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New techniques in pig carcass evaluation

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CONTENTS

General Introduction

In recent years there have been many developments in techniques for measuring body composition in pigs. These are of great interest for a range of objectives such as grading commercial carcasses for payment; measuring body composition in live pigs as a basis for genetic selection and measurement of body composition in live and dead pigs for experimental purposes such as breed comparisons, nutritional studies or growth physiology studies. The increased consumer awareness of the importance of lower fat diets has added to the emphasis on the accurate assessment of lean in live and dead pigs. These reasons influenced the EAAP Pig Commission to select "New Techniques's in Pig Carcass Evaluation" as the topic for its Special Symposium organised in conjunction with the VI World Congress on Animal Production at Helsinki, Finland in 1988. The Organisers hoped to assemble specialists with detailed knowledge of the operation of the newer techniques and methods used in the automatic carcass grading systems which are now in operation in a number of countries. They also desired to have the techniques used in live carcass assessment discussed and to look ahead at future developments which may become operational in the next decade. The papers presented at the Seminar are reproduced in this volume and they should form a summary of developments in the field together with an outline of agreed operational systems in the European Community as well as in the wider European and the Canadian scenes.

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President, EAAP Commission on Pig Production

BREED INFLUENCES ON THE VALIDITY OF GRADING RESULTS AND THE EFFECT OF DIFFERENT SYSTEMS ON MEAT QUALITY

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Key words: Pork, instrumental grading, breed influences, meat quality, selection of carcase traits

Summary

The breed bias in estimates of lean percentage and the influences of different grading systems on meat quality had been described for a genetically defined material. 393 carcases (full dissected) of the breeds German Landrace (DL), crossbreeds PietrainxDL (PIxDL) and hybrids BHZP had been tested. The study is based on carcase measurements under experimental conditions and on the gradings of the classification methods approved in West Germany (Fat-o-Meat'er - FOM, SKG II, two-point-method - ZP). From the results the following conclusions can be deduced:

o The breed bias appears even when using the more suitable trait combination (FOM). It is minimized by combining the traits used by FOM with the ham width or by omitting loin fat measurements. The latter trait seems to be especially critical with respect to breed bias.

o Generally, little influence of the grading systems on meat quality parameters seems to exist. Therefore, from objective grading powerfull incentives to meat quality are not to be expected. The only exception is the ham angle which seems to be more critical with regard to meat quality.

1. Introduction

In the Federal Republic of Germany, two grading devices (Fat-o-Meat'er, SKG II) and a simple method (two-point-method ZP) are officially approved. They differ in their technique of measurement and in the carcase traits used for estimation of lean meat content. The Fat-o-Meat'er (FOM) measures at two points in the loin-back region beside the midline two fat depths and the muscle thickness (fig. 1b - S2,S3,F).The SKG II measures the width of ham (fig. 1a - D), the width of loin (E), the ham angle (WK) and the fat thickness over the M.glutaeus med. (fig. 1c - LSP1). The ZP uses the same fat thickness and, in addition the thickness of the loin muscle (fig. 1c - LM).

Previous to the adoption of the objectiv grading in the Fed. Rep. of Germany it has been shown that different classification methods may give different classification results when grading the same group of carcases. There is some evidence, that the different carcase traits used for esti-

Shape traits:

a) angle of ham (WK), width of ham (D), width of loin (E)

Measurements beside the midline:

b) loin fat thickness S2 (3./4. loin vertebra), back fat thickness S3 and muscle thickness F (3./4. last rib)

c) measurements in the split line: loin fat thickness over M.glut.med.(LSP1), loin muscle depth (LM)

d) length of carcase (Os pubis - atlas - KL)

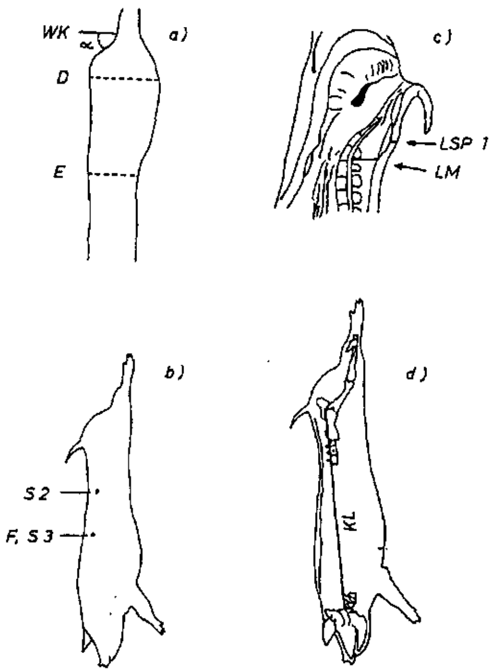

Fig. 1.The localization of the carcase traits used in this study.

mation of lean meat content are the cause of these differences (Branscheid et al, 1986). Such differences in the grading level are of great importance for the transparency of the market, as grading results are the base for the official price reportings. For this reason the German authorities decided to standardize the grading system with respect to the carcase traits used for calculation of the lean percentage. In preparation of this standardization the present study has been undertaken with the following objectives:

- to study the influence of the breed on the estimation results and the precision of estimation realized by different methods;

- to find out the correlation between grading and meat quality parameters.

2. Material and methods

In this study, a total of 393 carcases has been tested which has been from the breeds German Landrace (DL), crossbreed PietrainxDL and hybrids BHZP. The carcases were derived from 4 different regions of West Germany and should nearly represent the spectrum of the German market. In order to keep the costs of the study within reasonable limits it seemed necessary to use a sample which was stratified according to several factors and not to use a random sample. The following strata were taken into consideration:

- 4 slaughter houses (regions)
- 3 breeds (DL, PIxDL, BHZP)
- 5 carcase weight groups (65-70, 70-80 .... 100-110 kg)
- 2 sexes (gilts, castrates)

With exception of the slaughter houses, each stratum was represented with nearly the same sample size (table 1). All carcases were graded with

Table 1. Number of carcases in the various strata (n = 393).

Breed		DL				BHZP		PietrainxDL			
"Region"		Han	Cob	Pfa	Tha	Han	Tha	Han	Cob	Pfa	Tha
Weight group	n										
65 < 70	78	5	5	6	8	16	12	5	4	9	8
70 < 80	84	4	8	6	12	16	12	4	7	7	8
80 < 90	77	4	6	6	8	16	13	3	7	6	8
90 < 100	80	4	7	4	13	16	11	3	7	6	9
100 < 110	74	5	-	15	3	15	12	8	2	6	8
Breed		129				139		125			
Castrates: 194						Gilts: 199					
Hannover: 124		Coburg: 53		Pfarrkirchen: 71				Thalfang: 145			

the three approved systems within 45 min after slaughter. At the same time measurements were taken for the same carcase traits measured by the apparatuses (fig.1) using "experimental methods". These methods should give optimal and more accurate measurements. The experimental methods are:

- caliper rule: loin fat, loin muscle, width of ham and loin
- SKG II: ham angle (the same as in the apparatus)
- Ultrasonic Scanner SSD 256 (Hellige, Freiburg, W.Germany): fat depths and muscle thickness beside the midline.

Additionally, the measurement of the carcase length (Os pubis - atlas) is shown in fig.1. With respect to meat quality, pH_1 is described here only. It has been measured at 45 min p.m. in the M.long.dorsi (3./4. last rib) with the pH-meter pH 191 (WTW, Weilheim, W.Germany). All carcases were dissected according to the EC-reference method ("Kulmbach method", Scheper & Scholz, 1985), which were followed by the full dissection separating the carcases into the tissue compartments (muscle, fat, bone, tendon, rind). From the tissue proportions the actual lean meat content has been determined. This is the reference value (dependent variable) in the following analysis. The evaluation of the estimates of the different methods has been done on the basis of the following statistical parameters:

$y - \hat{y}$ deviation of predicted ($\hat{y}$) from actual (y) lean meat content (prediction error of single carcase; the negative sign signifies an overestimation (and vice versa); the mean of the deviation gives the bias of a stratum or overall

R correlation between y and $\hat{y}$

s standard deviation around the regression line

(The EEC Commission Reg.No 2967/85 gives as a limit of correlation $R \geq .80$ and of standard deviation $s \leq 2.5$)

For the criterion of meat quality (pH_1) only correlations has been determined.
Significant effects are signed by asterisk (*p > 0.05 **p > 0.01).

3. Results and discussion

3.1 Description of the sample

Primarily, the following question is of crucial importance wether the strata differ markedly in the mean lean percentage. The table 2 demonstrates that not only the breed but also carcase weight and sex have a significant effect on lean percentage.

Table 2. Actual lean meat content (%) in the strata (n = 393).

