DETERMINATION OF LEAN MEAT IN PIG CARCASSES WITH THE AUTOFOM CLASSIFICATION SYSTEM

HANS BUSK[1*], ELI VIBEKE OLSEN[2] AND JESPER BRØNDUM[3,4]

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1 Danish Institute of Agricultural Sciences, Research Centre Foulum, P.O. Box 50, DK-8830 Tjele, Denmark
2. Danish Meat Research Institute, Maglegaardsvej 2, DK-4000 Roskilde, Denmark
3. SFK Technology A/S, Transformervej 9, DK-2730 Herlev, Denmark
4. Danish Veterinary and Agricultural University, Food Technology, Rolighedsvej 30, 1958, Frederiksberg C, Denmark
* To whom correspondence should be adressed.

ABSTRACT

A fully automatic classification equipment called Autofom for use at pig abattoirs has been developed and tested. It measures fat- and lean depth in carcasses by use of ultrasound. Measurement with Autofom is very fast (measuring up to 1250 carcasses per hour), it is non invasive and low maintenance costs can be expected (no moving parts). The repeatability and the reproducibility have been estimated. An equation for calculating lean meat percentage on the basis of Autofom measurements has been calculated. The accuracy of the equation, expressed by residual mean square error (RMSE) and by standard error of prediction (SEP), is 1.84 and 1.95 respectively. A functionality test shows that, when installed on-line at the abattoir, 99 percent of the carcasses can be classified by Autofom. The equipment will be a suitable alternative to automatic on-line determination of lean meat percentage in pig carcasses.*

INTRODUCTION

Different technologies have been used at abattoirs for on-line measurement of lean meat percentage in carcasses. The most common method is measurement of fat- and lean depths by an optical probe, and subsequently calculating the lean meat percentage on the basis of the measurements. Examples of manually used equipment are Fat-o-Meater (FoM), Manual Classification equipment (MC) and Hennessy Grading Probe (HGP), whereas the Classification Centre (CC) is a fully automatic equipment, which measures fat- and lean depth by robot technique (Swatland 1995, Jensen 1991, Commission 1992, Fortin 1984, Hulsegge 1994). Satisfactory results have been achieved by all the types of equipment mentioned.

Measurements with probes are invasive, which may cause damage or potentially introduce contamination, although several experiments have been unable to demonstrate the last mentioned. Therefore, attempts have been made for some years to make use of non invasive methods for measurement of characteristics, which can be used for calculating lean meat percentage in carcasses. Examples of this type of equipment are Computerized Tomography (CT), Nuclear Magnetic Resonance (NMR), Electrical Conductivity and Ultrasound (Baulain 1997, Vangen 1984, Morgan Jones 1995, Allen 1997). Good results have been achieved, but in spite of this fact, such methods are not implemented or only used on a small scale in abattoirs.

Measurements of fat- and lean depth with ultrasound have for many years been used on live animals, and with good results (Busk 1988). However, it is more difficult to achieve corresponding results on carcasses (Liu and Stouffer 1995, Gresham et al. 1992). The reason may be that the measurements on carcasses are normally carried out after singeing. In recent years the company SFK-Technology A/S has developed a fully automatic grading equipment called Autofom, which by use of ultrasound is able to measure the lean meat percentage in carcasses before singeing (Branscheid 1997).

The objectives of this study were to determine the accuracy of the measurements and to develop an equation for calculating lean meat percentage in carcasses on the basis of Autofom measurement, and in addition to this to test Autofom's suitability for on-line measurements at abattoirs.

MATERIAL AND METHODS

AUTOFOM SYSTEM

A short description of the Autofom is hereby stated. More details have been described by Brøndum et al. (1998). Autofom is an automatic classification equipment, which measures fat and muscle depth by means of ultrasound. The scanning device (Figure 1) consists of 16 2.0 MHz transducers embedded in a U-shaped frame and with a distance of 25 mm between each transducer. From each transducer data are sent to the data processing unit via an acquisition module.

