SUPPLEMENTARY MATERIAL

Estimation of dairy goat body composition: A direct calibration and comparison of eight methods

Sylvain Lerch[a,*], Anne De La Torre[b], Christophe Huau[c], Mathieu Monziols[d], Caroline Xavier[a,e], Loïc Louis[f], Yannick Le Cozler[e], Philippe Faverdin[e], Philippe Lamberton[e], Isabelle Chery[g], Dominique Heimo[h], Christelle Loncke[i], Philippe Schmidely[i], Jose A. A. Pires[b,*]

[a]Agroscope, Ruminant Research Unit, Route de la Tioleyre 4, 1725 Posieux, Switzerland
[b]INRAE, Université Clermont Auvergne, Vetagro Sup, UMR Herbivores, 63122, Saint-Genès-Champanelle, France
[c]GenPhySE, Université de Toulouse, INRAE, ENVT, 31326 Castanet-Tolosan, France
[d]IFIP institut du porc, 35650 Le Rheu, France
[e]PEGASE, INRAE, Institut Agro, 35590 Saint Gilles, France
[f]Université de Lorraine, AgroParisTech, INRAE, SILVA, 54000 Nancy, France
[g]IPHC, CNRS, Université de Strasbourg, 67037 Strasbourg, France
[h]Agroscope, Feed Chemistry Unit, Route de la Tioleyre 4, 1725 Posieux, Switzerland
[i]Université Paris-Saclay, INRAE, AgroParisTech, UMR Modélisation Systémique Appliquée aux Ruminants, 75005 Paris, France

*Corresponding authors :
sylvain.lerch@agroscope.admin.ch, Agroscope, Ruminant Research Unit, Route de la Tioleyre 4, 1725 Posieux, Switzerland; Tel. +41 58 461 41 29
jose.pires@inrae.fr, INRAE, Université Clermont Auvergne, Vetagro Sup, 63122, Saint-Genès-Champanelle, France; Tel. +33 4 73 62 47 56

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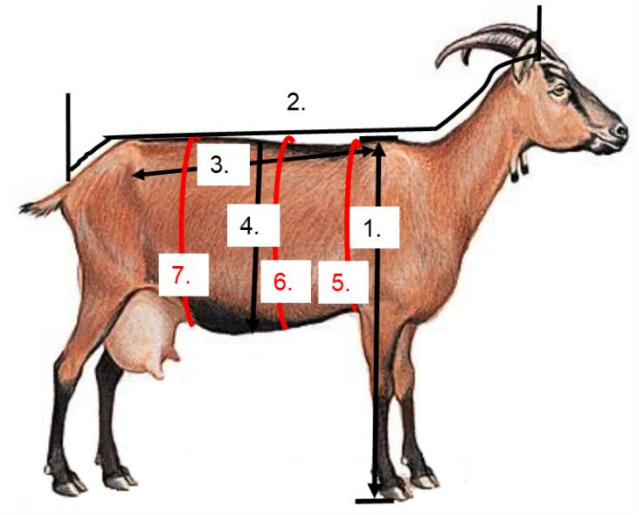
Supplementary File S1. Description of measurement locations and respective methods.

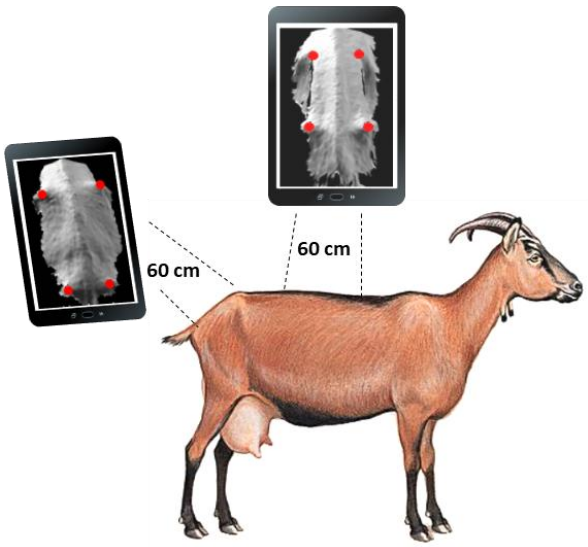
Morphological traits measured on live goats :