Breed		DL				BHZP		Pietrain x DL				
Region		Han	Cob	Pfa	Tha	Han	Tha	Han	Cob	Pfa	Tha	Weight
Weight	Sex											group
65< 70	1	56,6	62,6	56,4	53,7	52,6	54,5	55,2	57,5	58,5	54,0	57,1
	2	59,7	62,5	61,4	55,9	56,2	58,4	59,2	54,6	59,8	61,0	
70< 80	1	51,2	54,1	51,5	49,8	54,9	52,4	52,7	60,7	55,9	56,9	55,6
	2	58,5	58,8	58,3	55,8	57,2	54,1	57,9	61,0	57,1	59,7	
80< 90	1	51,3	50,2	54,3	51,6	51,4	52,7	51,1	57,1	53,1	54,1	55,0
	2	60,6	55,0	54,2	53,8	55,5	57,2	57,9	62,0	57,6	62,7	
90<100	1	48,5	48,8	50,2	49,9	50,6	50,4	51,9	56,9	52,3	51,6	53,5
	2	58,8	58,7	57,3	52,8	55,7	53,2	54,1	60,3	56,2	58,3	
100<110	1	46,2	-	52,4	51,0	48,3	48,3	52,2	54,8	51,4	54,1	53,2
	2	57,4	-	56,4	52,7	52,8	53,5	55,6	59,2	58,9	58,3	
Breed		54,5				53,5		57,0				54,9

Castrates (1): 52,8 Gilts (2): 57,0

Hannover: 54,0 Coburg: 57,3
Pfarrkirchen: 55,7 Thalfang: 54,4

Significant effects: breed (**), sex (**), weight (**), breed x region (**), breed x region x sex (*)

Furthermore, there are significant interactions between breed x region and breed x region x sex. This shows clearly that we have to take into account some local breed particularities.

The given effect of weight and sex should not have a lot of negative effects on a fair grading under the actual fattening conditions of the German pig production. But the influence of the breeds seems to be more critical. Especially the regional concentration of some breeds (PIxDL in the south, BHZP in the north-west of Germany) may lead to some disturbance of the transparency of the market. Therefore we focused the following evaluation particularly on the comparison between the breeds.

With respect to the morphological data (table 3) differences between the breeds are expressed nearly in a comparable manner to lean percentage. As it is to be expected the more meaty animals are the PIxDL, the less meaty are the BHZP. But not all of the traits are showing a behaviour strictly corresponding to the lean percentage of the carcase.

Table 3. Morphological parameters and the carcase traits used for grading - means and standard deviations (n = 393).

Traits		Breeds							
		total		BHZP		DL		PixDL	
		$\bar{x}$		$\bar{x}$		$\bar{x}$		$\bar{x}$	
Lean perc.	%	54,9	4,61	53,5	4,10	54,4	4,74	57,0	4,31
Lean of ham	%	69,1	4,23	68,2	3,74	68,0	4,31	71,2	3,91
Lean of belly	%	50,8	6,02	49,4	5,60	50,9	6,55	52,1	5,63
Carcase lenght(KL)	cm	97,9	5,89	97,6	5,76	100,6	5,13	95,5	5,67
Loin width	cm	13,1	1,01	13,1	0,93	13,0	1,09	13,1	1,02
Ham width	cm	19,9	1,29	19,3	0,95	19,8	1,23	20,6	1,34
Ham angle	°	42,1	5,33	45,1	4,23	40,9	5,52	39,8	4,64
Loin fat (LSP1)	mm	16,6	5,15	17,3	5,09	16,8	5,07	15,5	5,16
Loin muscle (LM)	mm	71,8	6,81	69,8	6,60	72,6	6,93	73,3	6,42
Loin fat (S2)	mm	21,4	5,75	21,9	5,40	22,6	6,28	19,7	5,12
Back fat (S3)	mm	17,8	5,24	19,0	5,26	18,0	5,22	16,3	4,85
Loin muscle (F)	mm	58,8	6,55	56,7	5,73	57,7	6,34	62,4	6,16

This is namely the case for the width of loin, where are little differences between breeds, and for carcase length, lean of ham and the loin fat thickness (S2). The last point is the most important in the context here, because it may have an influence on the problem of prediction of lean percentage. In fact, at the location (S2) the BHZP have a lower fat depth than the DL, which have the thickest of all three breeds. This aspect will be discussed later on.

3.2 Correlations of the single carcase traits

The correlations of the single carcase traits to the lean percentage of the carcase are shown in table 4. The original measurements of the grading devices and the measurements under experimental conditions are specified. The correlation between lean meat content and fat depths is much higher than the correlation between muscle or shape traits and lean meat as is well known from the literature (Sack et al., 1981; Pedersen &

Table 4. Correlations of the single carcase traits to lean meat content - experimental measurements and measurements of the classification apparatuses (n = 393).

Carcase traits	r		
	experimental	classif.apparatus	
Loin width	- 0,534	- 0,338	SKG II
Ham width	0,199	0,187	"
Ham angle	- 0,348	- 0,348	"
Loin fat (LSP1)	- 0,747	- 0,724	"
Loin muscle (LM)	0,252	-	
Loin fat (S2)	- 0,812	- 0,781	FOM
Back fat (S3)	- 0,829	- 0,815	"
Loin muscle (F)	0,455	0,423	"

Busk, 1982; Sack, 1983:; Küchenmeister & Ender, 1984; Scheper et al., 1984; Kempster & Monk, 1986). The higher suitability of the measurements beside the midline confirms the results of former studies, too (Sack et al., 1981; Scheper et al., 1984; Branscheid et al., 1987a). However, the relation of ham and loin width with each other is to be stressed: in a previous study (Branscheid et al., 1987a) a stronger correlation of the ham width than of the loin width has been found. That is not the case in the study presented here. This seems to be attributed to the extremely wide range of carcase weights in this data set. Introducing a correction with respect to the weight (partial correlation with constant weight) the coefficient of the ham width goes up numerically to r -.57 and that of the loin width drops to r -.45. Apart from the correlation to the actual lean percentage of the carcase, the correlations of the single traits to each other are of fundamental interest. The lower these correlations are the higher the probability that one gets additional information if the traits are combined in a estimation formula (Branscheid et al., 1987b). As it would be expected, all fat depth are highly correlated with each other, but the correlations between these and nearly all other traits are considerably lower (table 5).

Table 5. Mutual correlations of the single carcase traits - experimental measurements (n = 393).

Carcase traits	r							
	carcase traits							
	1	2	3	4	5	6	7	8
1. Loin width	1	.476	-.099	.654	.363	.665	.668	.255
2. Ham width		1	-.562	.116	.649	.079	.073	.674
3. Ham angle			1	.162	-.434	.110	.163	-.490
4. Loin fat (LSP1)				1	.051	.808	.822	-.094
5. Loin muscle (LM)					1	.064	.045	.677
6. Loin fat (S2)						1	.893	-.167
7. Back fat (S3)							1	-.196
8. Loin muscle (F)								1

Therefore, this two groups of traits principally meet good conditions for being combined in a estimation formula. But the case of the loin width seems to be a little bit different. This trait has a relatively high correlation to the three fat depths coming to roughly r .65. Probably, this is in part an effect of the wide weight range of the material, too.

3.3 Precision of estimates in different breeds

The most important analyses of this section were made using the experimental data only. This protected us against influences from shortcomings of the grading devices. Such shortcomings are visible namely in the case of the loin width, but a certain drop in correlation generally appears (table 4). The results of the estimations are shown in table 6. The following conclusion may be drawn:

o Looking at the experimental data (table 6 upper half) the traits combined in the FOM are giving the more reliable estimates (R, s). The bias within breeds is relatively low, the range of bias between breeds reaches a moderate level.

Table 6. Precision of estimation of the fitted and the officially approved formulae (n = 393).

Formula	Parameter	Total	Bias within breeds DL	BHZP	PIxDL	Range of breed bias*
ZP exp.	R	0.80				
	s	2.76				
	bias	-	-.54	-.71	.93	1.64
FOM exp.	R	0.90				
	s	2.04				
	bias	-	.25	-.30	.20	.55
SKG II exp.	R	0.84				
	s	2.50				
	bias	-	-.47	-.06	.17	.64
SKG II exp.+weight	R	0.84				
	s	2.49				
	bias		-.40	-.02	.10	.50
ZP offic.	R	0.80				
	s	2.79				
	bias	-0.50	-1.00	-1.32	.32	1.64
FOM offic.	R	0.88				
	s	2.17				
	bias	0.72	1.17	.29	.73	.88
SKG II offic.	R	0.77				
	s	2.98				
	bias	-1.47	-1.67	-1.65	-1.35	.32

* max.bias + [min.bias x (-1)]

o The combination of carcase traits used by SKG II gives estimates of lower precision which meet hardly the EC-requirements of admission, but the range of bias reaches a little lower level than the FOM.

o The combination of ZP seems to be unsatisfactory in precision and in respect to breed bias.

o Looking at the officially approved formulae applied to the original measurement data of the apparatuses (table 6, below) the results are of more practical relevancy.

o Under these conditions only the FOM gives satisfactory estimates, which are comparable to the results under experimental conditions only being the bias somewhat higher.

o In all cases inevitably a certain breed bias occurs and can not be eliminated even by taking the carcase weight into consideration (shown for SKG II only, which gave the best results with respect to this).

