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Prediction of tissue composition of live dairy calves and carcasses by computed tomography

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HIGHLIGHTS

- The accuracy of computed tomography to study carcass composition was evaluated.
- Prediction equations had 0.66 and 0.54 RMSEP for fat and protein carcass content.
- The technique allows the study of body composition evolution in life calves.

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ABSTRACT

Computed tomography (**CT**) is a non-destructive technique, based on X-rays, that has been used in several livestock species to evaluate carcass composition. The objective of this study was to construct predictive equations to estimate carcass and viscera composition for preweaning calves using CT. For this purpose, 24 Holstein male calves (4 ± 0.9 d of age; 40 ± 2.2 kg of body weight) were fed a milk replacer (**MR**; 23% CP; 15% fat) either 4 L/d or 8 L/d of MR at the rate of 125 g/L of water to ensure different levels of fat and protein accretion and generate sufficient variation to obtain the equations of calibration. Then, at 30 ± 2.4 d of age, 3 calves from each feeding program, and at 50 ± 1.9 d of age, 9 calves from each feeding program were CT-scanned, and humanly sacrificed. Carcasses were also CT scanned 24 h *post mortem*. Images from CT were analysed and used to predict content of protein and fat of carcasses, red and white viscera. The models rendered a residual predictive deviation between 1.1 (protein red viscera) and 2.6 (fat white viscera) in live animal images and between 1.1 (carcass moisture) and 4.5 (fat white viscera) in carcass images. The root mean square error of prediction relative to the mean ranged between 1.32 (carcass moisture) and 17.3% (fat white viscera) in live animal images and between 1.38 (carcass moisture) and 17.3 (fat red viscera) in carcass images. The coefficient of determination ranged between 0.19 (protein red viscera) and 0.88 (fat white viscera) in images from live calves and between 0.26 (carcass protein) and 0.98 (fat white viscera) in carcass images. In conclusion, it is possible to predict body composition of calves using a non-destructive technique by means of computed tomography images and this prediction could be used in studies were the estimation of this content would be relevant.

1. Introduction

The effects of different milk feeding programs on body composition and development of skeletal muscle have been studied slaughtering the animals (Azevedo et al., 2016; Mills et al., 2010). But to assess the evolution of body composition throughout a specific period, serial by slaughtering is required at different intervals of time assuming no variation among calves within the same treatment (Brown et al., 2005). Computed tomography (**CT**) scanner is a non-destructive technology used in medicine, but also in livestock, and it has been used to evaluate live animals or carcasses of several species such as pigs (Font-i-Furnols et al., 2009; Carabús et al., 2015; Gjerlaug-Enger et al., 2012), sheep

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(Navajas et al., 2007; Kongsro et al., 2009; Kvame and Vangen, 2006; Lambe et al., 2008), rabbits (Szendrö et al., 2012), poultry and turkey hens (Dewez et al., 2018; Grandhaye et al., 2019), or beef cuts (Navajas et al., 2010; Font-i-Furnols et al., 2014). The composition of live animals can be evaluated with CT scanners in a particular moment of their growth. However, because the animals are kept alive, it is possible to scan them several times allowing the study of the evolution of body composition across time (with the limitations of CT scanner capacity) and avoiding serial slaughtering. In this sense it has been used to study the evolution during growth of body composition of pigs following different feeding regimes (Font-i-Furnols et al., 2020; Lambe et al., 2013) or from pigs (Carabús et al., 2014, 2015) or lambs (Lambe et al., 2007) from different genotypes and sexes.

As far as the authors know, the use of CT scanners to evaluate the whole live calves has not been previously reported. Most of the medical CT scanners are used in humans or small animals and do not allow to evaluate big animals such as horses or cattle because they have a small gantry (75–85 cm) and the table supports a weight up to 200 kg approximately. Nevertheless, there is the possibility to use an adapted CT scanner to evaluate standing horses or cattle (Nade et al., 2005) and it is quite used mainly for diagnosis purposes. Recently, Gibson et al. (2020) used a peripheral quantitative CT scanner to scan the metacarpus of the right limb of calves at one, six and twelve weeks of age in order to relate the strength and morphology of the bones with the stature characteristics of the calves.