1. Height-at-withers : distance from the floor to the withers ; 2. Length vertex-tail : distance from the external occipital protuberance to the base of the tail ; 3. Body length : distance between the point of the shoulder to the right tuber ischia ; 4. Chest depth : maximal distance of the thoracic cage ; 5. Heart girth : girth measured behind the front legs and withers ; 6. Middle girth : girth measured after the 13th rib ; 7. Rear girth : girth measured before the hips and the mammary gland

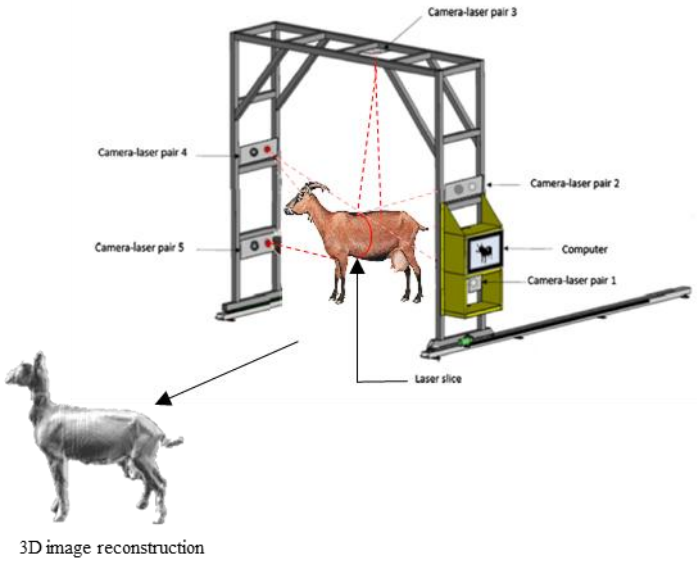
3D imaging

a) Portable system : Camera sensor Primesense Carmine (ASUSTek Computer Inc., Taiwan)



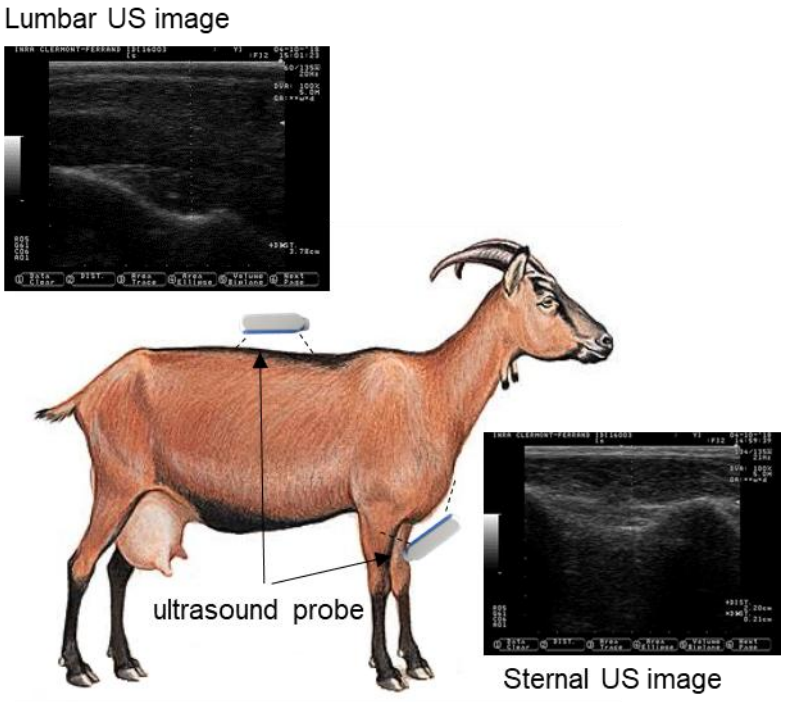
Anatomical locations used as reference points are materialized by red circles

