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Method paper

Method: Body composition assessment of sows using dual-energy X-ray absorptiometry

J. Heurtault[a,c], G. Maïkoff[b], M.P. Létourneau-Montminy[c], P. Schlegel[a,*]

[a] Agroscope, Swine Research Group, 1725 Posieux, Switzerland
[b] Agroscope, Mandates Animal Research Group, 1725 Posieux, Switzerland
[c] Department of Animal Sciences, Laval University, Quebec G1V 1A6, Canada

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ABSTRACT

For about 30 years, the introduction of dual X-ray absorptiometry (**DXA**) scanners in swine research has enabled the non-invasive study of body composition kinetics in animals. So far, the use of DXA technology in swine was focused on piglets, growing pigs up to about 140 kg of BW, as well as carcasses. Due to their size and weight, measuring a sow's body composition is beyond the technical limits of the device. Furthermore, the chemical composition derived from DXA values is based on equations developed for pigs weighing between 20 and 100 kg. The present aim was to focus on the sow to (1) present a standard operation procedure to obtain the body composition of sows by DXA, and (2) assess the ability of available equations to predict a sow's chemical body composition. For (1), a study investigated the effect of the animal's position on DXA body composition. A total of 58 DXA acquisitions of sows were obtained on the standard ventral position (front and back legs extended) and on the lateral position (on left flank with right legs placed inward and left legs placed outward). The predicted BW, lean tissue mass, fat tissue mass, bone mineral content, bone area, and bone mineral density of the standard ventral position from the obtained lateral position resulted in root mean square prediction errors expressed as a percentage of the observed mean value of 0.5, 1.9, 5.0, 2.7, 3.1 and 3.5%, respectively. For (2), 3 sows were scanned alive and then slaughtered to measure chemical composition, then, these results were compared with equations based on growing pig data. The chemical composition of the carcass was predicted more accurately than that of the empty body. Regarding minerals, the Ca and P contents of the empty body were overestimated (12 and 3% respectively), as with the Ca content of the carcass (6%), while the P content of the carcass was underestimated (5%). In conclusion, the proposed material and operation procedure enables the scanning of sows which exceed the maximal specification of a DXA device. Furthermore, before concluding the accuracy of the chemical body composition prediction equations based on DXA data for pigs weighing between 20 and 100 kg, additional data are required to determine their applicability to sows.

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Implications

The dual-energy X-ray absorptiometry scanner is a valuable device for non-invasive and non-destructive determination of the body composition. The presented standard operational procedures allow a comprehensive data assessment of sows. This technology accelerates the gain of knowledge regarding body composition of sows and their changes over time (e.g., lactation-gestation; parity), dietary nutrient content or performance criteria (e.g., litter size) compared to classical methods such as dissection or chemical body composition. Ultimately, the assessment of nutrient requirements and nutrient excretion of sows is greatly enhanced by the availability of data obtained through such technology.

* Corresponding author.
E-mail address: patrick.schlegel@agroscope.admin.ch (P. Schlegel).

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Specification table

Subject	Nutrition
Type of data	Table, Graph, Figure
How data were acquired	Body composition data were obtained from sows alive and from their carcasses using dual-energy X-ray absorptiometry (i-DXA, GE Medical Systems, Glattbrugg, Switzerland). Nutrient content in sow's empty body and carcass was obtained from chemical analysis of five body fractions and their respective weights.
Data format	Row and analysed data (Microsoft Excel,.docx)
Parameters for data collection	BW, lean tissue mass, fat tissue mass, bone mineral content, bone area, bone mineral density, water content, protein content, lipid content, ash content, Ca content, P content
Description of data collection	The data were collected from DXA scanner and chemical analysis of BW fractions following slaughter of the animal.
Data source location	Agroscope, Swine Research Group, 1725 Posieux, Switzerland.
Data accessibility	Data used for this paper can be obtained from the repository. Access: https://figshare.com/s/bcb2e0b9341b4ec8c42e
Related research article	Heurtault, J., Hiscocks, S., Létourneau-Montminy, M. P., Schlegel, P., 2024. Dynamics of bone mineralization in primiparous sows as a function of dietary phosphorus and calcium during lactation. animal 18, 101130.