In this technology, the X-rays go through the body and are attenuated at different degrees depending on the density of the tissues. The attenuation is measured in Hounsfield units (HU). Negative HU approximately between −200 and −1 are related to fat, positive between 0 and 140 or 200 to lean and higher to bones. The thresholds used to define each tissue vary slightly between works. Fat tissue has a peak between −100 and −120 in live pigs and rabbits, and –70 in cold pig carcasses and beef cuts (difference probably due to the temperature and fat composition), whereas lean has positive values with a peak around +40 and + 80 in live pigs and rabbits, cold pig carcasses and beef cuts (Font-i-Furnols et al., 2009, 2014, 2015a; Romvari et al., 1996). Bones have HU values greater than 140 or 150 in pigs, broilers and turkey hens (Dewez et al., 2018; Font-i-Furnols et al., 2015a; Grandhaye et al., 2019). From these values and by means of a reconstructing algorithm, an image of the interior part of the body is built in gray tones, with the light tones representing high attenuation values and the dark tones representing the low attenuation values.

The aim of the present work was to develop calibration equations from CT scanner images of live pre-weaning calves and their carcasses in order to determine the fat and lean content of the carcass, and white and red viscera.

2. Materials and methods

All research methods and procedures in both trials were approved by the ethics and animal experimentation committee of Generalitat de Catalunya under the authorization code 9733 and were followed according to animal welfare guidelines.

2.1. Animals, housing and treatments

Twenty-four Holstein male calves of 4 ± 0.9 d of age and 40 ± 2.2 kg of body weight (BW) were gathered from two different farms and raised at the facilities of IRTA (Monells, Girona). Calves were managed according to common animal management conditions under the supervision of IRTA technicians and they were allocated in individual pens (1 × 1.6 m) bedded with sawdust on a daily basis. Calves were distributed randomly in two different feeding programs to achieve differences in body composition. The two feeding programs consisted of feeding 4 L/d of MR (23% CP; 15% fat) offered in nipple-bottles at the rate of 125 g of MR/L of water in both treatment groups from d 1 to 7 of study, and then from day 8 until the end of the study calves were either fed 4 (**LM**) or 8 (**HM**) L/d of MR. Concentrate (19.3% CP, 16.9% NDF, 6.4% ADF, 5.7 Ash, 3.0% Fat in DM basis, Pinallet, Cardona, Spain), barley straw and fresh water were offered *ad libitum* throughout the study. To ensure sufficiently different levels of body fat and protein content to generate adequate variation for the calibration, 3 calves were CT-scanned and slaughtered at 30 ± 2.4 d of age, and 9 calves at 50 ± 1.9 d of age per feeding program. Calves in LM feeding program weighted 54.5 and 67.8 ± 2.78 kg of BW, and calves in HM feeding program weighted 60.9 and 72.6 ± 2.78 kg, in the first and second slaughter time, respectively.

2.2. Computed tomography scanning

Calves were scanned *in vivo* (Fig. 1a) 3–4 h after the morning MR feeding. In order to minimize disturbances in CT scanner images, they were previously sedated with an intramuscular injection of xylazine at the dose of 0.01 mL/kg BW. Animals were fully scanned with a General Electric HiSpeed Zx/I (GE HealthCare, Madrid, Spain) CT placed at IRTA (Monells, Girona). Acquisition parameters (i.e.: axial, 140 kV, 145 mA, 512 × 512 matrix, thickness 10 mm) were those used in live pigs (Carabús et al., 2014), and displayed field of view adapted to the size of the animal.

Calves were slaughtered (see section below) and at 24 h *postmortem*, the cold left half carcass was CT scanned. Seven carcasses from one slaughtering day could not be scanned, thus, the total number of scanned carcasses was 17. The scanning procedure was the same as that applied in pig carcasses (i.e., helical, pitch 1, 140 kV, 145 mA, 512 × 512 matrix) (Font i Furnols et al., 2009), thickness 10 mm and displayed field of view adapted to the size of the animal.