In summary it may be deduced that prediction functions which are calculated omitting the traits beside the midline are suffering a considerable loss of information. However, functions calculated exclusively out of traits beside the midline have a range of breed bias which may lead to unfavorable consequences for the single producer as well as the pig market of a region in the whole. Therefore, in the following section shall be tested if it is possible to diminish the range of bias by combining traits beside the midline with traits in the loin area of the split line or with shape (type) traits within the same formula.

3.4 The effect of new combinations of traits on the range of breed bias

Table 7 shows the most important examples out of a lot of combinations tested. With respect to the precision of prediction (R, s) really none has essential advantages over the other combination and especially over these which use traits beside the midline, exclusively. But with respect to the breed bias we can make the following remarks:

o The range of bias drops considerably if the function is made from (S3, F) instead from the conventional FOM-combination (S3, F, S2). The very limited change in precision of estimation seems to be tolerable.

o The range of bias drops even more if these two traits (S3, F) are combined with weight or ham width or that two together.

o The combination of (S3, F) with loin fat (LSP1) gives results similar to the conventional FOM-combination (relatively high range of bias).

The analyses of this section lead to the conclusion that the breed bias may be minimized in two ways: by using exclusively measurements beside the midline in the region of the last ribs omitting fat depths of the loin region or by combining the measurements in the region of the last ribs with the ham width and the carcase weight. Especially the fat depths in the loin region seems to have a tendency to increase biased estimates. It seems very probable that this reflects in part the paradoxical behaviour of the loin fat (S2) described earlier (3.1). In re-

Table 7. Precision of prediction with functions using new carcase trait combinations - experimental measurement (n = 393).

Carcase traits combined*	Parameter	Total	Bias within breeds DL	BHZP	PIxDL	Range of bias **
S3, F	R	0.88				
	s	2.18				
	bias	-	-.03	-.07	.23	.35
S3, F, weight	R	0.88				
	s	2.17				
	bias	-	.00	-.04	.25	.29
S3, F, S2	R	0.90				
	s	2.04				
	bias	-	.25	-.30	.20	.55
S3, F, D	R	0.88				
	s	2.15				
	bias	-	-.04	.02	.16	.20
S3, F, S2, D, weight	R	0.90				
	s	2.00				
	bias	-	.29	-.12	-.03	.41
S3,F, D, weight	R	0.89				
	s	2.11				
	bias	-	.05	.13	.00	.08
S3, F, LSP1	R	0.89				
	s	2,06				
	bias	-	-.03	-.24	.25	.49

* for abbreviations see fig. 1
** max. bias + [(min bias x (-1)]

gard to the minimizing of the bias, the best of the ways stressed here should be in fact the technically simplier, because the difference between the two possibilities is very low (0.2 % difference in the range of breed bias). Therefore, the option with (S3, F) or any other version which uses traits beside the midline in the region of the last ribs should have some advantages. The option with the additional use of ham width is relatively time consuming and technically more complicated.

3.5 Calculation of estimation functions on basis of the extreme breeds

In a former study (Branscheid et al., 1987b) we stated that calculation of estimation functions on basis of a partial material instead of the overall data set did not essentially affect the precision of estimations (R, s) but led to a considerably higher bias in some breeds. On this data set two further formula with the simple trait combination (S3, F) had been calculated, the first on basis of the PIxDL exclusively and the second on basis of the BHZP. The results given in table 8 show clearly that on these data, too, the change of the basis of function calculation doesn't affect the precision of estimation (R, s).

Table 8. Prediction results of estimation functions calculated on basis of the breeds PIxDL and BHZP - experimental measurements (n = 393).

Formula	Parameter	Breeds DL	BHZP	PIxDL
S3, F - PIxDL	R	0,887	0,875	0,842
	s	2,26	1,99	2,34
	bias	-0,62	-0,66	0
S3, F - BHZP	R	0,888	0,875	0,841
	s	2,24	2,00	2,33
	bias	0,02	0	0,58

But as in the earlier study, the bias is changing. The PIxDL-formula causes an overestimation in the two other breeds of practically the same level, the BHZP-formula causes an underestimation in the PIxDL, but an exact estimation in the DL. From this results it becomes impressively clear that for judging estimation formulae the bias has to be respected as an obligatory criterion. The fact that the bias doesn't count as a test parameter in the EC Regulation is hardly understandable under this point of view. A second conclusion can be drawn that especially the crossbreeding with Pietrain seems to change not only the body shape but also the distribution of the tissues in such a manner that the estimation of lean percentage is affected. Finally these results demonstrate clearly that breed bias exists inevitably even when fitting the formula to single breeds. Only the use of breed specific formulae would be able to resolve that problem.

3.6 Correlations between grading results and meat quality

Between fleshiness and meat quality exists a well known antagonistic relation. For this reason it is evident that each type of grading according to lean percentage may have an adverse effect to meat quality parameters. However, not all aspects of fleshiness contribute to the same extent to this antagonistic correlation. Especially the preference given to the ham type seems to be the main cause for more frequent occuring PSE problems in the Federal Republic of Germany (Glodek, 1980). In accordance to this, in a former study (Fewson et al., 1987) the stronger correlations to meat quality parameters had been found in grading systems which are using type traits (SKG II). These correlations reached moderate levels (near r .60), but the correlations of the other methods has been only a litte weaker. However, the trait which showed the strongest single correlation of all has been the ham angle. Taking as an example the pH_1 (table 9) the results of this study show exactly the same tendencies but the correlations reach generally a low level, only.

Exclusively the ham angle has a somewhat higher overall correlation to pH_1 (r .43) which is confirmed especially in the BHZP. All other single carcase traits and the estimation results of the classification apparatuses as well as the actual lean meat content of the carcase, the ham and the belly have correlations to pH_1 in an order which shouldn't have practical significance. From the shape characterizing traits only is of additional interest that the carcase length (which is not used for grading) seems to be important especially for the BHZP. Generally, from the results of the BHZP shown here it is to suppose that in this breed a certain heterogeneity exists which is the cause of the relatively high correlations of this breed.

Table 9. Correlations (r) between pH_1 and carcase traits and estimated lean percentage as well.

Carcase traits /estimation formulae	Breeds			
	total	DL	PIxDL	BHZP
	n=393	n=129	n=125	n=139
Lean meat cont.carcase	-.33	-.27	-.15	-.28
Lean of ham	-.29	-.24	-.13	-.26
Lean of belly	-.29	-.23	-.19	-.29
Carc.length (Os p.- atlas)	.27	.27	.29	.39
Ham angle	.43	.27	.12	.38
Ham width	-.26	-.18	.04	-.12
Loin width	.10	.12	.13	.03
FOM offic.	-.27	-.24	-.01	-.25
SKG II offic.	-.33	-.29	-.13	-.25
S2, S3, F, D, weight	-.32	-.29	-.03	-.26

Finally, a combination of the FOM traits with the ham width and the weight has been tested. The results demonstrate, that in comparison to the FOM combination this version rises only little in correlation to pH_1.

In conclusion, it is to state, that this study shows the problem of antagonistic correlation between grading and meat quality not as marked as former studies. Here, it is demonstrated that the method of grading or the carcase traits used are of minor practical importance with respect to meat quality. Only the ham angle seems to be more critical. This is in good accordance to the fact that the angle gives the strongest correlation (r .72) to the subjective ham type grading.

4. Concluding remarks

From the results of the study the following conclusions can be drawn:

- Breed, sex, weight and (under German conditions) the region have an influence on the average lean percentage of a sample. Therefore, they are to be taken into account if a stratified sampling is provided.