Introduction

Assessing the body composition of animals is required to obtain nutrient retention, a critical information for nutrient requirements assessment. The obtained nutrient retention in the body is also suitable to determine nutrient excretion and use efficiency, particularly in response to various nutritional strategies (Pomar et al., 2014; Floradin et al., 2022). This approach consists of calculating the difference between dietary nutrient intake and retained nutrient in the body for a defined period (long term, expressed in months or for a physiological period, expressed in days).

Traditionally, two destructive methods have been employed to determine body retention from body composition: either carcass dissection, which separates fat, lean and bone tissue (Font-i-Furnols et al., 2015) or grinding the whole animal or animal body compartments (half carcass, offals and empty gastro-intestinal tract, blood, hair and hooves; e.g., Ruiz-Ascacibar et al., 2017, 2019) followed by chemical analysis. Despite their effectiveness, these methods have drawbacks: they are labor-intensive and time-consuming, and they do not allow repeated measurements on the same animal.

An alternative non-destructive method to assess body retention of nutrients is balance studies with complete faecal and urinary collection (Everts and Dekker, 1994; Beckmüller et al., 2023). This approach consists of calculating the difference between dietary nutrient intake and nutrient excretion for a defined period (short terms in days). This approach can however be considered as invasive due to confined individual housing. In addition, it is not suitable for assessing body composition and it is not optimally suitable for assessing nutrient requirement for accretion due to the short-term assessment of body retention. An alternative non-destructive and non-invasive method to assess body composition and retention of nutrients is imaging techniques (Laskey, 1996; Mitchell et al., 1996), such as X-ray computed tomography, magnetic resonance imaging and dual-energy X-ray absorptiometry (**DXA**). The DXA techniques have the advantages of being easy to operate, cost-effectiveness, have minimal image processing requirements (Scholz et al., 2015), and present low level of ionising radiation (Genton et al., 2002). The DXA technology provides values for lean tissue mass, fat tissue mass, bone mineral content and their sum which represents the total BW. These values are representative for tissue weights of dissected pig carcasses (Scholz and Förster, 2006; Soladoye et al., 2016; Kipper et al, 2019), but the dissection technique is not suitable to represent the whole animal. These values are also in conformity with the chemically assessed body composition of water, lipids, protein, ash, Ca and P by applying prediction equations as proposed by Mitchell et al. (1996) and by Kasper et al. (2021). However, these equations were obtained from data on growing pigs (20–100 kg BW), outside of the expected weight range of sows (more than 180 kg BW).

The technical limitations of available DXA devices for body composition acquisition are the maximum supported weight, the maximal scan surface and the maximal scan height. These limitations are not a concern in piglets (Mitchell et al., 2012), growing pigs (Mitchell et al., 1996; Pomar et al., 2014; Gonzalo et al., 2018; Kasper et al., 2021) and gilts (Floradin et al., 2022), but are clearly limiting for sows, especially of larger breeds, such as Large White.

The aim of this paper consists of presenting a standard operation procedure to measure body composition by DXA of sows to overcome the technical limitations of the device. Then, the data acquisition quality regarding adapted sow positioning and regarding the DXA–derived chemical body composition was verified.

Material and methods

The used DXA device (i-DXA, GE Medical Systems, Glattbrugg, Switzerland) had the following specifications: maximal load of 204 kg, scan area of 196.8 × 66.0 cm and the distance between the scan table surface and the X-ray receiver was 45 cm. As a sow easily exceeds maximal load and a height of 45 cm when laying on ventral position, adaptations were required. The scan acquisition of a sow included the following steps:

Animal anaesthesia

The onset of anaesthesia was proceeded in two steps. First, an intra-muscular injection of azaperone (1 ml per 20 kg BW, Sedanol, Streuli Pharma, Switzerland) was administered at the ham area. About 15 min later, the sow was set into anaesthesia by providing isoflurane (maximum 5% in oxygen, Isoflo, Abbott Laboratories, North Chicago, USA) via an inhalation mask for the duration of the acquisition procedure. The mask opening was oval-shaped, with dimensions of 15.5 × 13.0 cm and a depth of 28 cm.