2.3. Image analysis

Images obtained from CT scanner from each animal (n = 24) and carcass (n = 17) were analysed with Matlab (version R2008b; The MathWorksTM Inc., Natick, MA, USA) using a house-made script. Frequency of voxels (3D pixels) associated with each Hounsfield value were obtained from the images of live calves (without removing anything, thus, including viscera and organs) and carcasses. Then, voxels were transformed into volume using the displayed field of view, matrix size and image thickness as described in Font i Furnols et al. (2009). As an example, the distribution of volume associated with each Hounsfield value relative to the total volume for live calves with four different fat contents was graphically represented (Fig. 1b) to see differences according to fat content, measured as explained below. Looking at the volume distributions, the limits for fat and muscle were established at −120 and +120 HU, respectively. A preliminary work using limits from −149 to −140 HU showed that the extremes were not relevant and it was decided to remove them. The part of the HU range representing bones (HU>140) was also excluded because it was not useful in the predictions.

2.4. Slaughtering, sampling and chemical analyses

Calves were slaughtered in a commercial slaughterhouse (Verges, Girona, Spain) and CT-scanned 24 h thereafter. After bleeding, and removing the viscera, the head, the skin, the tail and the front feet, carcass weight was recorded. Carcasses were kept refrigerated at 4 °C for 24 h at the slaughter plant. Viscera were collected, emptied and weighed. White viscera (intestines, kidneys and pelvic-renal fat plus spleen) and red viscera (heart, lungs, gallbladder and windpipe, and without spleen) were transported to IRTA the day of the slaughter and frozen at −20 °C after being processed. The day after slaughter the left half carcasses were transported in refrigerated conditions to IRTA (Monells, Girona), CT scanned (see previous section), and frozen at −20 °C until further processing.

Frozen carcasses were cut into small pieces using a cutting guillotine

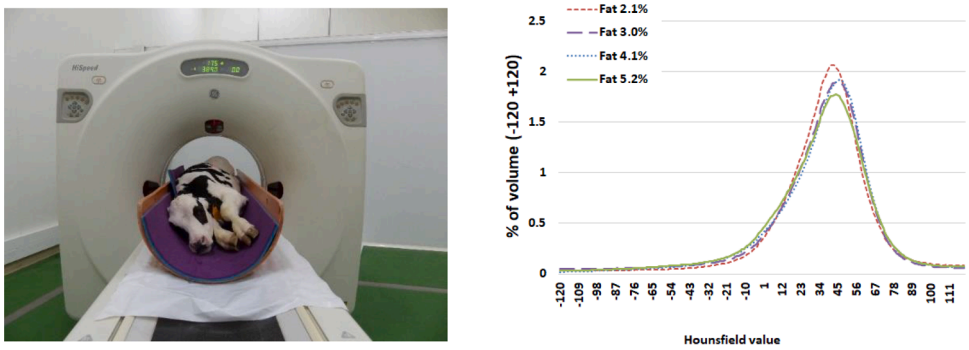

Fig. 1. Scanning of a calf with computed tomography equipment (a) and distribution of the volume associated with each Hounsfield value relative to the total volume (from Hounsfield values between −120 and +120) in live calves with four different fat contents (b).

(Cruells, Model D, Olot, ES). The pieces where then minced using an industrial mincer with a final hole size of 3 mm (Groinder Cato-pa160, Spain). After mincing, they were homogenized and a sample of 400 g was taken, vacuum-packed and stored at −20 °C until processed. Frozen viscera were cut in small pieces with an electrical saw (Bosch, Gerlingen, DE). Then pieces were minced with a final hole size of 3 mm in a small mincer (Tecmaq SA, Sentmenat, ES). After mincing they were homogenized, vacuum-packed and stored at −20 °C. Minced carcass and white and red viscera were chemically analysed for moisture (ISO 6496, 1999), fat content following Soxhlet extraction (ISO 1443:1973) and protein content by Kjeldahl (ISO 5983-1, 2005).