- With respect to the correlations of the single carcase traits to lean percentage of the carcase, the study confirmes the results of former publications. Only for the ham and the loin width a reversal behaviour is shown: the wide range of carcase weight in this study induce a stronger correlation of loin width in comparison to ham width. In summary, the traits beside the midline in the loin back-region are the most suitable for prediction of lean meat content. Omitting these traits from an estimation formula results in a remarkable loss of information.

o Using a structure of the estimation formulae corresponding to that of the officially approved, in all cases, a considerable breed bias appears. This is particularly true if exlusively traits beside the midline are used.

o Two ways of diminishing breed bias in such functions are demonstrated: combining traits beside the midline with ham width or omitting the loin fat depth calculating the function exclusively on basis of a fat and muscle thickness at the region of the last ribs. The latter possibility seems to have some advantages even if it drops a little in precision of estimation (R, s). It is faster to carry out and is technically simplier than a combination of probe measurements with the measurements of shape traits.

o As shown in the context of these caculations, especially the fat depth in the loin region seems to increase the breed bias. In part this reflects possibly the pardoxical behaviour of the loin fat (S2) with respect to breeds with different lean percentage. Contrary to this, the ham width shows a tendency to compensate breed differences.

o In model calculations on basis of the extreme breeds it is demonstrated that calculation of the estimation function on a partial material does not affect the precision of estimates (R, s) in comparison to overall functions. However, problems appear in the changing breed bias. This is one reason why bias has to be considered when estimation functions are judged. Further it becomes obvious from this calculations that the crossbreeding with or without Pietrain is one of the main causes for the breed bias appearing under German conditions.

o Correlations of actual or estimated lean meat content to meat quality seems to be relatively weaker than calculated in former studies. From the results presented here, the method of grading and the traits used are of minor practical importance for meat quality. This confirmes the opinion that meat quality should be influenced directly with the respective measurements (pH, conductivity, reflexion value). From objective grading, powerfull incentives to a better or inferior meat quality are not to be expected.

o This is true with the only exception of the ham angle. This trait has the strongest correlation to the subjective graded ham type and therefore seems to be more critical with regard to meat quality.

o In summary of all these points, theoretically we have to take into consideration the precision of estimation and the correlation to meat quality when choosing a classification system or carcase traits used for grading. As the results of this study demonstrate the most important prerequisite is the use of one or more carcase traits beside the midline within an estimation formula. Beyond that very strong argument doesn't exist for or against the additional use of shape traits for estimating lean percentage. With regard to precision of estimation and to meat quality the combination of traits beside the midline with shape traits has limited advantages on the one hand and little disadvantages on the other hand.

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AUTOMATED GRADING PROBES FOR PIGS CURRENTLY IN USE IN EUROPE, THEIR ACCURACY, COSTS AND EASE OF USE

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Summary

After the visual classification of pigs and the first generation of apparatuses for estimation of the lean meat percentage, a second generation of automated grading probes has been installed or will be installed in various European countries.

The more sophisticated instruments Destron, FOM, HGP2 and SKGII have the highest accuracies, from which FOM and HGP seem to be the best. The accuracy of the somewhat older apparatuses, like KSA and the older Optical Probes is slightly lower. Another category of systems is based on, or derived from the LSQ-system. Such systems have accuracies in the same order or slightly less than the first generation of apparatuses, although there is evidence that the Porkitron would be better than the SKG.

The Commission of the EC has set regulations for approval in the member countries. The residual standard deviation and the R^2 should not be higher than 2.50 % or lower than 0.64 respectively. Some countries allow more than one system to be used; other countries allow only one system. Of the second generation of systems the FOM is approved now in the Federal Republic of Germany, Ireland and the United Kingdom, the HGP in The Netherlands, Ireland and the United Kingdom and the SKG in the Federal Republic of Germany and Belgium. In Denmark there is approval for the KSA.

Sweden is using the HGP for some time.

The simpler instruments are not necessarily easier in use. The degree of automation is important in this respect, but differences in the number of pigs per hour to be probed exist between the systems.

The more sophisticated instruments are the more expensive. An attempt to compare prices is given, but prices also depend on the degree of automation.

Introduction

Classification of pig carcasses by visual assessment is now outdated. The demand of consumers for lean meat led to more emphasis on production of pigs with less fat. A more exact estimation of the lean mass is necessary to justify a more differentiated payment system for the effort of farmers to produce pigs of the desired composition.

The accuracy of estimation of lean meat content by the so-called second generation of automated grading probes is much better than by visual assessment of median backfat class and fleshiness (type). The accuracy, expressed as residual standard deviation, differs by 1 to 1.5 % (De Boer et al., 1979; Scheper et al., 1983). In more and more European countries therefore automated grading probes have been or will be introduced.

Development of grading probes

Classification by means of visual scores was mostly based on fat thickness(es) at the dorsal mid-line of the split carcass and often also a score for type of the animal was given. The latter was an attempt to estimate the muscularity. Within the former six countries that founded the EEC a uniform system was made, but nevertheless concern grew. People did not believe e.g. the percentage top-class as established in the various countries. Parallel classification sessions with judges from different countries revealed too large differences (Huiskes et al., 1983). Of course differences are inherent in such a system largely based on visual assessment.

Furthermore it became clear that lean meat percentage was predicted worse by fat thickness at the dorsal mid-line than by fat thickness taken 5-8 cm from the mid-line (De Boer et al., 1979; Pedersen & Busk, 1982; Diestre & Kempster, 1985; Kückenmeister & Ender, 1985; Branscheid et al., 1987a). In that light probes could develop that were able by means of needles to measure fat thickness at these positions.

When the United Kingdom, Ireland and Denmark entered into the EEC optical probes (Intrascope, Ulster probe) were in use in the first named countries, while in Denmark the KS-meter had been developed. They are based on measuring side fat thickness, as also was the FDI produced in New Zealand. The KS-meter already measured muscle thickness as well, but had to be read on a scale.

A further finding was that measurement of muscle thickness off the mid-line contributed to the precision of predicting lean meat percentage. Thus a second generation of grading probes was developed: KSA, FOM, HGP and Destron, that could measure fat and muscle thickness at the same time and moreover recorded the data automatically .

A quite distinct way of thinking led to the development of the SKG in the same period. This machine combines a measurement of fat thickness at the mid-line with that of an objective estimate of the shape of the ham, and is therefore favoured in areas where well-shaped animals, like the Pietrain, are produced.

Description of grading probes and systems

Some of the probes mentioned in the preceding section are hardly in use anymore, viz. KS-meter and FDI (Fat Depth Indicator). The former was further developed to the KSA-meter and the latter to HGP. Others of the first generation are still used together with those of the second generation.

In European countries various systems are in use now.

Intrascope

It is produced by SFK Ltd., Hvidovre (Denmark) and it is an optical probe. The source of light at the end of the probe detects the change in light reflectance at the boundary of fat and muscle. Fat depth can be measured from about 5 to 50 mm and is visualized by means of a mirror system on an engraved sliding barrel (marked in mm).

Ulster probe

The Mark II Ulster probe works along the same principle as the Intrascope. It is produced by the Northern Ireland Automation Centre, Queens

University, Belfast. Although it has a resolution of 0.1 mm, fat depth is displayed on the probe to the nearest mm, and it can be measured up to 50 mm. The probe can be connected to computer terminals.

KSA (Kod-Spaek-Automatisk)

It is produced by SFK Ltd., Hvidovre (Denmark). The probe is based on an electric conductivity principle. Ring sensors are situated at the end of the probe and detect the difference of conductivity between different tissues, but also between rib wall and air. It has an operating distance of 5 to 97 mm. The impulses from the KSA-pistol are fed to an electronic unit and a microcomputer calculates the lean meat percentage from the measurement of fat and lean thickness.

HGP (Hennessy Grading Probe)

This probe is produced by Hennessy and Chong, Ltd., Auckland (New Zealand) and is based on an optical principle. The light source near the end of the probe emits light in the green-yellow range; the reflection of light is different for fat and muscle tissue. Muscle depth measured is only that of the m. longissimus, unlike the KSA, where the total thickness including the rib wall was measured. The latter gives more variation and is therefore less precise. The lean meat content is calculated in the pistol itself. The various measurements and the lean meat percentage consecutively appear if required on a display on the probe. There is a measuring distance up to 120 mm. The probe can be connected to printers or computers in a separate room. If required the lean meat percentage may be calculated via a computer in stead of in the pistol itself. Like the FOM, the HGP would indicate by reflection values whether the meat quality is normal or PSE-like. The HGP can also measure marbling (intramuscular fat) within the longissimus muscle.

FOM (Fat-O-Meat'er)

Like the KSA it is also produced by SFK. The measuring principle is the same as with the HGP; the emitted light, however, is in the near infra red. The measuring distance is from 5 to 105 mm. The consecutive measurements can be seen on a display on the probe. The measurements are fed to a terminal consisting of a microprocessor, keyboard and display, and where the lean meat percentage is computed.

SKG (Schlachtkörper-Klassifizierungs-Gerät)

The instrument was developed by Breitsameter (Aichach) and is marketed by Tecpro GmbH, Aichach and München (FRG). The working principle is quite different from FOM and HGP. On the one hand fat depth is measured by a pistol with an electro-mechanical procedure (potentiometer) over m. gluteus medius at the split carcass. The measuring distance is up to 50 mm. On the other hand the shape of the ham is measured (in an objective way). This was first performed by video cameras (SKG I), but is done now in an electro-mechanical and electro-pneumatic way by extending bars (SKG II). The instrument contains an integrated keyboard, the necessary software and an interface for a printer, while the system can be connected with a computer of the abattoir. Also meat quality evaluation based on conductivity would be possible.

LSQ (Lenden-Speck-Quotient)

The procedure was proposed by Pfeiffer & Falkenberg (1972) and is based on measurement of fat depth over the m. gluteus medius (a_1), fat depth at the anterior edge of the m. gluteus medius (a_2) and muscle thickness from the latter point to the dorsal side of the spinal column (b); all measurements at the split surface of the carcass. The quotient

$$\frac{a_1 + a_2}{2b}$$

is used as the estimate for the lean meat content. It can be further developed to a measuring design and be used in connection with a simple calculator.

