FAIM

Farm Animal IMaging

FARM ANIMAL IMAGING

A SUMMARY REPORT

EDINBURGH 2015

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EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

Comparison of density and volume measurements from a range of different Computed Tomography scanners across Europe

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Value for industry

- Computed tomography (CT) is an excellent means to measuring in vivo or carcass body composition on farm animals.
- Every institute uses its own method for CT body composition measurement and comparisons between methods are complicated because of the lack of harmonised methods.
- A harmonised method would be useful for every comparison between different institutes' studies on body composition for genetics, animal breeding, carcass composition or for classification purposes.
- The COST Action FAIM has worked towards a harmonized method by collaborating to evaluate CT measurement differences between different CT-scanners/protocols in Europe.

Background

The main objective of COST Action FAIM (FA1102) workgroup 1 was to propose reference methods for measuring body composition by medical imaging (CT or magnetic resonance imaging (MRI)). This paper will only consider CT, but a similar study should also be implemented for MRI.

Many institutes involved in the COST Action FAIM that own a CT scanner have published or presented studies which show the ability to measure body composition by CT (Daumas and Monziols 2011, Font i Furnols *et al.* 2009, Judas *et al.* 2006, Bünger *et al.* 2011). Currently, each institute uses its own method of image acquisition and image analysis and comparing methods for discussions about a common reference method is complicated.

A starting point is that every image analysis method should give the same result on the same image. This simple statement becomes more complicated to apply on images acquired by different CT scanners, under different conditions and with different acquisition parameters.

In theory, every CT scanner in the world is calibrated on air and water in order to create a signal scale called Hounsfield scale in which the output is expressed in Hounsfield units (HU). Every scanner is supposed to measure -1000 HU for air and 0 HU for water. Furthermore, every scanner is considered to measure an exact volume by combining pixel size in the acquisition plane and slice thickness.

One of the most important questions in the FAIM COST WG1 discussions was does each CT really measures 'the same things'? Different approaches were considered to answer this question such as the use of meat, fat and bone phantoms (Christensen and Breusch, 2013). However sending phantoms by post around Europe and analysing such complex round-robin trial between all CT owners dedicated to farm animals is not feasible in the framework of COST which supports networking but not research projects. Therefore the idea here is to begin with a very simple protocol to assess CT differences regarding density and volume measurement between different CT scanners.

Why the work is needed

The main objective of this work is to evaluate measurement differences between different CT scanners in Europe (dedicated to farm animals) by using a very simple protocol based on density measurement and water volume measurement. This work is important to evaluate the magnitude of these differences and to derive from this, ideas to improve and harmonize current measurement methods.

The methods used

The first step of this study was to design a simple protocol for CT quality measurement.

It consisted in two parts. The first part was to evaluate the quality of the density measurement realized by CT. It was based on density calibration used in bone density measurement (Zhang *et al.* 2001). The idea is to use KH_2PO_4 dilutions to mimic densities differences. The original protocol suggested 9 densities dilution in distilled water at 2, 4, 6, 8, 10, 12, 14, 16 and 20 g/cm^3. These solutions were obtained by dissolving 20 to 200 mg of KH_2PO_4 (Sigma Aldrich) in 100mL of distilled water. These solutions samples had to be scanned by different institutes using a reference acquisition (recommended clinical acquisition by the manufacturer) and their standard acquisition for animal body composition measurement. No acquisition parameters were imposed in order to evaluate European wide differences as they are right now. Image analysis was achieved by a simple region of interest (ROI) measurement in the sample images and mean CT density (HU) of the ROI recording. Figure 1 shows the dilution sample measurement as performed in the Universidade de Trás-os-Montes e Alto Douro (UTAD).