2.5. Data analysis

All analyses were performed using SAS (ver. 9.4, SAS Institute Inc., Cary, NC, USA). Descriptive statistics of all the variables were performed with the MEANS procedure. Correlations of proximate composition of carcasses with those of viscera and with CT scanner variables were carried out with the CORR procedure.

Multiple linear regression (REG procedure) was performed to estimate fat, protein, and moisture of the carcass, red and white viscera both, from the images of live calves and from their carcasses. The best predictors were selected through a stepwise procedure. Stepwise selection criterion was the F statistic value ($P < 0.15$). Predictors were added or removed to the model, step by step, selecting the combination that explained the maximum variation (maximizes R^2). Goodness-of-fit was evaluated by means of the root mean square error of prediction (**RMSEP**) obtained by cross-validation leave-one-out, the coefficient of determination ($\boldsymbol{R^2}$), and the residual predictive deviation (**RPD** = standard deviation/RMSEP). For this prediction, volume was calculated for intervals of 20 HU consecutive values, between −120 and +120 HU (i.e. 12 volumes per animal). This allows to group volumes associated with HU values with similar attenuation. To avoid the effect of the weight of the animals, the proportions of volume associated with each interval of HU values relative to the total volume considered (between −120 and +120 HU values) were calculated. These relative volumes were used as the predictor variables in the linear regression analysis. The 20-HU interval was selected after testing the volume (and relative volume) associated with a narrower interval of 10 HU values, because it produced the lowest prediction error. Partial least square regression was also tested for predicting using the volume (and relative volume) associated with each HU value individually. Results were similar or with lower goodness of fit (higher prediction error) than those obtained with multiple linear regression and, consequently, were discarded.

3. Results and discussion

The work carried out has demonstrated that is possible to scan anaesthetized live calves in a medical CT, if they dimensions are less than 90 kg BW. The most critical point in the scanning of the entire animal is the hip width, and it is necessary to ensure that is feasible to fit it within the maximum field of view allowed by the equipment.

The carcass characteristics of the calves used in the calibration study are presented in Table 1. As intended, there was a great variability in carcass and viscera weights, as well as a great variability in composition, especially fat content. In this sense, the coefficient of variation of the fat content was 27.3%, 44.4% and 23.8% for carcass, and white and red viscera, respectively. Tikofsky et al. (2001), comparing calves with three different diets varying in fat with an empty body weight of 79.0 kg, reported carcass fat content that varied between 8.5 and 10.9%, which was greater than in the present work (between 2.1–6.9%), and protein content varying between 17.7 and 18.3%, which was lower than in the present work (18.8–21.9%). These differences can be due to the feeding strategy used in these studies and because calves in the present experiment were 12 kg lighter (in live weight) and, consequently, they could have deposited less fat tissue. When compared to 30-kg pigs (Zomeño et al., 2016), protein content was similar to that observed in calves from the present study (19.9% in calves and 18.0% in pigs), fat content was much lower in calves (4.3%) than in pigs (9.9%). This lesser amount of fat was also observed when the volume associated with different Hounsfield values was studied (Fig. 1b). Thus, the volume associated with fat (negative values) was very low, and it was not possible to detect

Table 1
Carcass and viscera description and chemical composition of the calves used for calibration ($n = 24$).

	Mean	SD	Minimum	Maximum
Live weight (kg)*	68.56	9.89	54.50	89.00
Carcass weight (kg)	36.84	6.41	25.40	47.50
Carcass yield (%)	55.40	2.23	51.45	59.97
White viscera[a] (kg)	4.87	1.03	3.10	7.13
Red viscera[b] (kg)	3.42	0.63	2.36	4.58
Kidneys (kg)	0.30	0.07	0.16	0.46
Pelvic-renal fat (kg)	0.27	0.12	0.11	0.64
Chemical composition				
Carcass				
Fat (%)	4.29	1.17	2.10	6.89
Protein (%)	19.93	0.74	18.82	21.88
Moisture (%)	70.94	1.09	68.45	73.19
White viscera[a]				
Fat (%)	9.07	4.03	2.70	19.86
Protein (%)	12.31	0.83	10.78	13.55
Red viscera[b]				
Fat (%)	3.49	0.83	1.99	5.19
Protein (%)	15.98	0.66	14.91	17.28