b) Fixed system : Morpho 3D, 3D Ouest, France

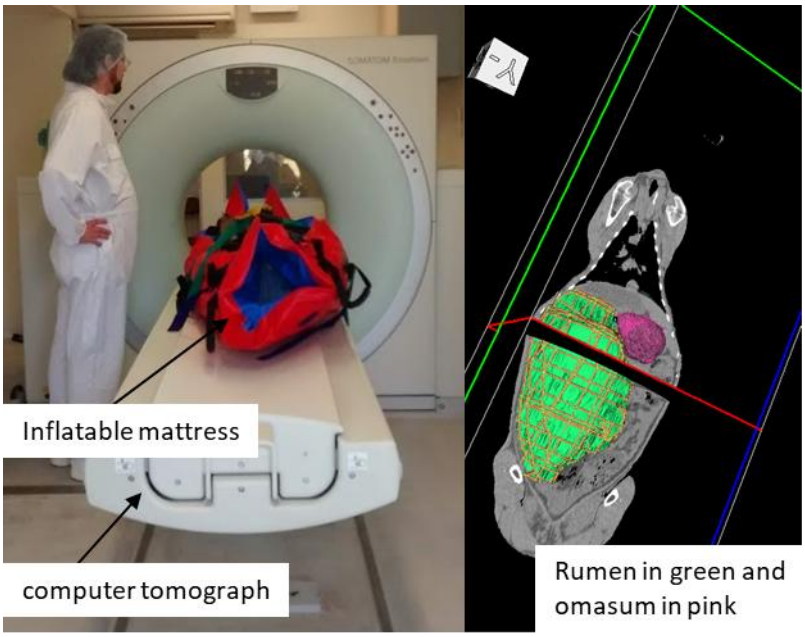


Design of the Morpho 3D according to Le Cozler *et al*, 2019 [19]

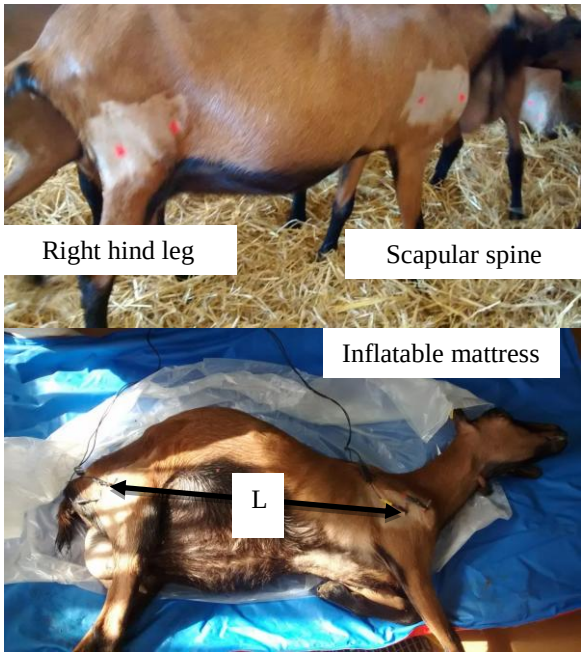
Ultrasound imaging



Computer tomography



Bioelectrical impedance spectroscopy



Four needles inserted subcutaneously were used as electrodes

L : distance between electrodes,

Supplementary Table S1. Details of calculated variates derived from the bioelectrical impedance spectroscopy

Description	Equation
Impedance measurement at 50 kHz (Ω)	$Z_{50} = (R_{50}^2 + Xc_{50}^2)^{0,5}$
Impedance measurement at 500 kHz (Ω)	$Z_{500} = (R_{500}^2 + Xc_{500}^2)^{0,5}$
Ratios between square of the distance within electrodes and body resistance at infinite frequency (cm^2/Ω)	L^2 / R_∞
Ratio between square distance within electrodes and body resistance at 0 frequency (cm^2/Ω)	L^2 / R_0
Ratio between square distance within electrodes and body resistance at 50 kHz (cm^2/Ω)	L^2 / R_{50}
Ratio between square distance within electrodes and impedance at 50 kHz (cm^2/Ω)	L^2 / Z_{50}
Ratio between square distance within electrodes and body resistance at 500 kHz (cm^2/Ω)	L^2 / R_{500}
Ratio between square distance within electrodes and impedance at 500 kHz (cm^2/Ω)	L^2 / Z_{500}