Positioning for acquisition

Following the azaperone injection, the sow walked into a cage used for the scanning procedure. The cage measured 261 × 81 × 135 cm (length × width × height) and was installed on a wheeled base (Fig. 1a). Each side of the cage was removable. The cage floor was made of an original DXA plate (233 × 71 cm, GE Medical Systems, Glattbrugg, Switzerland) positioned on each side on a 2 cm metal bar and covered with an original table pad (GE Medical Systems, Glattbrugg, Switzerland). To prevent from any damage of the scanning plate when the sow walked into and stood in the cage, two sub-boards measuring 211 × 35.5 × 0.5 cm (length × width × height) were placed between the plate and the table pad. Once the sow was anaesthetised, each side of the cage, as well as the sub-boards were removed (Fig. 1b).

Then, the sow was positioned, depending on its height when laying on ventral position. If the maximal body height was less than 45 cm (distance between the DXA GE table and the X-ray receiver), the sow was positioned on the reference "ventral" position with the front and back legs extended (Fig. 2a). If the maximal body height was greater than 45 cm, the sow was positioned on the alternative "lateral" position. The animal was placed on the left flank with the right legs placed in direction of the belly and the left legs extended (Fig. 2b). Two wooden boards (174 × 28 × 5 cm) were placed lengthwise on each side of the cage to secure the sow's position during handling (Fig. 1c). Additionally, two wooden slats (174 × 28 × 2 cm) were positioned on either side of the sow to avoid any body part being placed over the 2 cm of the metallic structure of cage. As X-rays do not pass through metal, any body part that would be positioned over a metallic structure, would not be detected by DXA.

Once the sow was positioned, a winch with a force of 2 × 250 kg (Meili, Zürich, Switzerland) was used to lift the cage up and to position it over the DXA. Previously, the DXA table and table pad, usually mounted on the DXA device, were removed (Fig. 1d). To avoid excessive weight load on the device, the cage touched the device to stay in a stable position but remained supported by the winch.

Acquisition

The device's calibration was checked and passed the requirements before each acquisition session a calibration phantom, according to the manufacturer's instructions. The acquisition procedure for the whole-body composition of the animal consisted of using the acquisition mode "Total Body – thick" within the provided Encore software for the use of the device.

Next to the whole-body acquisition, additional scans can be of interest. Within the subject of bone mineralisation, the acquisition of the spinal column (L1-L4 vertebra) using 'AP Spine – thick' mode or the front foot using 'Small Animal Body – Small' mode on ventral position (positioned in head direction) are suggested.

Recovery phase

Following image acquisition, the cage was moved back onto its wheeled base. The mask used for isoflurane inhalation was removed. The cage was pushed into a pen dedicated to let the sows waking up in a calm area. The pen floor was covered with a