* Body weight of 3 animals could not be recorded ($n = 21$).
[a] Cleaned White viscera without kidney and pelvic-renal fat and with spleen.
[b] Red viscera including lungs, liver, gallbladder, windpipe and heart.

a peak in this region as it can be seen in 30-kg pigs (slightly) and in heavier pigs (clearly differentiated), who show a clear bimodal distribution (Font-i-Furnols et al., 2015a). In CT data from the cut of beef taken between the 9th and 11th last ribs of 10–14 months old bulls and steers, this peak in the fat region could also be appreciated (Font-i-Furnols et al., 2014), presumably because older animals presented a greater fat tissue content. However, the greatest correlation with fat content was found in the volume associated with HU values between −20 and −39 ($r = 0.75$, $P < 0.001$) and between −40 and −59 ($r = 0.73$, $P < 0.001$). Similarly, the fat of the white viscera also presented the greatest correlations in this range of volumes ($r = 0.77$ and $r = 0.85$, respectively, both with $P < 0.001$).

The average distribution of volume associated with each Hounsfield value for live calves and carcasses is presented in Table 2. Logically, the total soft tissue volume of live calves was greater than those of half carcasses (48.52 ± 8.14 *vs.*11.18±1.99 dm^3), because it included the head, feet, fore-legs, skin and viscera that were not in the carcass and because only half of the carcass was scanned. The relative maximum volume was associated with Hounsfield values between +41 and +60 both, in live calves and carcasses (31.51 ± 2.47 *vs.* 47.01 ± 3.22%), thus the peak is placed in this range (Fig. 1b). The proportion of fat volume placed between −120 and 0 Hounsfield in live calves was greater than in carcasses (14.00 *vs.* 9.44%). This was probably due to the fact that live calves were scanned at body temperature, whereas carcasses were scanned cold (<7 °C), and fat density is greatly affected by the temperature, being less dense (i.e. lower Hounsfield values) at high temperatures. Furthermore, in live calves, some voxels from the viscera or internal organs can be placed in the region of Hounsfield values associated with fat. Fig. 1b shows fat distribution for 4 calves with different fat content. To account for the effect of weight differences, the volume was calculated as a percentage related to the total volume between −120 and +120 Hounsfield values as explained before. This range is different from those used in live pigs (Font-i-Furnols et al., 2015a) and was selected to ensure that all fat and lean tissue was included for the analysis, according to the distribution of the volume. Then, it was observed that calves with greater fat content presented more volume associated with negative Hounsfield values (associated with fat) than those with lower fat content.

The final calibration equations and their goodness-of-fit for images from live animals are presented in Table 3, and those from carcasses are depicted in Table 4. The reliability and predictive ability of the model is measured with the RMSEP obtained by cross-validation. The lower the RMSEP the better the fit. The RMSEP was calculated relative to the mean to emphasize its importance. Probably, the use of a greater number of live calves and carcasses would have helped to reduce the error and the uncertainty of the prediction. The greatest coefficient of determination was found for fat from the carcass and the white viscera and protein from white viscera. Predictions for protein and moisture had lower accuracy. Regarding RPD, the minimum value recommended in the literature for suitable prediction models is 3 (Williams, 2001). In the prediction equations obtained from live calves, the RPD ranged from 1.1. to 2.6 and from carcasses, the RPD ranged from 1.1 and 4.5. Correlations between chemical analysis of fat and protein in the carcass or viscera and its prediction both, from live calves and carcasses images were all significant and higher for fat than for protein (Table 5). Predictions of carcass composition from the scanned carcasses had similar goodness-of-fit to those from live calves although live animal images were studied without removing the digestive tract, organs, skin, feet, head and digesta. In fact, correlations between predicted fat from live animals and carcasses (Table 6) were high and significant, while those of both predicted leans were low and non-significant. This is related to the fact that the R^2 of fat prediction is higher than those of protein prediction both, in live calves and carcass images. This might suggest that a

Table 2
Volume and relative volume associated to different Hounsfield value ranges in images from live calves and half carcasses used for calibration[a].