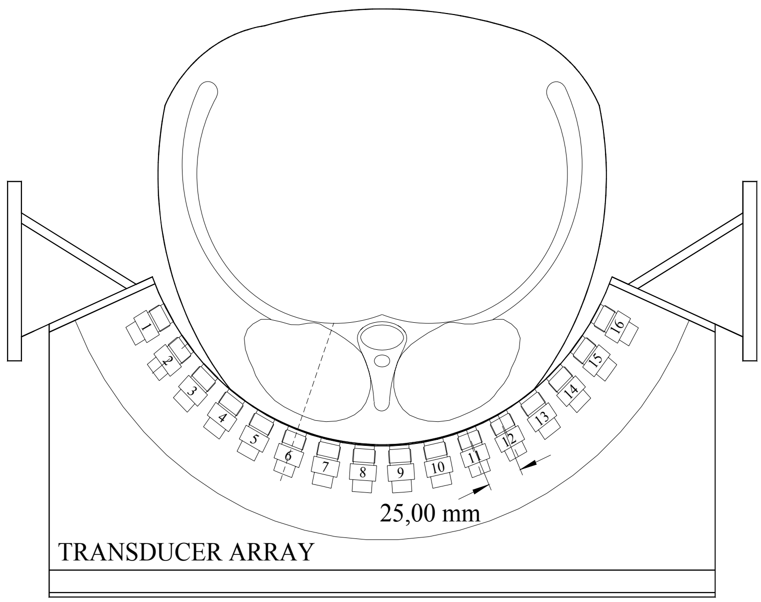

Figure 1. U-shaped frame with transducers

There are no moving parts at the Autofom. The gambrel elevator pulls the carcass over the transducer array, and the weight of the carcass ensures optimal contact with the transducers (Figure 2). The measuring frequency is synchronised with the conveyor speed in order to make a measurement for every 5 mm of the length of the carcass. On a normal carcass this means that for each transducer there are about 200 measuring positions. The result is that for the whole carcass there will be about 16 x 200 = 3200 measuring positions. On the basis of these measurements it is possible to construct a three dimensional image of the body.

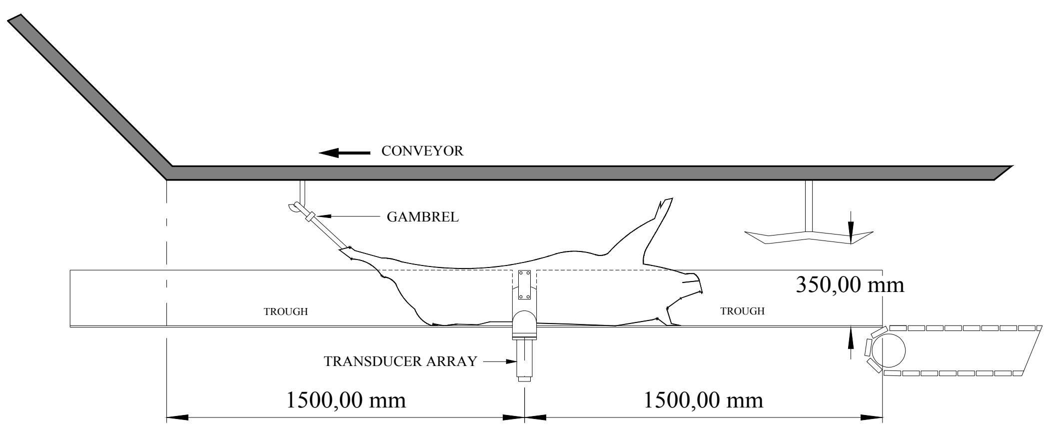

Figure 2. Outline of the measurement system at the abattoir

It is not necessary for the carcass to be positioned in the middle of the transducer array, because the software automatically adjusts the preceding data analysis according to the rotation of the carcass (Brøndum et al. 1998). Up to 1250 carcasses can be measured per hour.

The data analysis in the Autofom can roughly be separated into two steps. Firstly, the orientation of the carcass is determined by detecting the midline. Secondly, the position of the cross section and the longitudinal section in the three dimensional image, where the fat layer is thinnest on the loin, is determined. This thickness is called C. A further three measurements A, B and D are determined with C as a reference. B is the fat depth where the fat layer is thickest in the direction from C towards the hind leg. Having found B and continuing towards the hind leg, A is the position where the fat depth is thinnest. D is the thickness of the loin muscle at the same position on the carcass as C. The basic measurements are shown in Figure 3, which shows a longitudinal scan with the ham to the left, the loin in the middle, and the shoulder to the right of the image. Also note the ribs around the D-point.