Supplementary Table S2. Estimation equations of empty body chemical component mass measured after slaughter from simple regression with single independent variates derived from the different methods

Chemical component		Statistics		
Methods	Equations [mean (SE)][1]	rSD	rCV (%)	R^2
Water (kg)				
D_2O dilution space	*0.562 (0.082) × D_2OS - 1.432 (3.462)*	*1.599*	*6.4*	*0.722*
Bioelectrical impedance spectroscopy	*0.091 (0.027) × L^2/R_∞ + 10.014 (4.472)**	*2.381*	*9.5*	*0.418*
Body condition score	*2.982 (1.306) × sternal BCS + 17.113 (3.495)**	*2.671*	*10.7*	*0.225*
	*3.720 (1.605) × lumbar BCS + 15.678 (4.058)**	*2.662*	*10.7*	*0.230*
Whole body 3D imaging scan	*0.222 (0.085) × 3D total vol + 10.085 (5.717)*	*2.581*	*10.3*	*0.276*
Ultrasounds	*3.068 (1.402) × US lumbar muscle + 17.750 (3.358)**	*2.696*	*10.8*	*0.210*
Computer tomography	0.410 (0.038) × CT total vol + 1.765 (2.164)	1.109	4.4	0.866
Lipids (kg)				
Bioelectrical impedance spectroscopy	0.828 (0.146) × R_∞ - 18.307 (4.075)*	1.651	35.4	0.667
Adipose cell diameter	0.131 (0.016) × perirenal ACD - 4.911 (1.271)*	1.095	21.6	0.833
	5.964 (0.714) × perirenal AT weight - 2.110 (0.382)*	1.048	23.3	0.823
Body condition score	4.929 (0.680) × sternal BCS - 8.494 (1.820)*	1.391	30.9	0.745
	5.635 (0.997) × lumbar BCS - 9.582 (2.519)*	1.653	36.7	0.640
	*0.464 (0.145) × heart girth - 35.843 (12.600)**	*2.197*	*48.8*	*0.363*
Body condition score by 3D imaging	*3.401 (0.788) × sternal 3D BCS - 4.953 (2.233)**	*1.930*	*42.8*	*0.509*
	*5.135 (1.291) × lumbar 3D BCS - 8.104 (3.203)**	*2.009*	*44.6*	*0.468*
Whole body 3D imaging scan	*0.748 (0.317) × 3D chest depth - 23.088 (11.755)**	*2.429*	*52.8*	*0.246*
Ultrasounds	*3.646 (1.145) × US lumbar muscle - 4.085 (2.743)*	*2.203*	*48.9*	*0.360*
	2.497 (0.724) × US sternal muscle - 1.665 (1.852)	*2.137*	*47.4*	*0.398*
Computer tomography	0.811 (0.055) × CT fat vol - 3.033 (0.536)*	0.758	16.8	0.924
Proteins (kg)				
D_2O dilution space	*0.153 (0.030) × D_2OS + 0.317 (1.252)*	*0.578*	*8.6*	*0.597*
Bioelectrical impedance spectroscopy	*0.024 (0.009) × L^2/R_∞ + 2.834 (1.465)*	*0.780*	*11.5*	*0.316*
Adipose cell diameter	*0.029 (0.012) × perirenal ACD + 4.647 (0.920)**	*0.792*	*11.6*	*0.316*
Body condition score	*1.247 (0.334) × sternal BCS + 3.453 (0.895)**	*0.684*	*10.1*	*0.436*
	*1.438 (0.432) × lumbar BCS + 3.148 (1.092)**	*0.716*	*10.6*	*0.381*
	*0.232 (0.025) × heart girth - 13.415 (2.158)**	*0.380*	*5.6*	*0.830*
Body condition score by 3D imaging	*0.731 (0.329) × sternal 3D BCS + 4.711 (0.934)**	*0.807*	*12.0*	*0.215*
Whole body 3D imaging scan	*0.063 (0.026) × 3D total vol - 2.500 (1.748)*	*0.789*	*11.7*	*0.249*
	0.277 (0.097) × 3D chest depth - 3.455 (3.600)	*0.744*	*10.9*	*0.323*
Ultrasounds	*1.232 (0.374) × US lumbar muscle + 3.842 (0.896)**	*0.719*	*10.7*	*0.376*
	*0.755 (0.252) × US sternal muscle + 4.877 (0.645)**	*0.744*	*11.0*	*0.332*
Computer tomography	*0.124 (0.011) × CT total vol - 0.266 (0.625)*	*0.320*	*4.7*	*0.876*
Minerals (kg)				
D_2O dilution space	*0.035 (0.010) × D_2OS + 0.486 (0.441)*	*0.204*	*10.5*	*0.379*
Bioelectrical impedance spectroscopy	*0.007 (0.002) × L^2/R_{50} + 1.265 (0.225)**	*0.213*	*11.0*	*0.358*
Body condition score	*0.333 (0.099) × sternal BCS + 1.060 (0.265)**	*0.203*	*10.4*	*0.386*
	*0.374 (0.129) × lumbar BCS + 1.005 (0.325)**	*0.213*	*11.0*	*0.320*
	*0.058 (0.010) × heart girth - 3.083 (0.893)**	*0.160*	*8.0*	*0.640*
Ultrasounds	*0.377 (0.101) × US lumbar muscle + 1.052 (0.242)**	*0.194*	*10.0*	*0.436*
	*0.189 (0.076) × US sternal muscle + 1.474 (0.193)**	*0.223*	*11.5*	*0.257*