SFQ (Speck-Fleisch-Quotient)

The quotient is that between fat depth a_1 and muscle depth when proceeding from a_1 to the spinal column. By means of a mechanical sliding design produced by the Researchcentre Dummerstorf-Rostock (GDR) it is called QMS (Quotient Messschieber) and the quotient can be read. It is further developed as EQM1, an electronic version which can be connected to calculators.

ZP (Zwei-Punkt)-procedure

It is proposed by the FRG. The lean meat content is calculated from measurements a_1 and b of the LSQ-procedure. Measurements can be carried out simply by a ruler, but also instruments have been produced by Tecpro GmbH and they are being tested for measuring instrumentally by means of a pistol and/or calipers from which the data are fed to a terminal and if required connection with a slaughter house home computer is realized.

Porkitron

The instrument is produced by Zimmermann, Bahlingen a.K. (FRG) and the same measurements as with SKG II are taken, except for the angle between the rounding of the ham and the horizontal. It is much simpler than the SKG and works with sliding calipers. It has a measuring distance of 280 mm and a reproducibility of 0.5 mm. There is a keyboard with display and data are fed to a calculator/printer.

Grading probes in use in Europe

The newer generation of grading probes (FOM, HGP, SKG II) is only used for the past few years in Europe. Sweden was the first country where a grading probe was introduced at a national level, i.c. the HGP. In other countries it started at the same time with other probes in a limited number of abattoirs.

In the countries of the EEC specific regulations have been made. According to EC-Regulation No. 3220/84 classification of pigs has to be based on objective measurements that enable estimation of the lean meat percentage. Before January 1st 1989 the new system has to be applied in all member countries. The lean meat percentage is calculated after dissection of the carcass according to the EC-Reference method, which means complete separation of the muscles, including those of the head, as far as possible by knife. Allowance is given to dissect according to a national or institute's standard method if the relation between this standard method and the EC-Reference method is known.

The classification scheme is as follows:

lean meat %	class
≥ 55	E
50-54	U
45-49	R
40-44	O
< 40	P

If required class S (≥ 60 %) may be used.

Table 1. The use of grading probes in European countries*.

Country	Approved by EC-Commission	Used exclusively as a national system	Used extensively	Used in some abattoirs
Finland		HGP	HGP	
Sweden		HGP	HGP	
Denmark	KSA	KSA	KSA	
Great Britain	Intrascope		Intrascope	
	FOM			FOM
	HGP			
Northern Ireland	Intrascope			Intrascope
	Ulster probe	(Ulster probe)**	Ulster probe	
Rep. of Ireland	Intrascope			Intrascope
	FOM			FOM
	HGP			HGP
The Netherlands	HGP	HGP	HGP	
Belgium	SKG	SKG		SKG
France			FOM	
FRG	FOM		FOM	
	SKG		SKG	
	ZP		Porkitron	ZP
Austria		(LSQ)	LSQ	FOM
GDR		(QMS)	QMS	
				EQM1

* According to the producer, SKG is also used in Czechoslowakia, Hungary and the USSR.

**Between brackets means: almost exclusively used as a national system.

The conditions for estimation of the lean meat % are described in a further EC-Regulation (No. 2967/85). The estimate has to be based on a representative sample of at least 120 animals of the pig population in a country or in a certain area of a country. And a grading probe will be approved by the EC-Commission for application if the residual standard deviation (RSD) is lower than 2.50 % and the coefficient of determination (R^2) is more than 0.64. Some EC-countries asked and obtained approval for more than one probe; others only for one.

The usage of probes in various European countries is given in Table 1. In the table the extent to which a probe is used in a particular country is shown as well.

Experiments are going on in Spain, Italy, Norway and Switzerland. In these countries, and also in Greece and Luxemburg, decisions for use of one or more grading probes may be expected soon.

The accuracy of grading probes

In literature little is written about comparisons between probes in precision, expressed as the relationship between repeated measurements.

FOM and HGP were compared by Fortin et al. (1984a). Repeated measurements were carried out for fat and muscle depths 5 cm off the dorsal mid-line at the last rib (LR) as well as between the 3rd and 4th from last rib (3/4 LR). Precision varied depending on probing location. In the cases when differences were detected, the higher precision was found with the FOM, but the differences were small.

Casteels et al. (1984) looked at reproducibility: 2 operators carried out the same series of measurements with the SKG II reaching a correlation coefficient in lean meat % of 0.99. Sack and Bach (1984) found repeatabilities of 0.94 to 0.97 with a ruler for LSQ fat depth and of 0.85 for the muscle depth. The correlation coefficients between two operators were 0.92 and 0.83 for fat and muscle depth measurements respectively. Repeatabilities and reproducibilities reported by Walstra (1987) lay between 0.95 and 0.99 for fat depths at various sites and measured by 4 operators. Dependent on operator the figures were sometimes 0.10 to 0.20 lower. More variation was found for muscle depth measurements: the majority lay between 0.65 and 0.80, and sometimes 0.20 lower or 0.10 higher again dependent on operator. In the vast majority of these measurements there were no differences between FOM and HGP; in some cases FOM was better and in some cases HGP was better.

Accuracy may also be expressed as bias by comparing the mean probe measurement with the result of assessment of the lean mass by dissection. When the prediction formulae are determined by linear regression (least squares) the sample bias will always be zero. However, for another batch of animals the bias of formulae already established may be non-zero.

The accuracy of estimates of the lean meat % based on various measurements on the carcass is usually expressed as the residual standard deviation (RSD). The accuracy of probes approved by the EC-Commission is given in Table 2. In this table also the measurements on the carcasses that are included in the various regression formulae are given. These parameters are:

x_1 = cold carcass weight

x_2 = fat thickness between 3rd and 4th lumbar vertebra, 8 cm from the mid-line (3/4 LV)

x_3 = fat thickness 3/4 LR, 6 cm (or 6 to 8 cm in FRG) from the mid-line

$x_4 = (\frac{x_1 + x_2}{2})^2$

x_5 = fat thickness LR, 6 cm from the mid-line

x_6 = muscle thickness 3/4 LR

x_7 = fat thickness over m. gluteus medius, thinnest place at the mid-line

x_8 = thickest width of ham

x_9 = thinnest width of waist

$x_{10} = x_8/x_9$

x_{11} = angle of the rounding of the ham against the horizontal

x_{12} = muscle thickness from anterior edge of m. gluteus medius to dorsal side of the spinal column

$x_{13} = x_7/x_{12}$
$x_{14} = \sqrt{x_{12}}$
$x_{15} = \log x_7$
$x_{16} = \sqrt{x_7}$
$x_{17} = x_3^2$

Table 2. Accuracy, expressed as residual standard deviation (RSD) and R^2, of different probes approved by the EEC in various countries*. The measurements on which the estimates are based are given as well (for explanation see text).

Country	Probe	RSD	R^2	Measurement parameter
Fed. Rep. Germany	FOM	1.79	0.86	x_2, x_3, x_4, x_6
	SKG II	2.19	0.79	x_7, x_8, x_9, x_{10}, x_{11}
	ZP	2.45	0.74	x_{13}, x_{14}, x_{15}, x_{16}
The Netherlands	HGP2	2.19	0.75	x_3, x_6
Denmark	KSA	1.85	0.73	x_1, x_2, x_3, x_6, x_7
Rep. Ireland	Intrascope	2.07	0.67	x_3, x_7, x_{17}
	FOM	2.04	0.68	x_3, x_6, x_{17}
	HGP2	2.09	0.66	x_3, x_6, x_{17}
Belgium	SKG II	1.99	0.71	x_7, x_8, x_9, x_{10}, x_{11}
Great Britain	Intrascope	2.44	0.76	x_1, x_5
		2.31	0.78	x_1, x_3, x_5
	FOM	2.23	0.80	x_3, x_5, x_6
		2.18	0.80	x_1, x_3, x_5, x_6
	HGP2	2.37	0.77	x_3, x_5, x_6
		2.37	0.77	x_1, x_3, x_5, x_6
Northern Ireland	Intrascope	1.92	0.70	x_1, x_5
		1.82	0.74	x_1, x_3, x_5
	Ulster probe	2.00	0.68	x_1, x_5
		1.90	0.70	x_1, x_3, x_5

*The data given are from EC-documents

The RSDs between countries may not be compared as such, because of the use of different measurement parameters. Especially the parameters used with the SKG are very different from those with other probes. Measured on the same animals within countries the FOM has a better accuracy than the SKG, while the FOM and HGP are alike in the data of the Irish Republic. Even the Intrascope does not differ from FOM and HGP, but needs an extra fat depth measurement for that. In the UK data, however, the Intrascope cannot match with the FOM, where the muscle depth measurement contributes to this result. These UK data also point at a difference between FOM and HGP in favour of the former.