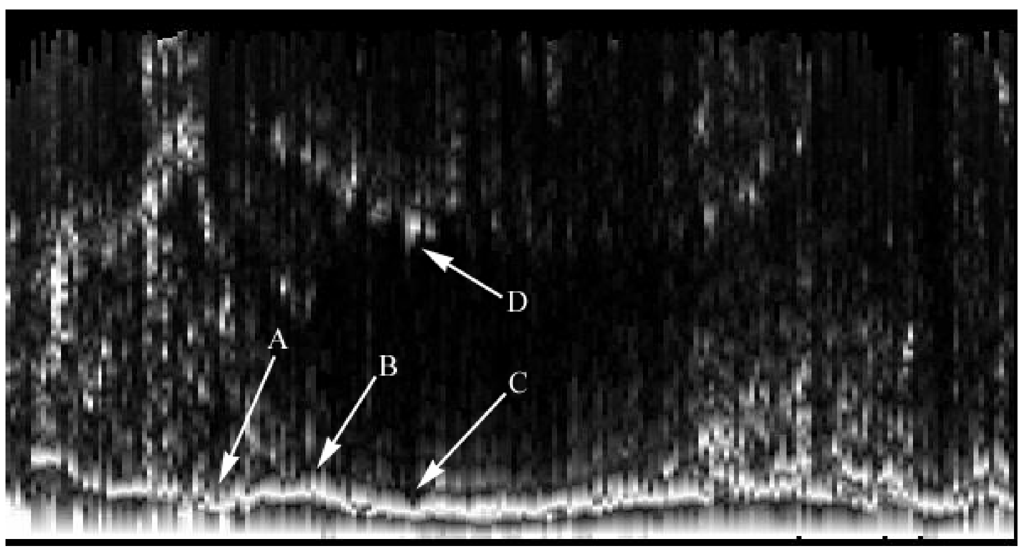

Figure 3. Ultrasound picture with the measurement positions A, B, C and D. The left parts of the picture show the ham and the right parts of the picture show the shoulder.

In total, 127 measurements have been extracted per carcass. These measurements are describing the fat depth close to the A, B and D points, and the fat- and lean depth in an area around the C point.

THE TRIAL SET-UP

Autofom equipments were set up in two separate abattoirs (Autofom-1 and Autofom-2) just after the dehairing machine and before the singeing oven. At this place in the slaughter process the carcass is wet, for which reason it is not, or only in a small degree, necessary to add water to the unopened carcass to ensure a good contact between the carcass and the transducers. The Classification Centre (CC), which is the grading equipment routinely used at the Danish abattoirs for determination of lean meat percentage in carcasses, is on the other hand placed at the end of the slaughter process, just before the carcasses are sent to the cooling room. At abattoir No. 1 the line speed was about 400 pigs per hour, and at abattoir No. 2 it was about 600 pigs per hour. During the trial period all carcasses were measured both with Autofom (Autofom-1 or Autofom-2) and CC (CC-1, CC-2 or CC-3).

The two Autofom used were prototypes. Therefore, some preliminary trials were carried out to test the possibilities of measuring different carcass quality traits with Autofom. Afterwards a dissection trial was conducted in order to calculate equations for determination of lean meat percentage on the basis of different fat- and lean depths measured by Autofom. The trials performed with Autofom have been divided into the following four experiments: 1) Repeatability. 2) Reproducibility. 3) Estimation of prediction formulae. 4) Functionality.

REPEATABILITY

An important feature of any measurement equipment is the repeatability. It has therefore been tested how repeatable measurements with Autofom are. At this stage of the trial, no formula for calculation of lean meat percentage on the basis of fat- and lean depth had been developed. Therefore, the C measure, which is the thinnest fat depth at the loin in the area of the last rib, was used as an expression of the Autofom measurements.

