shoulder	0.52	0.50	0.55	0.61	0.37	0.44	0.38	0.51
Back	0.47	0.45	0.50	0.77	0.41	0.40	0.43	0.44
Hindquarter	0.58	0.42	0.48	0.45	0.23ns	0.58	0.54	0.47

ns = not significantly different from zero ($P > 0.05$).

measurement uncertainty due to random effects. This within measurement uncertainty seems to be similar for all three scan sites. In case of muscle depth, US1 showed the highest correlation ($r = 0.95$). For fat depth, correlations for US2 and US3 were slightly better ($r = 0.95$ and 0.94, respectively) than for US1. As Bruton et al. (2000) pointed out, correlations tell only how values vary with each other and not about the extent of agreement. Therefore they should not be used in isolation to interpret repeatability. The values for repeatability according to Essl (1987) are also listed in Table 7. They can be read as degree of agreement from both measurements and range from 0 to 1. Values from 0.87 to 0.99 suggest a high repeatability for all three sites. Nevertheless, US1 seems to provide more repeatable results for both muscle and fat depth (repeatability = 0.95 and 0.98) than US2 and US3 (repeatabilities ranging from 0.87 to 0.92). This is notable, since the performing technician has years of experience testing and interpreting at US3 so one would expect US3 to deliver most constant results.

Generally, correlations and repeatability are on very high levels compared with literature results. However, most other studies on repeatability of ultrasound measurements are not directly comparable though, because they examined repeatability over longer time intervals (Stanford et al., 2001), over different operators or technical devices (Junkuszew et al., 2006; Olsen et al., 2007) and additionally have used different measures of repeatability (Bergen et al., 2003; Emenheiser et al., 2010; Olsen et al., 2007; Robinson et al., 1992), since there is no general consensus on how to estimate it. Further, results are influenced by sampling and statistical model.

3.6. Relationship between carcass scores and dissection traits

In Table 8, correlations for ECC, EFC and carcass composition traits are shown. ECC seems to be a good indicator for the amount of lean meat ($r = 0.76$, $P < 0.001$) but not for lean percentage (correlation not significantly different from zero). Additionally, it seems to be influenced by the fattiness of the carcass: ECC is positively correlated with amount ($r = 0.61$, $P < 0.001$) and percentage ($r = 0.39$, $P < 0.05$) of fat as well as EFC ($r = 0.38$, $P < 0.001$). Correlations of $r = 0.87$ and $r = 0.88$ ($P < 0.001$) suggest that EFC is a strong indicator for both amount and percentage of fat, as well as for lean percentage ($r = -0.70$, $P < 0.001$). Similar to the findings of Johansen et al. (2006) EFC seems to be the main predictor of lean percentage. When model [2] was extended with the covariates ECC and EFC and *proc glmselect* was applied, EFC was the only covariate selected for the prediction of lean percentage (data not shown). EFC showed a strong negative relation to lean percentage, but not to amount of lean. Whereas fat amount and percentage were positively correlated ($r = 0.93$, $P < 0.001$), amount and percentage of lean did not show a correlation significantly different from zero. Carcasses with a high amount of lean meat do not have a high percentage of lean, but have more fat and bone, too. Apparently these are the animals were growth is more complete. High percentage of lean is negatively correlated with fat kg ($r = -0.72$, $P < 0.001$) and percentage ($r = -0.84$, $P < 0.001$) and bone kg ($r = -0.51$, $P < 0.01$). This suggests that high percentage of lean is found in lighter animals earlier in their growth development. The simple linear regression for percentage of lean on live weight in kg is 71.96–0.357 * live weight; when keeping all other effects constant, the partial regression coefficient (Table 4, model [2]) is −0.032.

If one was to harvest the carcasses with the highest percentage of lean, slaughter should be earlier; if the absolute amount of lean meat should be maximised, slaughter should be later in life. Paying the farmer by carcass kg and ECC class clearly favours later slaughter.

In sum, correlations between EUROP classification and carcass composition were on similar levels as reported by Johansen et al. (2006).

3.7. Muscling scores

To evaluate if the subjective muscling scores of live animals have any power to predict the value or the composition of the carcass, correlations of muscling scores and carcass traits were calculated (see Table 9). Correlations ranged from $r = 0.23$ (hindquarter score and bone kg, $P > 0.05$) to 0.77 (back score and fat kg, $P < 0.001$). Although designed as 'muscling' scores, shoulder and back score seem to be more influenced by the fattiness of the animal. Both scores are almost equally correlated to ECC as to EFC and additionally, both are higher correlated with carcass and ultrasound fat measures (0.44–0.77) than with the equivalent muscle measures (0.38–0.50). The hindquarter score seems to relate differently: It is clearly stronger related to ECC (0.58) than to EFC (0.42) and is higher correlated with muscle than with corresponding fat measures. All muscling scores are positively correlated to muscle depth measured with ultrasound or on carcass. Table 9 lists only correlations to US3 since this is the site routinely used in meat performance testing, but correlations were similar among US1 to US3 (data not shown). Unexpectedly it was not the back score (0.40 and 0.43), but again hindquarter score that showed the strongest relation to (back) muscle depth (0.58 and 0.54). Moderate positive correlations of shoulder and back scores to amount of bone on carcass suggest that large-frame animals are favoured in scoring.

4. Conclusions

Generally, muscle scans are valuable to estimate amount of carcass lean and ECC, but fat scans have greater power to predict the fattiness of the carcass as well as lean percentage. Subjective muscle scoring of live animals seems to be mainly influenced by the fattiness of the animal. Only hindquarter scores show reasonable relations to carcass muscle traits. The comparison of three anatomical scanning sites did not give definite results. US1 seems to be favourable for estimating muscle depth, for the prediction of lean and in terms of repeatability whereas US2 and US3 had small advantages in scanning fat depth and in the prediction of EUROP classification and carcass fat, which are the basis of carcass payment.

The results indicate the usefulness of the current ultrasound measurements in combination with live weight as relatively easy method to predict slaughter traits and carcass composition in live lambs. A genetic evaluation of these traits as well as a definition of a meat index is in development.

Conflict of interest

We wish to confirm that there are no known conflicts of interest associated with this publication.

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