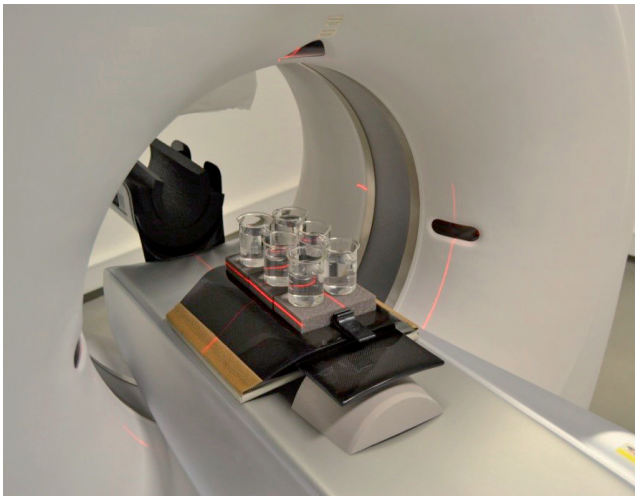

Figure 1. Dilutions samples scanned in UTAD institute (Portugal)

The second part of the protocol targeted the volume measurement evaluation. The protocol was to use a set of commercial plastic bottles of different volumes (0.5, 1.5, 2, 5 and 20 L). These bottles had to be scanned by using the same type of acquisition protocols used for the density measurement (a reference and an 'animal' acquisition protocol). The suggested image analysis was a simple threshold after table removal in order to count the water pixels. Then the water volume was calculated by multiplying the water pixel sum by the pixel size (plane resolution x slice thickness).

Water volume was measured by weighing the full bottle and empty bottle (after water removal and drying for 2d). The weight difference is considered as the volume (considering water density equal 1 g/cm^3). Figure 2 shows as an example the water bottle acquisition in IRTA institute in Spain:

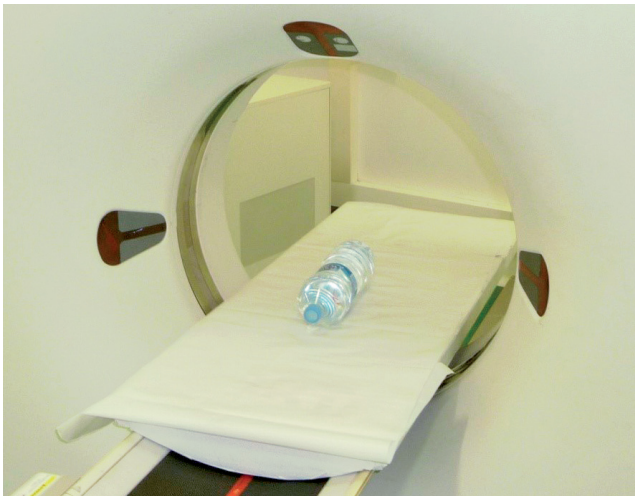

Figure 2. Water bottle scanned in IRTA institute (Spain).

This simple protocol was sent to different members of the COST FAIM network that own one or several CT scanners and results were compiled.

The results obtained

Seven different institutes participated in this trial for a total of 10 different CT scanners.

Unfortunately one institute was unable to realize the volume measurement in time.

Furthermore some protocol modifications appeared:

- For dilution protocol: some institutes (8 CTs) performed an useful scan of distilled water without KH_2PO_4, others (6 CTs) performed a 18 g/cm^3 KH_2PO_4 sample, and finally some institutes (3 CTs) had problems with 20 g/cm^3 dilutions (crystallization) , so their points were excluded as outliers.
- For volume measurement: it was difficult for all the institutes to obtain every type of bottle; so the table 1 resumes the number of CTs that have performed measures on different reference bottles.

In addition one institute only performed the density measurement so only 9 CT results were available for the volume part of the protocol.

Table 1. List of bottle type/sizes scanned and number of CT scanners that measured them

Bottle type/size	Number of CT scanners that performed the measurements
0.5 L	9
1 L	7
1.5 L	9
2 L	7
5 L	8
10 L	2
18.9 L	1
19 L	3
20 L	3

For the interpretation of the results 18.9L, 19L and 20L results will be pooled and considered as “big bottle”.

Numerous results were received from the partners in this project. So, to simplify the presentation of the results, only the results of the ‘animal’ acquisition protocol used on different CT scanners will be presented here.

Figure 3 presents the results from the ‘animal’ acquisition protocol on 10 different CT scanners showing the different relationships between the densities mimicked by concentration of KH_2PO_4 (mg/100ml) and CT signal (HU).