Except the data given here for approval in the EEC, differences in accuracy (expressed as RSD) are also given by various references. A comparison, however, is only justified when the probe measurements are carried out on the same batch of animals. But even then differences may occur and be interpreted wrongly when an already existing regression formula present in the equipment had been developed on quite different groups of animals. In fact Branscheid et al. (1986) showed that a different (genetic) background of animals resulted in different deviations from the mean lean meat % estimated by already existing formulae. A careful choice of a (representative) sample for developing a regression formula is very important to obtain an equation which is robust enough to estimate the lean mass in other batches.

Nevertheless careful measurements at the same positions on the carcass in different years may lead to a conclusion that FOM has a better accuracy than KSA (Seidler et al., 1984). In a direct comparison Scheper et al. (1983) also found the FOM better than the KSA (RSD: 2.13 vs 2.27 %) and also better than the HGP (RSD: 1.74 vs 2.32 %), but the batches of animals were not the same and in the latter case the formula for HGP was developed on the material itself, while that of the FOM came from another batch.

Differences in favour of FOM over SKG II were reported by Matzke et al. (1986) and Branscheid et al. (1987bc). The latter also found the accuracy of the ZP-procedure worse than that of the SKG II, but again formulas elsewhere developed were applied. The Porkitron would also be better than SKG II (Anon., 1987). Casteels et al. (1984) found that HGP had a better accuracy than SKG II (RSD: 1.95 vs 2.48 %).

Only small differences between Intrascope, Ulster probe, FOM and HGP were found in an Irish experiment (Allen, 1986). According to Kempster et al. (1985) FOM was only slightly better than Intrascope, while HGP scored unfavourably. Furthermore, however, there was some evidence of interaction between probe measurements and abattoirs.

In France FOM reached an RSD of 1.89 % (Desmoulin et al., 1984), but in another experiment the RSD was higher, viz. 2.21 % (Pommeret, 1987). The same RSD was found for HGP in the Swedish test (Hansson & Andersson, 1984). In Italy (Chizzolini et al., 1987) the RSD reached up to 1.97 % with FOM using quadratic terms as in the FRG-formula. The first Spanish results show small differences between FOM, HGP and Destron (Diestre, 1987).

The LSQ had a correlation coefficient with the primal cuts of -0.89 (Pfeiffer and Falkenberg, 1972). Küchenmeister & Ender (1985) still found the highest correlations (-0.77) with LSQ in comparison to other combinations, although SFQ also reached -0.76. Introduction of quadratic terms hardly improved the correlations.

Outside Europe probes were also compared. Intrascope and FDI did not differ, but KSA was less accurate (Giles, 1983). There were differences between operators. Fortin et al. (1984b) compared FOM and HGP at various positions. At most positions for fat depth as well as fat + muscle depth HGP predicted lean mass slightly, but insignificantly, better than FOM. Destron and HGP did not differ (Usborne et al., 1987); they both reached the low RSD values of 1.71 % in Canada.

From this overview it may be concluded that the accuracy of the Intrascope and the Ulster probe is only slightly less than that of FOM and HGP, and in some cases they match with them. KSA has a lower accuracy than FOM or even lower than Intrascope and SKG II. The LSQ and SFQ do not differ from each other.

In the cases where SKG II is compared with FOM and HGP it has higher RSD values, so is less accurate in this generation of probes. Also the Porkitron would be better than SKG II.

In the comparisons between FOM and HGP listed here the results vary from alike, slightly better or better for the FOM. In one case HGP was slightly better. HGP and Destron did not differ, or a slightly better accuracy was found for HGP.

Conclusions in this matter, however, must be handled with caution for reasons described earlier in this section. A negative result with respect to accuracy does not mean that a particular instrument will not be chosen for grading of pigs in a country or area. Other characteristics may be more decisive. Furthermore an important issue for comparing of accuracies is the sample of animals to be dissected as well as the dissection method itself. Confidence in a new classification system can only be given when realistic data within countries are obtained based on a good reference method.

Costs and ease of use

As pointed at in the preceding section the choice of an instrument need not to be based on the accuracy of the measurement, although this is very important. Other factors like reliability, ease of use, number of repeat measurments, ease to connect to computers, efficiency in operation, durability and costs may be more decisive.

In fact in Sweden (Hansson & Andersson, 1984) the Intrascope was found to be too sensitive to variations in the handling practices (large variation between operators). In the test the FOM suffered from failures. The HGP proved to stand a long durability test and was chosen. The UK did not announce the Destron for authorization by the EC-Commission, because of technical faults in the probe under test (Chadwick, 1988).

In the FRG the HGP did not stand the tests because of measuring failures and a too high frequency of repeat measurements, possibly as a result of difficulties to distinguish between fat and PSE-meat (Branscheid, 1987d). In Germany a new test series started with a number of grading probes and with complete dissection of a large number of animals. In The Netherlands a choice was made for HGP a.o. because of reliability and contracts for service and maintenance of the systems to be installed.

Although the optical probes are only slightly less accurate in predicting lean meat % from fat depth measurements and, like the LSQ, SFQ and ZP-procedures are much cheaper (except the Ulster probe), the second generation of grading probes may none the less be preferable. They combine muscle depth as an extra measurement with the possibility of connection to electronic equipment. Progress in the breeding of animals will gradually lead to increasing muscularity in pigs and more variability in this respect. Muscle depth measurement may therefore become more important.

Since the simpler systems would take too much time they cannot be used in large modern abattoirs. They may be nevertheless valuable in low speed lines and in small abattoirs.

The advantage of the second generation of grading probes lies in labour savings, the ease of use and the handling of the data. The trade and the farmers are quickly provided with useful information, and the abattoirs can use the data for the way of processing, the more when the potential for colour measuring (PSE) is fulfilled. Measurement of intramuscular fat (as a possibility in the HGP) would facilitate decisions as well and possibly leads to some prediction of eating quality.

Efficient operation has also to do with the frequency of repeat measurements and the number of measurements to be taken on the carcass. Kempster et al. (1985) reported indications for more repeat measurements in HGP than in FOM. On the other hand the HGP-system in The Netherlands is working now in practice without problems for one year and repeat measurements are rarely reported, while many slaughter houses have high speed lines of 350 pigs/h and more.

About 150 pigs/h can be measured with the FOM when beside the usual depths also fat depth over m. gluteus medius is taken (Desmoulin et al., 1984). Without the latter measurement 400/h was possible. According to the producer 200-250 pigs/h can be measured, but own experience rather points at about 300/h.

With the HGP a somewhat higher number is possible, because the two usual positions are nearer to each other and therefore easier to find. Since the HGP collects its data in 2 seconds, it is the computer or printer which slows down the capacity. Own experience showed that in slaughter houses where the line speed amounts to 420 pigs/h, the measurements (including judgement of type/shape of the animals) can be carried out without problems, but only with a single site measurement (at 3/4 LR) and further favourable conditions. Without simultaneous scoring for type up to 600 pigs/h is possible. Some individuals would measure 800/h.

According to the producer the SKG II in the FRG is used with line speeds up to 240 pigs/h. In the running operation in Belgium, however, 360 pigs/h are classified without problems.

The disadvantage of the second generation of grading probes is their price. It appeared to be difficult to give prices, because they largely depend on the degree of automation. Moreover prices given in the currency of the producing country also rises problems, e.g. because of the differences in taxes. Nevertheless an attempt is made by giving a ratio of the prices, where SKG II is 100 %. The ratio amounts to:

SKG	FOM	HGP	UP	ZP	Intrascope	QMS
100	55-60	50-55	25-30	± 10	2	< 1

The figures are given for the basic systems without spare pistols, while for ZP a more sophisticated procedure is chosen. Furthermore in case of the SKG II the device should be primarily leased. The price to be paid ultimately must be seen in relation to appointments that can be obtained with regard to maintenance and set-up of a service system.

The development of grading probes will not stop. A newer generation will come. The existing ones probably will be changed in a way that probing is not done manually any more but by means of a simple robot. A further development is on the way with the new grading station in Denmark, by which 17 needles are inserted giving an increasing precision for estimation of the lean meat content, not only of the carcass, but also for the important joints separately. Whether such a system is cost-effective lies in the future. In any case it will be 30 to 50 times more expensive than the existing second generation grading probes.

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Specifications of grading probes came from EC-documents and/or documentation of the manufacturers of the probes.

ERRORS IN CARCASS LEAN PREDICTION WITH SPECIAL REFERENCE TO THE EC GRADING SCHEME

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Summary

The EC Pig Carcass Grading Scheme presents a major problem of standardisation within and between member countries. It is necessary to evaluate different measurement techniques, to approve their use, and then to calibrate them against standard ranges of carcass lean content and ensure that the techniques are applied accurately and consistently. The difficulties involved in these operations are discussed, together with the types of error involved in the prediction of carcass lean content. It is argued that the current procedure adopted for approving equipment and establishing prediction equations may be subject to error and a further sampling exercise is proposed to confirm that the EC Grading Scheme is being applied consistently across countries. In future work the focus of attention for evaluating techniques should be the need to establish accurate regression equations for predicting carcass lean percentage. New techniques which are candidates for use in the Scheme should be tested against a standard technique rather than judged on absolute performance. These points are illustrated by the design of trials to obtain approval in Great Britain and elsewhere.
Keywords: carcass grading, fatness probes, statistical calibration.