	Mean	SD	Minimum	Maximum
Live calves ($n = 24$)				
Vol −120 to +120 (dm^3)	48.52	8.14	32.09	64.12
Vol% −120 to −100	0.93	0.25	0.52	1.46
Vol% −99 to −80	1.14	0.33	0.69	1.73
Vol% −79 to −60	1.46	0.39	0.82	2.31
Vol% −59 to −40	1.92	0.49	1.05	3.09
Vol% −39 to −20	2.86	0.65	1.68	4.59
Vol% −19 to 0	5.68	0.94	3.85	7.77
Vol% +1 to +20	13.02	1.10	10.01	15.68
Vol% +21 to +40	26.49	1.72	23.91	31.14
Vol% +41 to +60	31.51	2.47	28.07	38.97
Vol% +61 to +80	10.96	1.34	8.66	12.93
Vol% +81 to +100	2.61	0.36	2.13	3.41
Vol% +101 to +120	1.42	0.19	1.10	1.76
Carcass ($n = 17$)				
Vol −120 to +120 (dm^3)	11.18	1.99	7.74	14.07
Vol% −120 to −100	0.99	0.07	0.90	1.13
Vol% −99 to −80	1.03	0.06	0.95	1.14
Vol% −79 to −60	1.20	0.08	1.07	1.35
Vol% −59 to −40	1.53	0.16	1.28	1.83
Vol% −39 to −20	1.99	0.17	1.66	2.28
Vol% −19 to 0	2.70	0.21	2.24	3.04
Vol% +1 to +20	4.52	0.39	3.63	4.99
Vol% +21 to +40	11.65	0.94	9.99	13.25
Vol% +41 to +60	47.01	3.22	40.60	52.92
Vol% +61 to +80	21.80	3.66	15.44	29.87
Vol% +81 to +100	3.68	0.37	3.10	4.27
Vol% +101 to +120	1.89	0.29	1.47	2.47

[a] Vol −120 to +120: Total volume associated to Hounsfield values between −120 and +120 in dm^3.%Vol X to Y: Volume associated to Hounsfield valued between X and Y relative to total volume (Vol −120 to +120) in %.

Table 3
Prediction equations and goodness-of-fit[a] for carcass and viscera composition in live calves derived from computerized tomography images (calibration trial).

Content (%)	Prediction equation[b]	n[c]	RMSEP	R^2	RMSEP/ Mean	RPD
Carcass						
Fat	0.25 + 2.14*HU (−59 to −40)	21	0.66	0.69	15.38	1.8
Protein	24.36 - 0.35*HU (+1 to +20)	23	0.54	0.36	2.70	1.4
Moisture	73.53 - 1.35*HU (−59 to −40)	24	0.94	0.36	1.32	1.2
White viscera[d]						
Fat	4.33 + 40.87* HU(−79 to −60) - 17.52* HU(−120 to −100) – 20.14* HU(−59 to −40)	22	1.57	0.88	17.26	2.6
Protein	15.76 + 2.32*HU (−59 to −40) - 3.52*HU(−79 to −60) - 0.49*HU (−19 to 0)	24	0.61	0.60	4.95	1.4
Red viscera[e]						
Fat	2.59 + 7.02*HU (−79 to −60) – 4.74*HU(−110 to −100) – 3.63*HU (−59 to −40)	23	0.53	0.54	15.28	1.4
Protein	12.34 + 0.12*HU (+41 to +60)	24	0.63	0.19	3.95	1.1

[a] RMSEP: root mean square error of prediction by cross validation leave one out; R^2: Coefficient of determination; RPD: Residual Predictive Deviation (standard deviation/RMSEP).

[b] Predictors represent relative volume associated to Hounsfield values between the two numbers after HU in brackets with respect to total volume between −120 and +120.

[c] Initial $n = 24$. If different, it is due to outliers that were removed from the calculations due to stand out values for D'Cook distance and residuals.

[d] White viscera include kidney, intestines, pelvic-renal fat and spleen.