Computer tomography	*0.032 (0.005) × CT total vol + 0.155 (0.275)*	*0.141*	*7.3*	*0.704*
Energy (Mcal)[2]				
Bioelectrical impedance spectroscopy	*8.90 (1.74) × R_∞ - 165.08 (48.40)**	*19.61*	*23.9*	*0.622*
Adipose cell diameter	1.42 (0.21) × perirenal ACD - 21.58 (16.20)	13.96	16.2	0.782
	66.42 (7.99) × perirenal AT weight + 53.49 (4.28)*	11.74	14.7	0.821
Body condition score	54.10 (7.85) × sternal BCS - 62.44 (21.03)*	16.07	20.0	0.725
	*62.13 (11.26) × lumbar BCS - 75.09 (28.46)**	*18.67*	*23.3*	*0.628*
	*5.68 (1.51) × heart girth - 413.34 (131.54)**	*22.94*	*28.6*	*0.439*
Body condition score by 3D imaging	*36.25 (9.13) × sternal 3D BCS - 20.57 (25.88)*	*22.37*	*27.9*	*0.467*
	54.25 (14.97) × lumbar 3D BCS - 52.98 (37.13)	*23.30*	*29.0*	*0.422*
Whole body 3D imaging scan	*8.70 (3.46) × 3D chest depth - 240.79 (128.32)*	*26.52*	*32.6*	*0.271*
Ultrasounds	*41.62 (12.55) × US lumbar muscle - 17.82 (30.06)*	*24.14*	*30.1*	*0.379*
	27.82 (8.05) × US sternal muscle + 11.50 (20.59)	*23.75*	*29.6*	*0.399*
Computer tomography	9.08 (0.56) × CT fat vol - 4.18 (5.46)	5.57	9.6	0.937