A total of 155 carcasses, 66 at abattoir No. 1 and 89 at abattoir No. 2, were measured twice with as short a time as possible between the measurements. In spite of that, there were a few minutes between the measurements, and the carcasses could have dried out. Therefore, to ensure a good contact between the unopened carcass and the transducers, it was sprayed with water before the second measurement.

Outliers, obviously deviating differences defined by an absolute difference greater than 5 mm, were excluded from the data set. The difference between the two measurements of C on the same carcass is called $C_d = (C_{1st\ measure} - C_{2nd\ measure})$. The repeatability is defined by s_r and is estimated by s/%2, where s is the standard deviation of C_d.

REPRODUCIBILITY

Normally, reproducibility is defined as the closeness of agreement between the results of measurements on an identical test material, where the measurements are carried out under changing conditions. However, it is not possible to estimate the reproducibility of Autofom directly, because it is impossible to get identical carcasses to classify at different locations. As an alternative, the CC equipment was used to make an indirect comparison between the two sets of Autofom equipment. In fact, reproducibility is in this particular situation defined by “trueness” using the CC as the reference. One of the CC’s (CC-2) has been used to calibrate one of the Autofom and afterwards both Autofom were compared to the other two CC equipments (CC-1 and CC-3).

By using a Principal Component Regression analysis PCR (Draper et al.), a formula to predict the CC lean meat percentage by Autofom can be determined. The formula was estimated on data from 4640 carcasses measured by Autofom-2 and CC-2 and the RMSE of the model is 1.6 and the coefficient of determination (R^2) is 61 %.

After implementation of the equation in both sets of Autofom equipment, 2717 carcasses at abattoir No. 1 were measured by Autofom-1 and CC-1, and 3117 carcasses at abattoir No. 2 were measured by Autofom-2 and CC-3. The reproducibility is described by the differences in lean meat percentages between the corresponding Autofom and CC equipments and reported as the average and the standard deviation of the differences.

ESTIMATION OF PREDICTION EQUATION

In this trial the purpose has been to calculate an equation for prediction of lean meat percentage on the basis of measurements from the Autofom, and to determine the ability of the equation to make the calculations. All carcasses at the two abattoirs have been measured both by the Autofom and by the CC. Some carcasses have been selected for the trial according to lean meat percentage measured in the CC, sex and carcass weight as shown in Table 1. At abattoir No. 2, 44 heavy carcasses were supplementarily slaughtered and measured. In total, 344 carcasses were included in the trial, 150 from abattoir No.1 and 194 from abattoir No. 2. The day after slaughter the carcasses were cut and dissected into meat, fat and bone in accordance with the EU-regulation (Walstra 1996).

Table 1. Plan for selecting carcasses at the abattoirs (number of carcasses)

Sex	Lean meat % Classification Centre (CC measurement)	Warm carcass weight, kg < 71.0	71.0-76.9	> 76,9	Supplementary 80.0-110.0
Females	< 59.0	16	15	16	
	59.0-62.4	18	16	19	24
	∃62.5	16	18	16	
Castrates	< 57.0	16	19	15	
	57.0-60.9	18	17	19	20
	∃61.0	16	16	14	

After measuring by Autofom, 127 measured values have been selected for development of the equation for calculating the lean meat percentage. Because the number of x-variables is substantial, inter-correlation can become a problem.

Therefore, the Partial Least Squares Regression method (PLS) has been used for estimation of the prediction equation to calculate percentage of lean meat on the basis of fat- and lean depths measured by Autofom. The PLS method is described by Helland (1990) and Skovgaard (1993), and for calculation the programme package Unscrambler 6.1 (Camo, Norway) has been used.

In order to validate the model for calculation of lean meat percentage a cross validation procedure has been used (Weisberg 1985, Brockhoff et al. 1993). The data set has been divided into K subsets of the same size with m observations each, which are approximately identical regarding allocation on slaughter weight and evenly selected regarding sex and equipment/abattoir. Each of the K subsets have in turn been regarded as a test set, and the other K-1 together as a training set with M=(K-1)m observations. When K=1 then no division in subsets has been done and M is the total number of observations.