[e] Red viscera include lungs, liver, gallbladder, windpipe and heart.

Table 4
Prediction equations and goodness-of-fit[a] for carcass and viscera composition from half carcass of calves derived from computerized tomography images (calibration trial).

Content (%)	Prediction equation[b]	n[c]	RMSEP	R^2	RMSEP/ Mean	RPD
Carcass						
Fat	−4.63 + 7.37*HU(−39 to −20) – 5.50*HU (−99 to −80)	16	0.58	0.88	13.43	2.1
Protein	23.68 - 0.87*HU(+1 to +20)	17	0.57	0.26	2.85	1.2
Moisture	64.96 + 7.56*HU (−120 to −100) - 2.8*HU(−39 to −20) + 0.36*HU(+21 to +40)	17	0.97	0.59	1.38	1.1
White viscera[d]						
Fat	31.61 – 58.85*HU(−99 to −80) + 46.71*HU (−79 to −60) + 5.54*HU(−19 to 0) - 2.09*HU(+21 to +40) - 0.39*HU(+61 to +80)	15	0.89	0.98	9.83	4.5
Protein	27.63 - 5.19*HU(−39 to −20) - 0.11*HU(+41 to +60)	17	0.50	0.69	4.04	1.6
Red viscera[e]						
Fat	−1.80 + 2.63* HU(−39 to −20)	17	0.61	0.35	17.30	1.3
Protein	18.93 - 4.46* HU(−59 to −40) + 1.45* HU (−19 to 0)	17	0.54	0.56	3.40	1.3

[a] RMSEP: root mean square error of prediction by cross validation leave one out; R^2: Coefficient of determination; RPD: Residual Predictive Deviation (standard deviation/RMSEP).
[b] Predictors represent relative volume associated to Hounsfield values between the two numbers after HU in brackets with respect to total volume between −120 and +120.
[c] Initial $n = 17$. If different, it is due to outliers that were removed from the calculations due to stand out values for D'Cook distance and residuals.
[d] White viscera include kidney, intestines, pelvic-renal fat and spleen.
[e] Red viscera include lungs, liver, gallbladder, windpipe and heart.

pre-treatment of the images is not needed, and it is interesting since removing these components from live animal images is very time consuming and operator-dependent. However future work can be done to study more in deep the effect of the viscera and organs on the image analysis. In fact, in the same direction, Font-i-Furnols et al. (2015b) reported high correlations between tissue depots predicted from CT scanner images of live pigs with and without viscera and internal organs. This similarity between composition estimated from images with and without viscera in live pigs, which are monogastric animals, is also similar in live calves, which are ruminants. Prediction of viscera composition from carcasses images (that do not include viscera) may seem useless. Nevertheless, prediction of fat content in white viscera from carcass images had an RPD = 4.47, indicating the model obtained was good. The high standard deviation of this parameter might have an important effect on this result. Moreover, this could probably be explained by the fact that the correlation between fat content of the carcass and that of the white viscera is high ($r = 0.71$; $P < 0.001$). One of the reasons might be that the pelvic-renal fat, which is related to the level of fatness of the animal, was included in the white viscera. Thus, prediction of white viscera composition could be of interest because it is related to carcass composition. On the other hand, correlation between fat content of the carcass and fat of the red viscera was low ($r = 0.34$; $P < 0.209$) (results not shown).

According to the all the results, prediction of fat is more accurate than those of protein and can be done in studies in live calves when this information would be needed. In the present work, the whole animal has been scanned, being this technique useful for nutritional studies to evaluate feeding strategies (Diaz et al., 2001), or for breed comparison or crossbreed selection (Clarke et al., 2009). The technology can also be applied to study bone measurements and density (Fabà et al., 2019), osteochondrosis problems (Aasmundstad et al., 2013), for breeding purposes (Gjerlaugh-Enger et al., 2012; Grandhaye et al., 2019; Lambe et al., 2008; Szendrő et al., 2012) and to find out relationships between bone strength and morphology with phenotypic and growth characteristics of the animals (Gibson et al., 2020). Further work could be done to study if, scanning only one part of the animal is enough to predict its body composition with a similar or lower error of prediction than those obtained in the present work scanning the whole animal. Moreover, further work is needed to optimize the image analysis by means of segmentation techniques trying to reduce the prediction error.