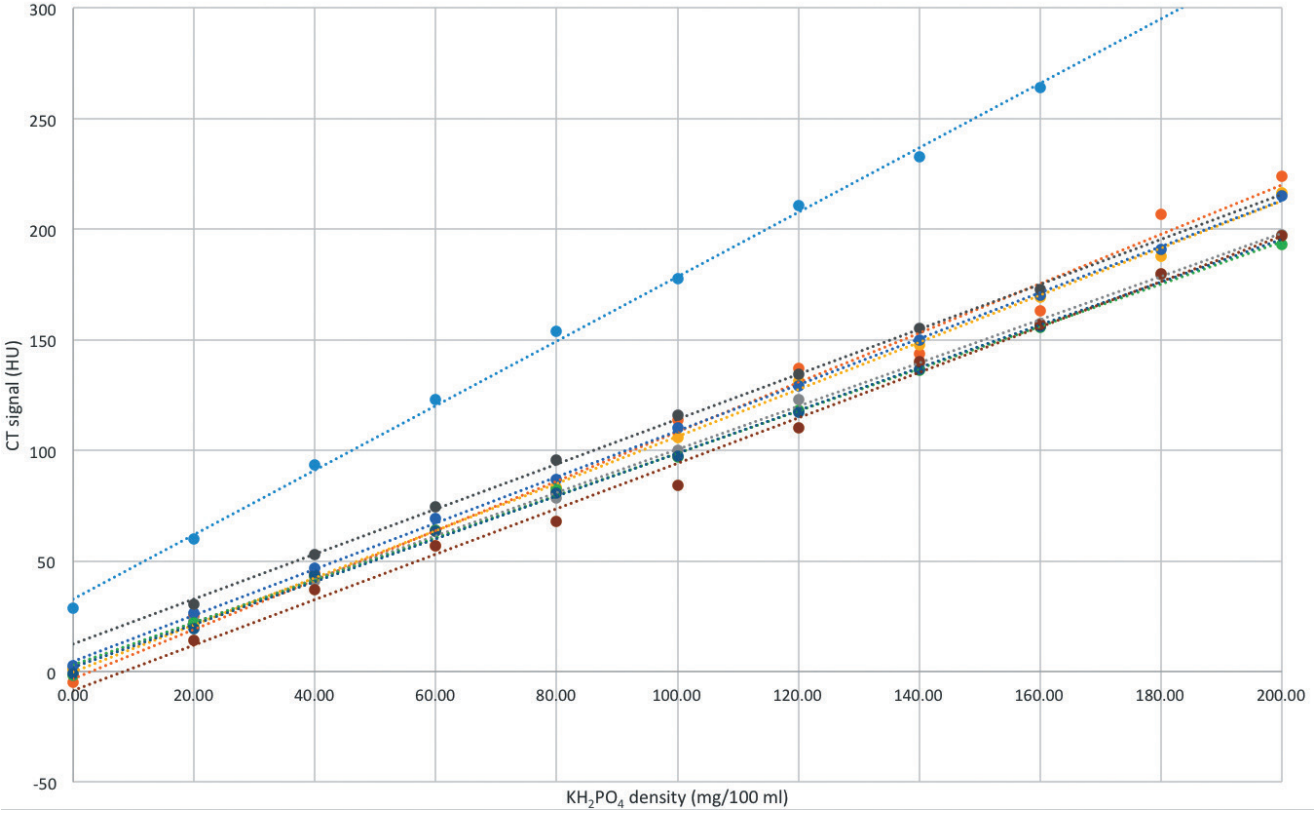

Figure 3. Density measurement relationship between CTs and dilution references.

Clearly, one CT scanner (blue line) had a larger calibration problem or the dilutions prepared were not correct, so this CT scanner was considered as an outlier and the data were removed from the analysis. For the others CT scanner, the figure shows that for every CT scanner the relationship between mimicked density and CT density (HU) is quite linear (each relationship as a $R^2 > 0.99$) as previously expected. Nevertheless, the relationships are quite different from one CT scanner to another. Indeed for a same KH_2PO_4 concentration up to 37 HU difference can be observed on this figure.

Table 2 shows the differences observed between CT scanners for each KH_2PO_4 concentration; in order to have unbiased result the data from outlier CT scanner have been removed.

Table 2. Density measurement differences between CTs for each dilution reference without outlier CT.