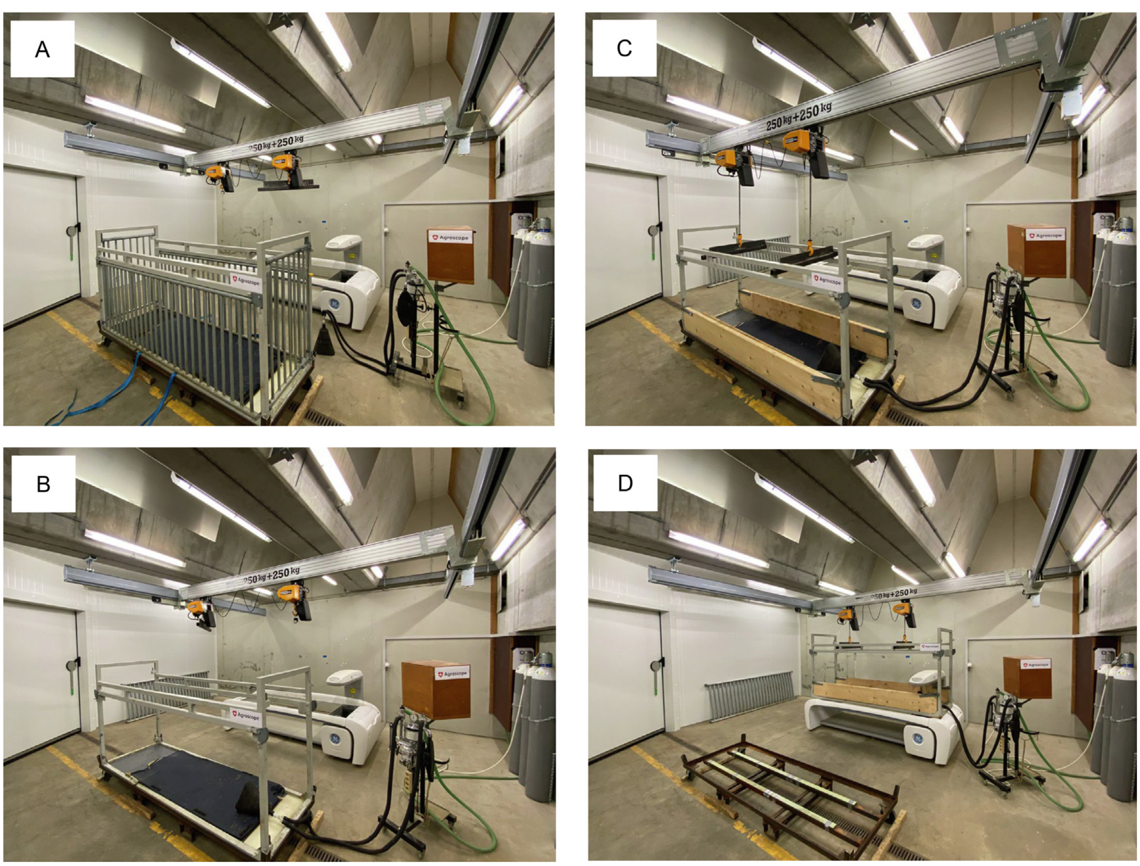

Fig. 1. Experimental set-up including restraint cage, anaesthesia and DXA device; A: cage setting for restraining the sow during until onset of anaesthesia; B: Cage setting for acquisition of an anaesthesised sow in ventral position; C: Cage setting for acquisition of an anaesthesised sow in lateral position; D: Cage positioned above the DXA device for acquisition procedure.