[1]Abreviations and units: D_2OS: D_2O dilution space (kg), CT total vol: total body volume measured by computer tomography (L), 3D total vol: total body volume measured by 3D whole body scan method (L), L^2/R_∞ distance between electrodes divided by body resistance at infinite frequency measured by bioelectrical impedance spectroscopy (cm^2/Ω), R_∞: body resistance at infinite frequency measured by bioelectrical impedance spectroscopy (Ω), perirenal ACD: perirenal adipocyte cell diameter (µm), perirenal AT weight: weight of perirenal adipose tissue (kg), sternal BCS: body condition score at the sternal location (0 - 5 scale), heart girth: girth measured behind the front legs and withers (cm), lumbar 3D BCS: body condition score at the lumbar location estimated by 3D imaging method (0 - 5 scale), 3D chest depth: maximal distance of the thoracic cage estimated by 3D whole body scan imaging method (cm), CT soft vol: volume of soft tissues measured by computer tomography (L), CT fat vol: volume of fat tissues measured by computer tomography (Liter), US lumbar AT: thickness of lumbar adipose tissue measured by ultrasound (cm), US lumbar muscle: thickness of lumbar muscle measured by ultrasounds (cm), US sternal muscle: thickness of the sternal muscle measured by ultrasound (cm).

[2]One Mcal is equivalent to 4.186 MJ.

*indicates that intercept is significantly different from 0 ($P < 0.05$).

Equations reported in italic are of lower accuracy than the one using body weight alone.

Supplementary Table S3. Estimation equations of chemical component percentages in empty body measured after slaughter with independent variates derived from the methods

Methods	Equations [mean (SE)][2]	Statistics		
		rSD	rCV (%)	R^2
Water (% EB fresh mass)				
Body weight	- 0.42 (0.13) × BW + 88.78 (7.01)*	3.64	5.5	0.376
D_2O dilution space	86.14 (10.46) × D_2OS.kg BW^{-1} + 0.01 (8.01)	2.11	3.2	0.790
Bioelectrical impedance spectroscopy	- 0.21 (0.11) × BW - 1.12 (0.26) × R_∞ + 108.47 (6.93)*	2.61	4	0.721
Adipose cell diameter	- 0.19 (0.02) × perirenal ACD + 79.49 (1.68)*	1.45	2.2	0.862
Body condition score	- 8.20 (1.15) × sternal BCS + 87.49 (3.08)*	2.35	3.6	0.739
Body condition score by 3D imaging	- 0.19 (0.09) × BW - 8.93 (1.71) × 3D lumbar BCS + 97.82 (5.37)*	2.56	3.9	0.707
Ultrasounds	- 4.27 (1.19) × US sternal muscle + 76.40 (3.05)*	3.52	5.3	0.416
Computer tomography	- 68.20 (6.60) × CT fat vol.total vol^{-1} + 86.10 (2.00)*	1.75	2.7	0.856
Lipids (% EB fresh mass)				
Body weight	0.51 (0.14) × BW - 16.55 (7.60)*	3.94	35.2	0.429
D_2O dilution space	- 99.82 (10.76) × D_2OS.kg BW^{-1} +87.50 (8.24)*	2.17	19.4	0.827
Bioelectrical impedance spectroscopy	0.27 (0.11) × BW +1.29 (0.26) × R_∞ -39.09 (6.99)*	2.64	22.9	0.779
Adipose cell diameter	0.24 (0.02) × perirenal ACD - 5.70 (1.77)*	1.53	12.3	0.895
Body condition score	9.48 (1.23) × sternal BCS - 13.79 (3.29)*	2.51	22.4	0.768
Body condition score by 3D imaging	0.25 (0.09) × BW + 9.73 (1.88) × 3D lumbar BCS - 26.28 (5.90)*	2.82	25.1	0.725
Computer tomography	77.70 (7.22) × CT fat vol.total vol^{-1} - 11.87 (2.18)*	1.91	17.1	0.866
Proteins (% EB fresh mass)				
Body weight	- 0.06 (0.02) × BW + 21.26 (1.13)*	0.59	3.3	0.356
D_2O dilution space	12.85 (1.98) × D_2OS.kg BW^{-1} + 7.90 (1.53)*	0.40	2.3	0.7
Bioelectrical impedance spectroscopy	- 0.19 (0.05) × R_∞ + 23.12 (1.26)*	0.51	2.9	0.535
Adipose cell diameter	- 0.03 (0.01) × perirenal ACD + 20.25 (0.30)*	0.33	1.9	0.793
Body condition score	- 1.35 (0.30) × lumbar BCS + 21.11 (0.76)*	0.50	2.8	0.527
Computer tomography	9.41 (2.33) × CT soft vol.total vol^{-1} + 12.00 (1.42*)	0.53	3.0	0.476