KH_2PO_4 concentration mg/ML	Mean CT signal (HU)	CT signal standard deviation (HU)	CT signal range (Max – min)	Number of CT scanners involved
0	-0.5	2.3	7.6	7
2	22.7	4.4	16.6	9
4	44.2	4.1	15.8	9
6	65.3	3.2	18.7	9
8	83.6	8.1	27.8	9
10	105.0	11.0	37.3	9
12	126.5	9.3	27.7	9
14	145.2	7.6	22.5	9
16	164.8	8.8	26.6	9
18	190.8	10.0	27.5	6
20	209.2	11.9	30.9	7

These results show that there are differences between CT scanners for density measurement which have to be considered. For example muscle measurements in pig carcasses give values around 60 HU (Daumas and Monziols 2011); for this range of HU, table 2 shows that differences 15 or 20 HU can occur between two different CTs.

Concerning volume measurement, as the bottles were different from one CT scanner to another and as water volume measured by weight differences is not the same between CT scanners, measurement errors can only be presented as volume percentage. Table 3 shows for every type/size of bottle the statistics of the errors. The errors are calculated in absolute values. Generally volumes have been underestimated but some measurements are overestimations.

Table 3. Measurement errors for water volume measurement by CT.

	Mean measurement error (%)	Error standard deviation	Min error	Max error	Number of CT scanners involved
0.5 L	6.4	4.3	0.4	12.2	9
1 L	5.0	3.6	0.8	9.6	4
1.5 L	5.4	2.7	1.4	8.4	9
2 L	7.2	2.3	3.6	9.9	8
5 L	4.1	2.4	0.7	7.0	8
10 L	4.0	1.9	2.6	5.3	2
“Big bottle”	2.7	3.0	0.3	8.9	7

The table shows that the mean volume measurement error is around 5% but there is an important variability in the measurement errors. It seems that the measurement error is reduced for higher volumes, which is consistent with the limitation of some parameters such as slice thickness and spatial resolution.

The scientific conclusions

The main conclusion of this study is that there are larger than trivial differences between different CTs. As the protocols were quite simple and deliberately allowed some freedoms for the CT scanner owners to perform it, these resulting differences may have several explanations.

Firstly just by analysing densities differences, one CT scanner presents a big problem of calibration which is really surprising. For the other densities differences, the first finding would be some image acquisition differences. Although the differences between reference acquisition and animal acquisition for each CT scanner have not been shown in this paper, they were found to be quite negligible (mean difference is around 5 HU which is in the range of the acceptable noise).

So, density differences seem to come from CT calibration. The main explanation for which seems to be the manufacturer calibration. Indeed in quality protocol measurements, the manufacturer makes a CT calibration against a "water" phantom which can differ from one CT to another. Secondly, each CT start-up is followed by a CT calibration against air, it is highly possible that air is calibrated differently for one machine to another. These differences in the 0 HU (water phantom) and -1000 HU (air) calibrations can lead to the differences observed here. Nevertheless, even if differences between densities measurement exist, a correction is possible by placing density reference objects in the field of view during experimentations.

Volume measurement differences present a more important problem. These differences can be explained by giving the CT scanner users freedom in term of acquisition (pixel size and slice thickness) or image analysis. But the results show that no one CT scanner is perfect. None of the considered CT scanner seems to be consistently better than another for every measured volume. The only reassuring result is that it seems that measuring large volumes generates less errors than little volumes, and indeed, in vivo animal or carcasses are 'large volumes'.

The next steps

This study is a very important first step for evaluating CT difference in density and volume measurement.

The density part of the protocol seems quite usable for comparison and correction. It seems possible to derive a density correction method from this study.

For the volumes it is more complicated. The next step would be to provide a better protocol. The idea would be to use the same set of bottles for every CT scanner to be assessed, to apply nearly the same acquisition parameters and to use the same image analysis to understand the causes of the observed problems.

The present study shows that more work on CT scanner metrology is needed to increase the harmonisation and standardisation between different CT scanners/protocols for the measurement of animal body composition. This requires special research with appropriate levels of funding so that comparisons between the various different countries and different machined can be achieved.

Acknowledgements

The authors want to acknowledge the different technical personal that realized and analysed the images in the different institutes (MRI, SRUC, IRTA, IFIP, UTAD, DMRI, Kaposvar University) and COST, which enabled us to network in this area of research.

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