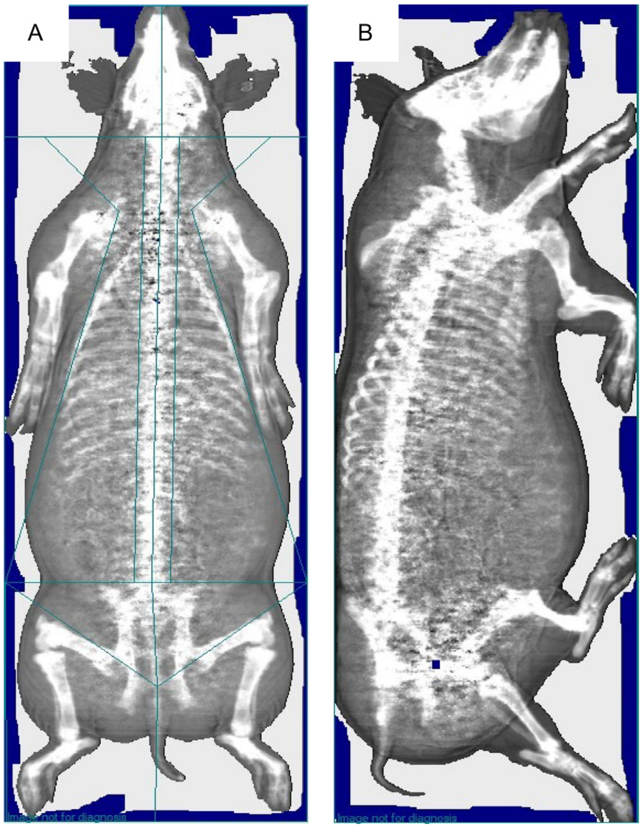

Fig. 2. Scan images of a sow positioned Ventral (A) and Lateral (B).

mattress for comfort and thermal isolation. The anaesthetised sow was slowly rolled sideways out of the cage onto the floor of the pen. The sow remained under regular visual supervision and could stay until she wakened up sufficiently to enable walking. For one total body acquisition, about 30 min are required per animal between the moment of mask application and the moment of bringing the animal into the recovery pen.

Imaging processing

Image acquisition was processed within Encore software to remove artefacts (such as the mask and anaesthesia tube). For ventral positioned acquisitions (Fig. 2a), regions of interest (head, left and right arm, trunk, spine, pelvis, left and right leg) were delineated, as described by Kasper et al. (2021). For acquisitions in lateral position (Fig. 2b), the standard setting of regions of interest is not possible. Those were moved to the side of the animal, meaning that the entire body of the sow was considered as the region of interest "right front foot". Regions of interest for the suggested front foot and L1-L4 vertebrae acquisitions were defined as shown in Fig. 3.

Study 1 –Ventral versus lateral position

A total of 58 DXA acquisitions (29 scans in ventral position and 29 scans in lateral position) were obtained from 15 Swiss Large White sows (13 primiparous and 2 of second parity) from the Agroscope herd at weaning (6 sows), day 40 of gestation (10 sows), day 80 of gestation (11 sows) and in non-pregnancy (2 culled sows). These 15 sows presented a body size of length and height which

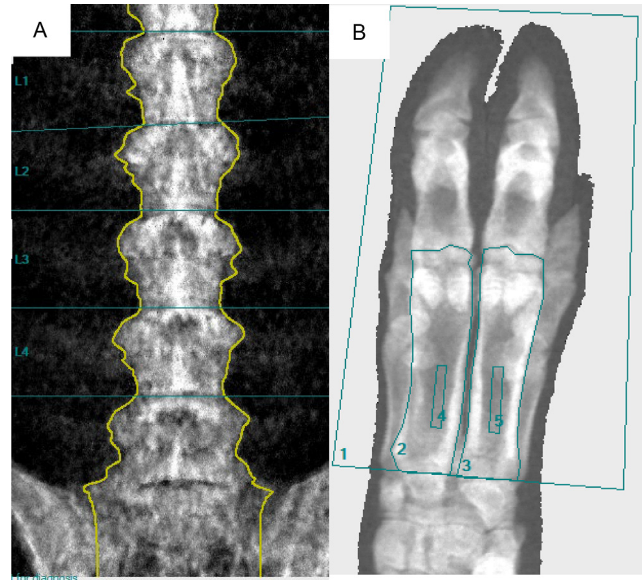

Fig. 3. Scan images of an L1-L4 spine (A) and right foot (B) of a sow.

was not limiting to be scanned by DXA on both, ventral and lateral positions. The whole-body data for BW (kg), lean tissue mass (kg), fat tissue mass (kg), bone mineral content (**BMC**; kg), bone area (cm^2) and bone mineral density (**BMD**; g/cm^2) were obtained following image processing. The data were analysed using a linear mixed model (Lmer package, R, version 4.0.3) including the sow as a random effect. These regression models were used to predict the ventral position data from lateral position. The mean square error of prediction and its root (**RMSPE**) were calculated using the Godness.of.fit procedure in the Zebook package on R (version 4.0.3).

