An accurate and simple Computed Tomography approach for measuring the lean meat percentage of pig cuts

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Abstract— **The global challenge was to develop a robust, unbiased, accurate and simple reference method for measuring the lean meat weight and percentage (in live animals, carcasses, cuts and meat pieces). The principal aim of this study was first to develop such a method on pig cuts.**

Sixty-three left sides, were taken as a representative sample of the French pig slaughtering, were jointed into the four primal cuts. These cuts were scanned by spiral Computed Tomography (CT) using a 3 mm slice thickness. Muscle volume was automatically measured as the voxels in the Hounsfield range 0-120. LMP (Lean Meat percentage) was calculated applying a constant muscle density.

The four cuts were fully dissected and LMP was calculated according to the EU definition.

Correlations between CT and dissection were all higher than 0.98. Biases between dissection and CT were not significant. The regression of dissection on CT for muscle weight gave an RSD in the range 45-51 g for loin, shoulder and ham, 80 g for belly and 186 g for the whole. For LMP the RSD was 0.54 %.

This CT procedure is presently the simplest and most accurate method to measure the lean meat percentage of the main pig cuts. It will be used in France for calibrating the classification methods and for composition studies.

Variability in muscle density is under investigation in order to assess the robustness of this approach. The detection of the different tissues, especially in the belly, could merit further improvement.

Keywords— **Carcass classification, Lean meat percentage, Computed Tomography.**

I. INTRODUCTION

Since January 1, 2009 the (EC) Regulation No 1249/2008 has introduced the possibility of using Computed Tomography (CT) for pig classification providing that the CT gives satisfactory results in comparison with dissection; unfortunately, no rules were defined.

The authors have promoted an EU procedure for using CT, especially by organizing a workshop in June 2010 [http://www.ifip.asso.fr/FANI/]. Among the conclusions of this workshop, most of the Member States preferred a national approach instead of a single common method. Most of them have already published their approach [1; 2, 3, 4], based on the scanning of sides.

The French pig classification board decided to calibrate the classification methods against the LMP, by CT scanning the 4 main joints instead of dissecting them.

The overall objective of the authors was to develop a robust, unbiased, accurate and simple reference method for measuring both the lean meat weight and percentage (in live animals, carcasses, cuts and meat pieces). The main aim of this study is to develop such a method on pig cuts. This article presents an improvement of a first attempt [5] by reducing the Hounsfield range for the muscle tissue.

II. MATERIALS AND METHODS

This study was based on a concomitant dissection trial aiming at checking the French CGM formula for pig classification [6].

A. Experimental design

A representative sample was selected of pigs slaughtered in France from two commercial slaughterhouses according to a balanced sex ratio (50 % females and 50 % castrated males).

After chilling overnight, sixty-three left sides were prepared and cut according to the EU reference procedure (Fig.1) [7]. The four main cuts (ham, loin, shoulder and belly) were transported on a trolley into a truck, which was parked on a shipping dock. A Siemens Emotion Duo scanner (Siemens, Erlangen, Germany) was installed in the truck. A radio-transparent styrofoam support was placed between the examination table and the cuts.

The following protocol settings were used: 130 kV, 40 mAs, 3 mm slice thickness, spiral scanning, FoV 500x500 mm, acquisition matrix 512x512, reconstruction filter B30S (soft tissues).

Acquisition duration was about 1mn30 for each cut.

After having scanned the cuts they were transported back in the cutting room. They were dissected there according to the EU reference procedure [7].