When the final choice of model had been made, a prediction formula for each training set was defined, and consequently a "predicted value" $\hat{y}_i$ for each observation. For each training set, indexed by k=1,2,3,..,K, the following formulae have been used:

$$PRESS1_k = \Sigma_{i=1..(K-1)M}(y_i - \hat{y}_i)^2$$

The mean square root prediction error sum of squares of the training set is calculated by

$$MRPRESS1 = (1/K)\ \Sigma_{k=1,2,..,K}\%[(1/M)PRESS1_k]$$

When no division in subsets (K=1), the classic method, multiple linear regression, is traditionally reported by Residual Mean Square Error RMSE, defined by the square root of $PRESS1_k$ corrected by M diminished by the number of parameters. To distinguish from the classic definition of RMSE, MRPRESS1 with K=1 has been substituted by RMSE* (Evidently, RMSE* is less than RMSE).

The prediction ability has been achieved by predicting the observations in the test set after the following formula:

$$PRESS2_k = \Sigma_{i=1..m}(y_i - \hat{y}_i)^2$$

The average square root of the square sum of the prediction error of the test set or the "prediction ability" is calculated by

$$MRPRESS2 = (1/K)\ \Sigma_{k=1,2,..,K}\%[(1/m)PRESS2_k]$$

The data set has been divided into 10 data subsets (K=10), and the Standard Error of Prediction SEP has been defined by MRPRESS2. SEP will be greater than RMSE* and is a more appropiate measure of the prediction ability. In this paper, both RMSE* and SEP are reported.

FUNCTIONALITY TEST

At the time when the estimated equation was implemented, the development of the Autofom equipment had also been completed, and it was ready for a functionality test. The aim of the test has been to investigate whether the equipment was stable in operation. The following items have been tested: 1) The number and time of break downs. 2) Correct match between identification number and measurement. 3) Correct data storage. 4) Number of error measurements. 5) Number of missing measurements. Both sets of Autofom equipment were followed in a test period of one week. A number of 10174 carcasses at abattoir No. 1 and 24056 carcasses at abattoir No. 2 were measured. Furthermore, the lean meat percentage measured both by Autofom and by CC has been compared for all carcasses over a longer period of time.

RESULTS

REPEATABILITY

An acceptable repeatability of the fat depth is a precondition for an acceptable repeatability of a predicted lean meat percentage, but it is difficult to predeterminate any specified requirement with the purpose of securing an acceptable precision at the end. The only way is to use earlier experiences. The CC is able to measure the fat depth with a repeatability standard deviation s_r between 0.8 and 1.5 mm depending on the measuring position of the carcass. The C measure from Autofom can be compared to three of the CC measurements, and the producer expects the same repeatability which means s_r .1 mm.

Some practical problems make it difficult to measure the same carcass twice, and a test of the distribution of the differences between the two measurements has shown some observations, which seem to be outliers. Table 2 shows the difference and standard deviation excluding the “outliers” for the measurement C, and the repeatability standard deviation s_r. Except from the outliers, which can probably be related to trial conditions, the repeatability is the same as for the CC with respect to fat depth. At this stage of development, the Autofom did not have the final validation algorithm, which will probably detect the outliers in the future.

Table 2. *Difference in fat depth between repeated measurements in mm (C_d), standard deviation (s) and repeatability (s_r).*

	Number	C_d	s	s_r
Autofom 1	64[1)]	-0.29 ns	1.56	1.10
Autofom 2	80[2)]	-0.10 ns	1.61	1.14

1) 2 outliers

2) 9 outliers

ns = no significance

REPRODUCIBILITY

The results given in Table 3 indicate that the Autofom devices are rather equal. Before further experiments, the results were used to make a forecast of the precision of the Autofom. The precision (RMSE) of CC is known to be approximately 1.5 percent, and consequently a real calibration of Autofom on the lean meat percentage by dissection is predicted to most likely be fulfilling the requirements given by EU, which means a RMSE lower than 2.5.