Study 2 – Chemical body composition derived from dual-energy X-ray absorptiometry

Three culled Swiss Large White sows (224 ± 5.9 kg BW) from the Agroscope herd were slaughtered in the Agroscope experimental slaughterhouse by exsanguination after CO_2 stunning. The weighing, the body fractioning, as well as the sampling procedures were proceeded according to Ruiz-Ascacibar et al. (2017). The body fractions consisted of the blood, the hair and claws, the organs (incl. brain) and emptied gastro-intestinal tract, and of the left half carcass (including tail and half head without brain). The contents of water (1000-DM) protein (6.25xN), lipid, ash, Ca and P were determined in each fraction as described in Ruiz-Ascacibar et al. (2017; 2019). Values were summed up relative to their respective weights to obtain the chemical contents of the empty body and the total cold carcass.

The day prior to slaughter, the sow was scanned in ventral position by DXA (acquisition mode "Total Body – thick"). On the day following slaughter, the cold left half carcass (incl. half head without brain) was scanned by DXA (acquisition mode "Total Body – thick"). The acquisition images of the half-carcass were processed as described for the lateral position. The obtained DXA data and tissue weights of the left half carcass were multiplied by the relative weight of the cold left to right carcass weight to obtain values on total cold carcass basis. The water, protein, lipid, ash, Ca and P contents of the empty body and of the total cold carcass were derived