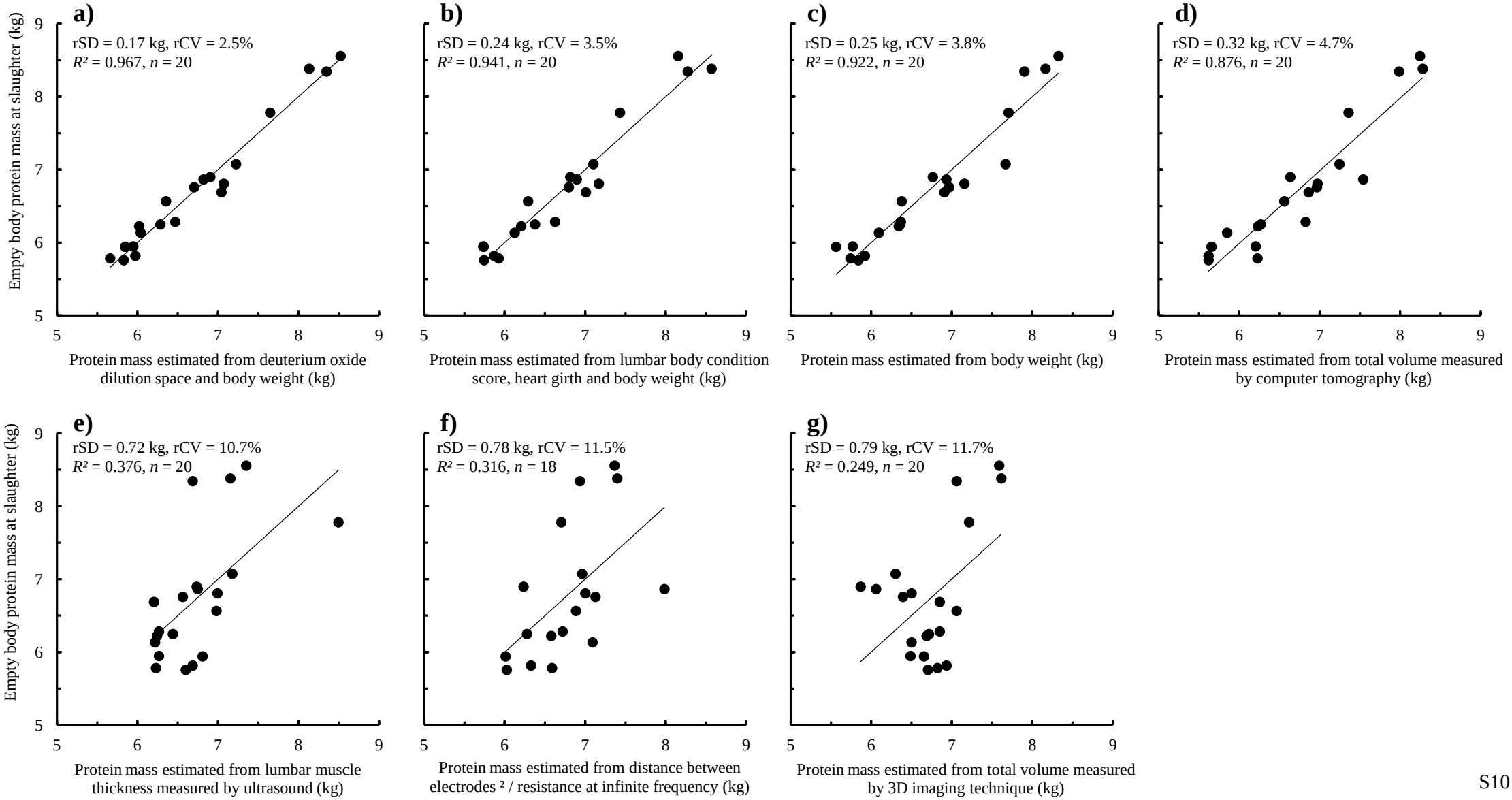
Minerals (% EB fresh mass)				
Body weight	- 0.03 (0.01) × BW + 6.59 (0.63)*	0.33	6.4	0.238
Adipose cell diameter	- 0.01 (0.01) × perirenal ACD + 6.11 (0.31)*	0.26	5.2	0.495
Whole body 3D scan	-0.13 (0.04) × 3D chest depth + 10.10 (1.40)*	0.29	5.7	0.428
Energy (Mcal.kg EB fresh mass^{-1})[2]				
Body weight	4.5 (1.3) × BW - 39.6 (69.9)	36.3	17.7	0.408
D_2O dilution space	- 885.8 (105.2) × D_2OS.kg BW^{-1} + 881.8 (80.5)*	21.2	10.3	0.798
Bioelectrical impedance spectroscopy	2.4 (1.0) × BW + 11.6 (2.5) × R_∞ - 244.7 (66.5)*	25.1	12.1	0.757
Adipose cell diameter	2.1 (0.2) × perirenal ACD + 56.8 (15.1)*	13.0	6.0	0.900
Body condition score	84.7 (11.5) × sternal BCS - 18.6 (30.7)	23.5	11.5	0.752
Body condition score by 3D imaging	2.2 (0.9) × BW + 88.6 (17.3) × 3D lumbar BCS - 129.4 (54.3)*	25.9	12.7	0.714
Computer tomography	704.4 (63.8) × CT fat vol.total vol^{-1} - 4.3 (19.3)	16.9	8.3	0.871