Table 3. Prediction of the CC-lean meat percentage by Autofom using a calibration of Autofom-2 on CC-2 (CC = Classification Centre). Differences in lean meat percentage (x) and standard deviation (s)

	Number	x	s
Autofom-1 - CC-1	2717	-0.1	1.5
Autofom–2 - CC-3	3117	0.0	1.8

ESTIMATION OF PREDICTION EQUATION

A total of 344 carcasses were selected for this part of the trial, and they were all measured by Autofom and CC. The day after slaughter, the carcasses were dissected according to the EU-reference method. Results from the dissection are shown in Table 4. The carcasses were selected in accordance with the average lean meat percentage per sex at the Danish abattoirs. There is a difference between females and castrates of 2.3 percent lean meat, which is equal to the average for the whole country. There is a difference between the sexes of about 2 percent for the different parts except for the belly, where the difference is 2.8 percent. No differences in carcass quality have been observed between the abattoirs.

Table 4. Means (x) and standard deviation (s) for percent lean meat determined by EU-dissection

	Females		Castrates		Female + castrate	
	x	s	x	s	x	s
Number	174		170		344	
Carcass weight, kg	76.6	7.80	76.4	8.17	76.5	7.98
Shoulder, %	69.4	2.96	67.3	3.21	68.3	3.26
Belly, %	61.9	4.98	59.1	5.26	60.5	5.29
Loin, %	64.7	4.64	61.2	5.08	63.0	5.18
Leg, %	74.8	3.07	72.8	3.35	73.8	3.36
Carcass, %	60.5	3.26	58.2	3.55	59.4	3.60

An equation for calculating lean meat percentage on the basis of Autofom measure has been developed. In total, 127 Autofom measures are included in the equation. The results from the calculations can be seen in Table 5. The accuracy calculated as RMSE* and SEP for the Autofom are 1.84 and 1.95 and for CC 1.70 and 1.77. For both types of equipment the results can fulfil the demands of grading equipment in EU (RMSE < 2.5).

Table 5. Determination of accuracy for calculating of lean meat percentage.

	RMSE	SEP
No of carcasses	344	344
Autofom	1.84	1.95
Classification Centre (CC)	1.70	1.77

FUNCTIONALITY TEST

At the end of the trial Autofom was tested in a functionality test. In one week all carcasses at the two abattoirs were measured with both Autofom and CC. The main results are shown in Table 6.

Table 6. The functionality test of Autofom – "stability"

	Total number of carcasses	Number of carcasses recorded in Autofom	Percentage not measured with Autofom	Errors. Percentage of recorded carcasses	Correct classificationPercent of total
Autofom 1	10187	10141	1%	1%	99%
Autofom 2	24204	23918	3%	2%	97%

The test period cannot simulate a real situation exactly, because the installation is only a test installation, and consequently most of the errors are in fact problems related to the readings of the identification number - a practical problem outside the control of the equipment. The classification has been observed during the whole test period, and all problems are logged. Therefore, the problems are well known, as well as the way they have been solved. It seems reasonable to assume that more than 99 percent of the carcasses can be classified correctly in a permanent installation.

The correct match between measurements and identification number has been tested on location, and no problems have been observed in the test period. Furthermore, the storage of data has been done correctly.

Most carcasses have been classified by both Autofom equipment and CC, in fact three CC have been used. Because of calibration the results from Autofom and CC, respectively, should be equal, except from some random error caused by the precision of the two sets of equipment. In Table 7 it can be seen that there is no difference between the Autofom and the CC.

Table 7. Comparison between Autofom and Classification Centre (CC). Difference in percent lean meat (x) and standard deviation (s).

	Number	x	s

CC-1 - Autofom 1	9455	-0.1	1.7
CC-2 - Autofom 2	11871	0.0	1.9
CC-3 - Autofom 2	10868	0.1	1.9

Supplementary, the classification by both types of equipments was observed for a longer period. Between 1210 and 2184 carcasses were measured per day in 49 days by Autofom-1 and CC-1. The average predicted lean meat percentage for the two types of equipment has been calculated and normalised with the average over the entire period. The normalised lean meat percentages predicted by both the CC and the Autofom are plotted in Figure 4. The figure shows an exellent accordance between the two types of equipments and demonstrate the stability of the Autofom over a longer period. Further, the figure indicates that the day to day variation represents a carcass variation and not a random variation caused e.g. by either of the equipments.