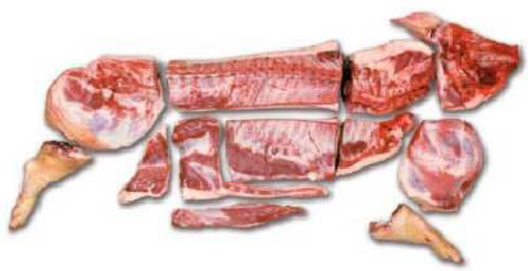

Fig. 1 EU reference cutting [7]

B. Image analysis

Dicom CT images were analysed by using software developed in our lab, written in C#. The examination table was firstly separated from the image by an automatic ROI selection in the radio-transparent Styrofoam support. Muscle voxels were then automatically measured as the voxels in the Hounsfield (HU) range 0-120 (Fig. 2). This choice, which is a crucial issue, was motivated by the following arguments.

Firstly, 0 HU is a natural threshold between muscle and fat, this value corresponds to CTs calibration on pure water. Secondly, a pure tissue distribution signal as muscle on a CT image was considered as Gaussian thus symmetric. Thirdly, many authors reported either a mean or a mode of pig carcases muscles around 60 HU [8; 4]. Finally, the upperbound of 120 HU was inferred from the symmetric value of 0-60.

For each side the number of muscle voxels was multiplied by the voxel volume (FoV/Matrix * slice thickness = 2.86 mm^3) in order to get the muscle volume.

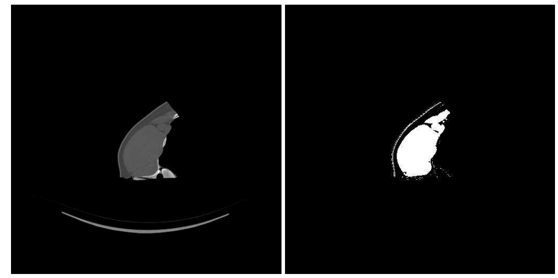

Fig. 2 Raw image Thresholded image

C. Calculation of Lean Meat Percentage (LMP)

LMP was defined in the Annex IV of the (EC) Regulation n° 1249/2008. The same definition held for both dissection and CT, the latter being considered as virtual dissection. Where partial dissection was carried out, LMP was defined as the muscle percentage in the four main cuts adding tenderloin, considered as 100% muscle. This value was scaled by a multiplicative factor of 0.89 in order to get approximately the same level as in the carcase.

$$LMP = 0.89 * 100 \frac{\sum lean(shoulder, loin, ham, belly) + tenderloin}{\sum weight(shoulder, loin, ham, belly, tenderloin)}$$

Where dissection was carried out, the weight of lean meat was obtained following dissection. Where CT was carried out, the volume of lean meat was obtained following scanning and thresholding. The weight of lean meat was then calculated applying a constant muscle density of 1.04 [9].

D. Statistical analysis

The comparison between CT and dissection was assessed by correlation, bias and regression. Proc CORR and Proc REG from SAS Software were used [10].

III. RESULTS

Table 1 gives the average proportions of the dissected tissues per cut. The proportion of 67.7 % of muscles in the 4 cuts corresponds to a LMPdis of 60.7 %.

LMPdis and LMPct had respectively a mean of 60.7 and 61.3 and a standard deviation of 3.65 and 3.59. The average LMP difference was not significant, as well as the differences of muscle weight by cut (table 2).

Table 1 Proportions (%) of the dissected tissues by cut

Cut	Muscles	Fat	Bones
Ham	73.8	18.1	7.6
Shoulder	68.8	21.7	9.0
Loin	60.5	28.5	10.4
Belly	57.2	35.6	6.2
4 cuts	**67.7**	**23.5**	**8.2**

Table 2 Mean bias of muscle weight by cut (g)

Cut	Dissected	Scanned	Bias
Ham	8339	8353	14
Shoulder	4217	4251	34
Loin	4652	4669	17
Belly	2462	2587	125
4 cuts	**19670**	**19860**	**190**

Table 3 Residual Standard Deviation (RSD) of the regression of the dissected weight muscle on the CT weight muscle (in g)

Cut	RSD (g)	RSD (%)
Loin	45	
Shoulder	45	
Ham	51	
Belly	80	
4 cuts & tenderloin	**186**	0.60
LMP reference		**0.54**