Introduction

The main aims of carcass classification and grading are to facilitate trade on a quality basis and improve the matching of production to demand by communicating consumer requirements back up the marketing chain to the producer. The effectiveness of such schemes depends on the accuracy with which characteristics of commercial importance are assessed and the strength of the price signals used to encourage production changes.

The operation of the European Community Pig Grading Scheme involves added problems of standardisation, beyond those of individual national schemes, because of the need for consistency across member countries as well as within. In the Scheme, attempts are being made to achieve standardisation by calibrating individual national approaches against a common baseline of carcass lean percentage obtained by a standard dissection technique. The Scheme now embraces a wide range of national measurement techniques (both instruments and measuring sites) and uses them to define leanness grades designed to be common across countries. This paper examines the Scheme with special reference to the problems of standardisation within and between member countries.

Development of the scheme

In the EC Pig Scheme set up by the original six member states and common to all, classes were defined within 10kg carcass weight ranges in terms of minimum carcass lean percentages. The classes were determined by backfat measurements taken in the mid dorsal line on the split carcass (the EC max) and a visual assessment of conformation (the type classification). The technique is relatively simple and requires no special equipment. However, it was unacceptable to Denmark, the Irish Republic and the UK when they acceded to the Community. Considerable research evidence was available to show that the measurements they used, taken over the m. longissimus by probe, were better predictors of lean than mid line fat depths (reviewed by Kempster, Cuthbertson & Harrington, 1982). These three new member states had also dropped visual conformation assessments, not only because they were subjective but because they contributed little to lean prediction for their particular pig populations.

These countries used a variety of techniques. Denmark measured two lateral fat thicknesses and a m. longissimus depth using the Danish Meat Fat Automatic probe (MFA) and a mid line fat measurement. The Irish Republic used a lateral fat depth over the m. longissimus at the last rib (P_2) measured by the Danish intrascope (optical probe) and two mid line fat measurements. The UK used several methods but all were based on fat depths over the m. longissimus, taken by optical probe in Great Britain and by the automatic Ulster Probe in Northern Ireland.

Following negotiations, the Council of Ministers accepted an amending Regulation (2507/74) which allowed each country to use the method it found most appropriate for predicting the carcass lean percentages which determine grade.

With such a wide diversity of techniques, there was concern that the scheme was not being applied consistently across countries. Experts were particularly critical of the use in the original six member states of visual assessments per se and of the standards sometimes employed. As a result, a co-ordinated trial, involving side to side comparisons, was carried out in 1978 to calibrate the various national dissection methods against the method devised by the German Meat Research Institute, Kulmbach, accepted as the EC standard (Commission of the European Communities, 1979). The intention was that proposed classification techniques would be calibrated and assessed against the national dissection method and this, in turn, calibrated against the standard method.

The scale of the trial with between 30 and 72 carcasses per national population, divided in some countries by weight range and breed type, was adequate for this calibration exercise in most countries, but the analysis of the data went beyond this and also compared the prediction of lean percentage from different measurement systems. Although providing some information on this, the samples were inadequate to provide accurate estimates and the results must be regarded with caution. On a sample of 30 carcasses, a correlation coefficient of 0.50 has 95% confidence limits of 0.15 and 0.72.

It is also important to note that the residual s.d.'s achieved in the trial were optimistic estimates of those likely in practice. The samples were limited to only a few abattoirs within each country and were measured by only a few personnel. Abattoir operations vary within country in many ways, in killing line speeds, dressing procedures, etc. and these can affect the regression equations. Similarly, a national classification scheme will be operated by a large team of men who, even though properly trained, will still show operator variation.

Nevertheless, the results of the CEC survey highlighted the fact that relationships between fat measurements and carcass lean content differ significantly between national populations, particularly where there are major differences in breed type. Belgian Pietrain pigs (sampled from abattoirs in Belgium) had approximately six percentage units more lean than the UK bacon pigs at the same lateral fat thickness. These findings are not surprising when similar differences have been found even within national populations (Evans & Kempster, 1979; Bereskin, 1984).

Since the publication of the CEC report there has been much discussion on the problems of standardisation in the EC Scheme but no further co-ordinated research : all the information for decision making has been based on trials carried out independently by the different countries. The Commission has laid down certain statistical requirements for the authorisation of methods of classification for use from January 1989. Each member state is required to provide supporting data based on a representative sample of at least 120 dissected carcasses to show that the classification technique, which may use only objective measurements, can predict carcass lean percentage with a residual s.d. of less than 2.5 and a correlation of over 0.8.

Evaluation of grading methods

The exact details of the requirements adopted are important because the pig industries in EC countries are changing rapidly and amendments will be required periodically.

Several automatic recording probes are now available and are being used to measure fat and muscle thickness. Important developments are also taking place in the use of ultrasound techniques, video-image analysis and robotics which have implications for the future operation of the EC Scheme. In principle, there is no reason why any new piece of equipment should not be introduced into the EC Scheme provided it is calibrated against the baseline carcass lean percentage and demonstrated to achieve the required accuracy. Against this background, it is important that the most appropriate tests and criteria are used to evaluate techniques. It would be most unfortunate, for example, if a novel and highly promising technique was rejected because the tests for acceptance were inadequate or biased against it.

There is also the question of how future developments in production methods and classification measurements should be handled. To what extent should small modifications to an automatic probe, for example, require resubmission of supporting data? Similarly, after a period of some years, countries with effective breeding programmes might be found to be operating classification methods which were authorised on the basis of data no longer relevant to the current population. There is also the possibility of dramatic changes in the average level of fatness of national populations if castration ceases to be used. These points are illustrated by Figure 1 taken from Diestre and Kempster (1985), which suggests that carcass lean percentage at a given carcass weight and P_2 fat thickness has increased over the past ten years.

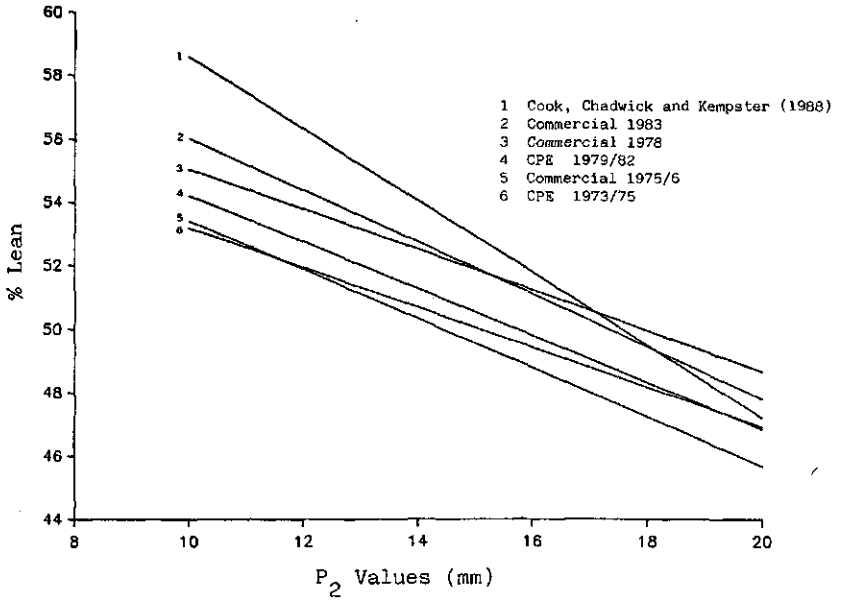

Fig. 1. Regression of carcass lean percentage on P_2 fat in different samples at 65 kg carcass weight.

Trial design

There are three main factors that have to be considered when designing the most appropriate trial to evaluate techniques, but they all revolve around the problem of establishing regression equations for predicting lean content in carcasses from national populations and the precision that can be attached to the estimates when applied in practice.

1. Establishing the regression equations accurately is the most important issue and samples for the trial should be chosen on this basis. The accuracy achieved for individual carcasses, although not unimportant because of the need to reduce variation, is a secondary issue. This is because it is batches of pigs which are traded, not individual carcasses, and it is the average price for the batch which is critical to buyer and seller. A relatively low level of precision may be acceptable provided that important differences in lean content between sub-populations (pigs from different producers or of different breeds etc.) are identified. The consequence of this argument is that the sample of carcasses used to construct the regression equations must be large enough and must be widely representative of the national population.