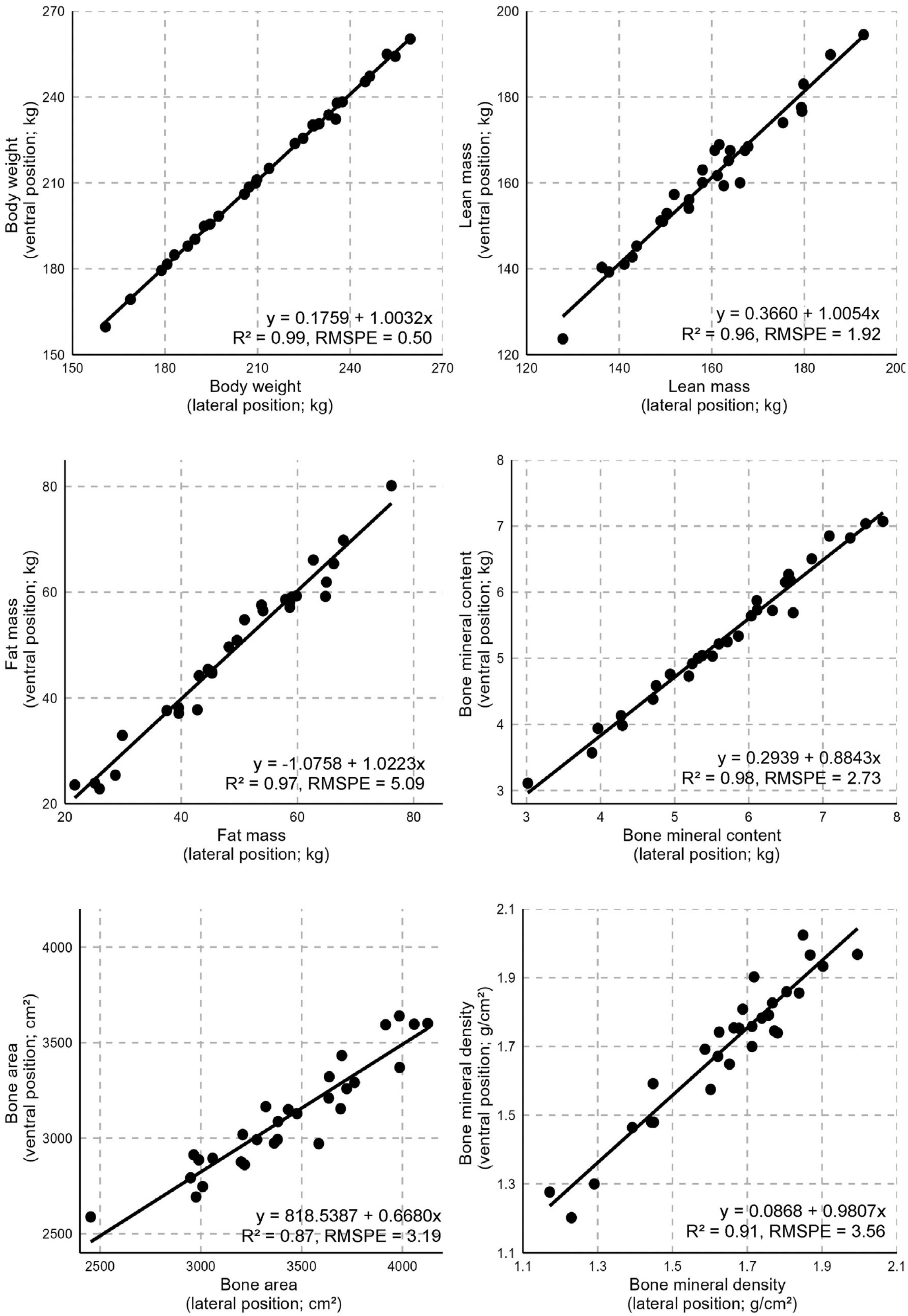

Fig. 4. Linear regressions between ventrally and laterally positioned sows of DXA obtained BW, lean tissue mass, fat tissue mass, bone mineral content, bone area and bone mineral density.

from DXA whole body and total cold carcass values, according to Kasper et al. (2021).

Results

Study 1

The body composition of sows scanned in the ventral position was as follows:

BW (215.0 ± 27.21 kg), lean tissue mass (160.6 ± 15.82 kg), fat tissue mass (49.0 ± 14.89 kg), BMC (5.3 ± 1.05 kg), bone area (3 110 ± 285.9 cm^2), BMD (1.6 ± 0.20 g/cm^2).

The regression models used to predict the ventral position data from lateral positions data had an RMSPE expressed as a percentage of the observed mean value (ventral position data) of 0.5, 1.9, 5.0, 2.7, 3.1 and 3.5%, respectively, for BW, lean tissue mass, fat tissue mass, BMC, bone area, BMD (Fig. 4).

Study 2

The chemical contents of the empty body, derived from DXA values overestimated empty BW (8%; Table 1), lipid (28%), ash (3%), Ca (12%), as well as P (3%) contents and underestimated water (−11%) and protein (−14%) contents in comparison to chemical analysis. The chemical contents of the cold carcass derived from DXA values were close, if not identical, to the values obtained by chemical analysis, except that the protein and P contents were slightly underestimated (4% and 5%, respectively) and the Ca content was slightly overestimated (6%).

Author's point of views

- The proposed standard operation procedure to determine the body composition of a sow by DXA allowed a safe scanning procedure for the sow, the staff as well as the DXA device. Therefore, with the given adaptations, DXA acquisitions can be processed on sows as accurately as on smaller animals, such as growing pigs.
- The recommended number of persons required to run this procedure is of two in order to allow a safe handling of the sow until anaesthetised and to limit the time required for positioning.
- Evaluation of sow's size prior to acquisition is recommended as its frame may exceed, even in lateral position, maximum distance between the scan table surface and the X-ray receiver. In case a sow exceeds the maximal scan distance, the solution consists of proceeding with two acquisitions. A first one as usual from the head onwards and a second one for the remaining part after having moved appropriately the cage to the side over the scan surface. During image processing, the regions of interest can be defined for the remaining part in the second image and following data export of the two images, the data can be summed up.
- Regarding anaesthesia, it is worth noting that without a preliminary intra-muscular injection of azaperone before isoflurane inhalation, the procedure was not successful. To save the used quantity of isoflurane, a decrease in concentration is possible from the acquisition procedure onwards. In case animal movements would be observed, isoflurane concentration needs to be raised again.
- Linear regressions are proposed to adjust the body composition of a sow scanned in the lateral position to the body composition of a sow scanned in the ventral position, which is considered as standard position for smaller pig categories or animals. The regression errors were small, meaning that the regressions can be considered as being robust.
- Imaging techniques should yield to results that are unaffected by animal size and body composition. When DXA values are transformed to ash, Ca and P in the empty body, those were acceptable with the chemically analysed empty body compositions, as their respective difference was within the error of the used regressions (Kasper et al., 2021). This was however not the case for water, lipids and CP. The fact that this discrepancy was not observed on carcass basis, the origin may come from the "fifth quarter" consisting of organs and empty gastro-intestinal tract. The observed difference in empty BW can probably be explained that the fasting time was uncontrolled in sows, whereas it was controlled in the growing pigs used to develop the applied regressions (Kasper et al., 2021).
- The dataset, originating from only 3 sows, is certainly limiting and the presented results require confirmation on a larger scale. The assessment of DXA−derived nutrient retention (for assessing nutrient requirement) and excretion calculated by the difference between two DXA acquisitions of the same animal as