[1]Abreviations and units: EB: empty body, BW: body weight at slaughter (kg), D_2OS.kg BW^{-1}: D_2O dilution space divided by BW at the time of D_2O injection (kg.kg^{-1}), R_∞: body resistance at infinite frequency measured by bioelectrical impedance spectroscopy (Ω), perirenal ACD: perirenal adipocyte cell diameter (µm), sternal BCS: body condition score at the sternal location (0 - 5 scale), 3D lumbar BCS: body condition score at the lumbar location estimated by 3D imaging method (0 - 5 scale), US sternal muscle: thickness of the sternal muscle measured by ultrasounds (cm), CT fat vol.total vol^{-1}: volume of fatty tissues divided by total volume (sum of fatty, soft and bones tissues volumes) measured by computer tomography (L.L^{-1}), lumbar BCS: body condition score measured at the lumbar location (0 - 5 scale), CT soft vol.total vol^{-1}: volume of soft tissues divided by total volume measured by computer tomography (L.L^{-1}), 3D chest depth: maximal distance of the thoracic cage measured by whole body 3D scan (cm).

[2]One Mcal is equivalent to 4.186 MJ.

*indicates that intercept is significantly different from 0 ($P < 0.05$).

Supplementary Figure S1. Plots of residuals for the most precise relationships between measured empty body proteins weight of dairy goats at slaughter and its prediction from multiple regression equations developed from a) D_2O dilution space, b) body condition score and heart girth, c) body weight, d) computer tomography, e) ultrasound imaging, f) bioelectrical impedance spectroscopy, and g) 3D imaging methods. When significant ($P < 0.05$), body weight was always added as a second predictive variate in the multiple linear regression. Details of equations are given in Table 4.



Supplementary Figure S2. Plots of residuals for the most precise relationships between measured empty body energy (expressed as Mcal, 1 Mcal is equivalent to 4.184 MJ) of dairy goats at slaughter and its prediction from multiple regression equations developed from a) adipocyte diameter and perirenal adipose tissue weight, b) computer tomography, c) D_2O dilution space, d) bioelectrical impedance spectroscopy, e) body condition score, f) 3D imaging, g) body weight, and h) ultrasound imaging methods. When significant ($P < 0.05$), body weight was always added as a second predictive variate in the multiple linear regression. Details of equations are given in Table 4.