Summarising, a good relation between the CC and the Autofom has been observed, both in the brief test period and in a longer functionality test running over 49 days. In general, the functionality test has proven the robustness and stability of the Autofom.

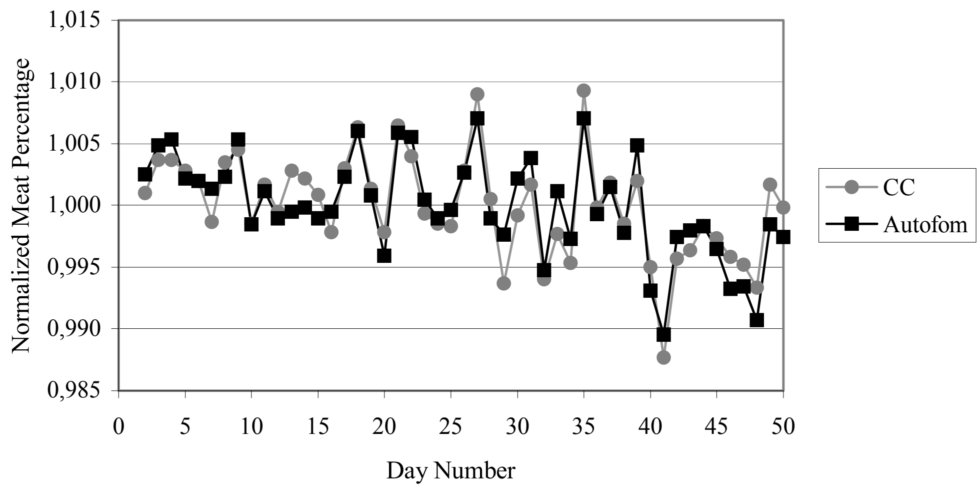

Figure 4. The average predicted lean meat percentage for the Classification Centre (CC) and the Autofom over 49 days. The predictions have been normalized with the average prediction for the entire period

DISCUSSION

When measuring carcass quality on-line at different abattoirs, there will be several possibilities for errors. If the measurements take place at the end of the slaughter process, and with a manual equipment measuring with a probe, the following factors will, among other things, influence the fat depth: time in the singeing oven, cleaning of the hide, and the operator of the grading equipment. The biggest error is the variation between operators. In a Danish trial, 9 operators have been compared. The results showed a residual standard deviation of 0.22 percent caused by the operators only, and thereby a maximum deviation between two operators of 0.62 percent lean meat (95 percent probability level).

Autofom is a fully automatic equipment, and it measures fat- and lean depth at the beginning of the slaughter process. There will therefore be no errors from operators and no effects from differences in the slaughter procedure. However, Autofom measures by ultrasound, and sound velocity in different tissues depends on temperature (Davis 1963, Thwaites 1984). Miles (1987) states that measurements on cattle carcasses must be performed as soon as possible after slaughter and probably within the first hour after stunning. According to Davis (1963) a difference of 5–7°C means about 0.5 mm thicker or thinner fat- and lean depth (about 0.20 mm fat and 0.25 mm muscle depending on the total thickness). An investigation at the Danish abattoirs concerning the place of installation of the Autofom has shown a variation in the temperature at the surface of the carcass of 9°C. The temperature just below the skin shows less variation. It can therefore be concluded that variation between the Danish abattoirs has very little effect on the Autofom measurements.

Compared to other known grading systems the Autofom seems to have some obvious advantages. It is fast (up to 1250 carcasses per hour), non invasive and there are no moving parts of the equipment (low costs of maintenance). Because the measurements are done very early in the slaughter process, there should be some possibility in the future to make use of the results in the automation of slaughter processes.

CONCLUSION

The Autofom classification system has been tested for on-line measurement of lean meat percentage at pig abattoirs. The results show an acceptable repeatability and reproducibility, and the EU demand for calculation of lean meat percentage can easily be fulfilled (RMSE < 2.5). In a functionality test it has been shown that about 99 percent of the carcasses are measured correctly and a high degree of correspondence with the Danish Classification Center has been observed. Further development of the equipment can give the possibility of using some of the results in automating the slaughter process. The equipment will be very suitable for on-line determination of lean meat percentage in pig carcasses.

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