Table 1
Sow empty body and cold carcass weights and chemical body composition according to slaughtering technique and chemical analysis and according to proposed regressions from DXA values (Kasper et al., 2021).

	Empty body		Carcass, cold	
	Mean	SD	Mean	SD
According to slaughtering technique and chemical analyses				
Weight, kg	205	10.2	170	13.0
Water, g/kg	598	53.3	567	46.1
Lipid, g/kg	194	58.5	215	59.8
Protein, g/kg	175	1.47	182	5.60
Ash, g/kg	34.5	3.21	40.1	4.88
Calcium, g/kg	9.7	1.27	11.7	1.84
Phosphorus, g/kg	5.95	0.71	6.97	1.04
According to DXA values				
Weight, kg	222	5.86	170	12.9
Water, g/kg	529	43.2	564	47.2
Lipid, g/kg	246	62.1	215	63.1
Protein, g/kg	150	12.5	175	14.7
Ash, g/kg	35.4	4.02	40.0	5.98
Calcium, g/kg	10.8	1.24	12.4	2.26
Phosphorus, g/kg	6.13	0.61	6.61	0.91

done for N, Ca and P in growing-finishing pigs (Pomar et al., 2014), gilts Floradin et al., 2022) and in primiparous sows (Heurtault et al., 2024) should however not be of great concern as the potential error between chemically assessed and DXA−derived values is identical for both acquisitions.

Conclusion

This study describes a standard operation procedure proposed to measure the body composition of animals, such as sows, which exceed the maximal specification of a DXA device. The body composition according to the standard ventral position can be assessed by using the alternative lateral position in case the standard ventral position would not be feasible. Finally, the chemical body composition prediction equations derived from DXA, with a BW validity range between 20 and 100 kg, need to be verified with additional data from larger pigs, such as sows.

Peer Review Summary

Peer Review Summary for this article (https://doi.org/10.1016/j.anopes.2024.100079) can be found at the foot of the online page, in Appendix A.

Ethics approval

This study's experimental procedure was approved by the Office for Food Safety and Veterinary Affairs (2020_42_FR, 2020_49_FR), and all procedures were conducted in accordance with the Swiss Ordinance on Animal Protection and Ordinance on Animal Experimentation.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

Author ORCIDs

Julien Heurtault: https://orcid.org/0009-0003-8670-1472.
Marie-Pierre Létourneau-Montminy: https://orcid.org/0000-0001-5364-2662.
Patrick Schlegel: https://orcid.org/0000-0001-5095-0889.

Author contributions

JH: Methodology, Investigation, Formal analysis, Visualisation, Writing- Original draft.
GM: Methodology, Resources, Investigation, Writing – Review and Editing.
MPLM: Funding acquisition, Supervision, Writing – Review and Editing.
PS: Conceptualisation, Funding acquisition, Supervision, Methodology, Investigation, Writing – Review and Editing.

Declaration of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Julien Heurtault reports financial support was provided by Mitacs Canada. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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