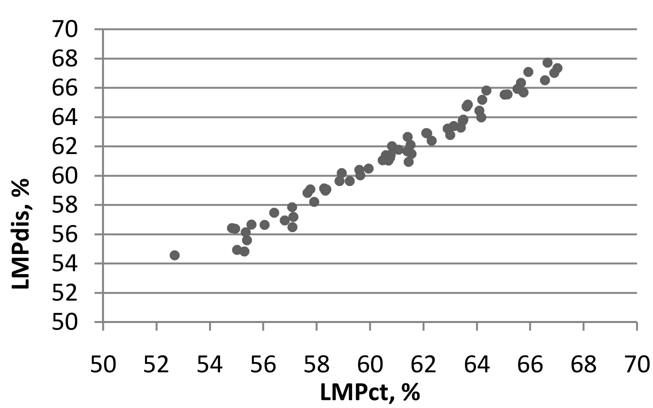

Fig. 3 Scatterplot between LMPdis and LMPct

Correlations between the muscle weights per cut were 0.976 for belly and higher than 0.995 for the 3 other cuts, giving 0.996 for all the cuts. Transposed into LMP the correlation was 0.989. Figure 3 shows the linear relationship between LMPdis and LMPct as well as the high degree of concordance between both references.

The regression of dissection on CT for muscle weight gave a RSD in the range 45-51 g for loin, shoulder and ham, 80 g for belly and 186 g for the whole (table 3). For LMP the RSD was 0.54 %.

IV. DISCUSSION

Representativity of the sample was high, as the French average LMP (predicted by CGM) was 60.0 in 2008 and 60.3 in 2010.

The bias between dissection and CT was low, 190 g, approximately 1 % in relative value, corresponding to 0.6 % LMP. In comparison, [8] reported a bias six times higher, with 1227 g of muscle weight and 3.07 % LMP, making necessary a prior calibration against dissection. The other authors calibrated CT against dissection using PLS and had therefore a very low bias. Our thresholding approach is therefore the only allowing consideration of CT as a primary reference.

Limiting the range to 0-120 HU for muscle led to a large decrease in RSD, compared to 0.86 % with a 0-200 HU range [5]. Scanning carcases and using spectral calibration (PLS) for predicting LMP in the carcase gave close errors or slightly higher: RMSE = 0.55 % [1], 0.56 % [2], 0.5 % [3], 0.8 % [4].

The main sources of error in the image analysis stem from both skin and partial volume effect, which consists in a mix of two tissues in the voxel volume. Firstly, as the skin signal on the CT image is near to the muscle one, the 0-120 HU range includes some skin, as illustrated by figure 2. Skin segmentation is not an easy task, an automatic skin segmentation based on mathematical morphology or a manual segmentation would have made the method far more complex.

Secondly, mixes of muscle and fat, bone and fat or bone and air can give a HU value within the chosen range. Nevertheless, the partial volume effect was limited, using a 3 mm slice thickness, contrary to most authors which have preferred a 10 mm slice thickness.

Another potential error source in measuring the CT muscle weight is the variability of the muscle density. As a first and simple approach we choose to work with a constant density based on human muscle density but the mean value and inter and intra carcase variability of pig muscle density is still under ongoing investigations.

V. CONCLUSIONS

This CT procedure provides satisfactory comparative dissection results. Moreover, it is presently the simplest and most accurate method to measure the lean meat percentage from the main pig cuts. It will likely be used in France for:

- periodically checking current classification methods
- updating current equations
- calibrating new classification methods
- performing composition studies.

This CT procedure could also be applied to calibrate the classification methods in the other countries either using the French mobile CT or their own CT if available.

As one of the most robust procedures, it is therefore a good candidate as a starting point when building a harmonised international CT procedure.

Variability of muscle density is under investigation in order to assess the robustness of this approach. The detection of the different tissues, especially in the belly, could merit further improvement.

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