4. Conclusions

From the present work, it can be concluded that scanning calves with CT equipment is feasible, and it is possible to observe differences in its fatness from the CT images. Moreover, it is possible to predict body composition (mainly relative to fat content) of live calves using non-destructively techniques by means of CT images. This information could be of great interest to determine the effect of fat deposition depending on the feeding program applied, allowing to modulate the fatness of the calves from early age, optimizing the following growth

Table 5
Correlation between chemical content of carcass and viscera and those predicted from computed tomography images from live calves and carcasses*.

	Chemical measures						
	Fat	Protein	Moisture	Fat white viscera	Protein white viscera	Fat red viscera	Protein red viscera
Prediction from live calves images							
Fat	**0.77**	−0.09	**−0.60**	**0.75**	**−0.67**	**0.56**	*−0.36*
Protein	−0.25	**0.60**	0.02	−0.15	*0.37*	−0.09	0.33
Moisture	**−0.77**	0.09	**0.60**	**−0.75**	**0.67**	**−0.56**	*0.36*
Fat white viscera	**0.72**	−0.21	**−0.49**	**0.91**	**−0.78**	**0.61**	**−0.50**
Protein white viscera	**−0.67**	0.32	*0.40*	**−0.74**	**0.78**	**−0.51**	**0.44**
Fat red viscera	**0.71**	−0.21	**−0.47**	**0.89**	**−0.78**	**0.64**	**−0.49**
Protein red viscera	**−0.61**	0.30	*0.39*	**−0.45**	**0.56**	−0.33	**0.43**
Predition from carcasses images							
Fat	**0.80**	−0.33	**−0.67**	**0.80**	**−0.79**	**0.62**	*−0.45*
Protein	−0.31	**0.56**	0.14	−0.19	**0.53**	−0.36	0.00
Moisture	**−0.74**	−0.02	**0.77**	**−0.83**	**0.61**	*−0.45*	*0.45*
Fat white viscera	**0.69**	−0.05	**−0.66**	**0.97**	**−0.78**	*0.46*	**−0.52**
Protein white viscera	**−0.69**	**0.54**	*0.46*	**−0.65**	**0.86**	**−0.68**	0.31
Fat red viscera	**0.75**	−0.35	**−0.57**	**0.77**	**−0.79**	**0.63**	*−0.48*
Protein red viscera	**−0.63**	0.10	*0.45*	**−0.80**	**0.54**	−0.29	**0.75**

* $P < 0.05$ if numbers in bold; $P < 0.10$ if numbers in italics; else, $P > 0.05$.

Table 6
Correlation between predicted carcass and viscera composition from live calves and carcass computed tomography images*.

	Predictions from live calve images						
	Fat	Protein	Moisture	Fat white viscera	Protein white viscera	Fat red viscera	Protein red viscera
Prediction from carcass images							
Fat	**0.85**	−0.40	**−0.85**	**0.81**	**−0.78**	**0.80**	**−0.72**
Protein	**−0.52**	0.36	**0.52**	−0.36	**0.50**	*−0.43*	**0.64**
Moisture	**−0.66**	0.13	**0.66**	**−0.70**	**0.57**	**−0.66**	*0.43*
Fat white viscera	**0.70**	−0.13	**−0.70**	**0.83**	**−0.70**	**0.80**	*−0.46*
Protein white viscera	**−0.84**	**0.64**	**0.84**	**−0.76**	**0.89**	**−0.77**	**0.85**
Fat red viscera	**0.85**	*−0.47*	**−0.85**	**0.81**	**−0.80**	**0.79**	**−0.74**
Protein red viscera	*−0.46*	0.30	*0.46*	**−0.72**	**0.59**	**−0.69**	*0.45*

* $P < 0.05$ if numbers in bold; $P < 0.10$ if numbers in italics; else, $P > 0.05$.

periods.

Declaration of Competing Interest

None.

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