2. The best estimate of a regression equation for a given cost will be obtained by taking carcasses at the extremes of the distribution for the independent variables, in this case weight and fatness. If there is serious concern about curvilinearity, some carcasses may be sampled from the middle of the distribution, but they will contribute nothing to the estimation of the regression slope. For Britain, there is some evidence of slight curvilinearity in the relationship between carcass lean percentage and P_2 fat thickness (Diestre & Kempster, 1985). There is also evidence in the CEC study that the overall pattern betwen national populations is curvilinear. Nevertheless, only two submissions (West Germany and the Irish Republic) for the new Scheme have included quadratic terms in their prediction. In any case, the errors resulting from linear interpolation between two extremes when the true relationship has slight curvilinearity will be small. Errors in extreme carcasses caused by fitting a line, whether straight or curved, to observations in which the extremes are under-represented, are likely to be large.

3. Regression lines can be sensitive to changes in pig populations and to the circumstances of measurement. It is important, therefore, that carcasses should be sampled from a large number of abattoirs on more than one day and measured by different classifying operators. Unfortunately, this diversity has the effect of increasing both the overall and the residual s.d's, thus, under the existing requirements for approval, penalising any country that chooses a sample with high variability. The procedures currently being approved should be tested again on a broadly based and independent sample of carcasses to determine their accuracy in actual use and their robustness, and should be repeated periodically so as to indicate when equations should be changed as pig populations and measurement circumstances change.

These principles of trial design are illustrated by the trial carried out in Great Britain to establish the equations for predicting lean and used to gain approval for their use in the EC Scheme (Cook, Chadwick & Kempster, 1988). Carcasses were selected from eight abattoirs chosen to represent the range of carcass weights and dressing procedures in Great Britain. Each abattoir provided carcasses for dissection on two separate days. Carcasses of all three sexes (entire males, gilts and castrates) were selected in similar proportion to their use in the slaughter population, but the sample concentrated on fat and lean carcasses. Two fat and two lean carcasses, approximately one standard deviation above and below the mean, were selected for each carcass of average fatness.

The representativeness of the sample for establishing regression equations is now supported by the results from 700 dissected carcasses from a trial carried out in 1986/87 at MLC's Stotfold Pig Development Unit (Table 1) (D G Evans unpublished results). The Stotfold sample comprised pigs of a wide range of genotypes : conventional White crosses and crosses by specialist meat sires from the main British breeding companies.

An attempt to summarise the approaches taken in other countries is made in Table 2.

Table 1. Comparison of equations in two independent samples of dissected carcasses (carcass lean percentages for carcasses of 65 kg).

P_2(mm)	EC trial (GB) (n = 162)	Independent sample (Stotfold) (n = 700)
8	60.9	60.0
12	56.3	56.0
16	51.7	52.0

Table 2. Summary of approaches and results from the EC calibration trials in varous countries.

	(1) No. of abattoirs	(2) Sampling	(3) S.d. (at=Wt)	(4) Slope on fat depth	(5) Residual s.d. (typical probe fat and muscle)
DK	2	equal	3.7	0.7	1.9
WG	1	rep.	4.7	quad	1.8
IR	3	rep.	3.6	quad	2.0
SP	4	rep.	4.6	0.8	2.2
N	5	rep.	3.7	0.8	1.8
GB	8	ext.	4.4	1.0	2.2

(1) Number of abattoirs from which carcasses were sampled
(2) equal = equal numbers at each fat level
rep = sampling of fat levels proportional to population
ext = sampling concentrated at more extreme fat levels
(3) Overall s.d. of lean percentage at constant weight
(4) Regression of lean percentage on typical fat depth
(5) Residual s.d. predicting lean percentage from typical probe fat and muscle depths

Statistical criteria

The EC requirements say little about the design of the trial needed for approval of techniques, only that it should contain at least 120 carcasses representative of the population. They are quite definite, however, about the statistical criteria for acceptance. Any method must be shown to predict lean with a residual standard deviation of less than 2.5 and a correlation of at least 0.8.

The specification of a minimum correlation seems unnecessary. This statistic is of limited theoretical value unless the variables in question have a multivariate Normal distribution.

National statistics in Great Britain indicate positive skewness in the distribution of fat thickness (Meat and Livestock Commission, 1987) and this is likely to be the case in other national populations, particularly where fat levels are low. More seriously, the correlation is computationally simply a function of the overall s.d. and the residual s.d., and the requirement may be translated to that of the s.d. being more than 1.67 times the residual s.d.. Countries with accurate classification measurements could therefore fail to meet the requirement because their carcasses were too uniform.

The choice of the residual s.d. as the criterion for acceptance is in principle the correct one, but as stated is ambiguous because of sampling error. On a sample of 120 carcasses, 95% confidence limits for an observed residual s.d. of 2.5 are approximately 2.2 and 2.9. Thus, if member states were required to demonstrate conclusively that the population residual s.d. is less than 2.5, the sample residual s.d. would need to be less than 2.2.

The need to calibrate the prediction method against the EC reference lean from a two stage process, via national lean, also produces problems. A trial set up to assess a method for approval will compare the prediction against lean calculated from the national dissection method. The only evidence of how this in turn is related to the EC reference lean is contained in the CEC (1979) exercise, which is now ten years old. It is also unclear whether the claimed residual s.d. should be inflated to take account of this extra step in the calibration. This problem has not been important for those countries (eg. Denmark and the UK) whose dissection method was closely related to the standard method or, for Holland which included the 'reference method' in the equipment comparison trial, but could create a serious problem for those whose dissection method was not so close and for those states which have joined the Community since the CEC exercise was carried out.

In view of the use of these historical data and that dissection methods can change over time (quite subtle differences in the degree of fat from lean separation could lead to substantial bias in estimated lean values) there is a strong case for repeating this calibration exercise to refine future estimates.

There are two other points although perhaps less important than those above. It is unrealistic to assume that the residual s.d. is the same at all levels of fatness. Most studies show a tendency for it to increase with fat thickness and with weight. Consequently, countries producing heavier carcasses are at a disadvantage in terms of achieving a satisfactory residual s.d.. The number of measurements or combinations that are considered in any trial should also be restricted. The accuracy achieved by the best relationship from many candidates is an optimistic estimate of what will be found in further samples.

Alternative approach

Drawing these various points together, it is evident that establishing a sensible and just protocol for the sampling from the national population and for the subsequent analysis is a problem of considerable complexity. Nevertheless, these trials will still be necessary in the future, both to test new methods and to update parameters. It is evident that the residual s.d. threshold approach is only tenable if stringent requirements are set down for the scale and sampling procedure for the tests and if the threshold is carefully chosen and monitored. Such requirements are unlikely to be met except possibly when major dissection exercises are carried out to establish regression equations for calibrating national measurement systems to the EC lean ranges. But such large dissection exercises are expensive, detailed dissection of one side requiring about half a man-day's work by a skilled butcher. Cheaper alternative approaches are required if new methods are to be tested as they become available.

Historically, alternative probing devices have been evaluated by comparing their performance against that of existing national systems in the same trial, and showing it to be at least as good. This comparative approach has some advantages over the present system of absolute standards. It is, for example, likely to be less dependent on the structure of the chosen sample, since abattoir and operator variation would apply to both methods. The extent to which this assumption is valid will depend on the sample and the particular techniques being compared, but the assumption is reasonable provided the sample is fairly representative of the national population and the methods not too different. As a consequence of this, the carcasses could often be taken from other studies in which the dissection costs have already been met.

Whatever the sampling method employed, there would be advantages in using the same standard technique in all national comparisons, for example the most commonly used combination of measurements from one of the automatic recording probes, i.e. the fat thickness over the m. longissimus at the last rib and the fat and muscle thicknesses over the m. longissimus between the third and fourth last ribs. Obviously, the standard technique would be upgraded periodically as new methods were accepted and old ones became obsolete. The best approach would then be to take a sample of the national population stratified by abattoir, breed type etc., and designed to optimise the precision of estimating the regression equations. A new method would be accepted for use in the EC Scheme if it were shown to be at least as good a predictor as the standard technique, the absolute level of residual s.d. achieved being ignored.

This approach would also allow the accumulation of information on the robustness of different techniques and identify sub-populations where bias occurred.

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NEW TECHNIQUES FOR ASSESSMENT OF PIG CARCASSES
- VIDEO AND ULTRASONIC SYSTEMS

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ABSTRACT

Automatic grading probes can be used to predict the lean content of pig carcasses through objective measurement of fat and muscle thickness. The assumption is that information on muscle thickness is important in describing the composition of 'meat-type' pigs which have more lean than would be predicted from fat thickness alone. However, the improvement in prediction is often small. In a sample of 310 pigs with a wide range in carcass weight (mean 64.2 SD 38.8 kg) and percentage lean in side (mean 57.3 SD 5.3%) and consisting of 238 pure Large Whites and 72 pure Pietrains, the residual standard deviation of percentage lean was only reduced from 3.36 to 3.07 when m. longissimus depth was combined with fat thickness (both measurements made at last rib). Only 66.5% of the variation in percentage lean was accounted for in the combined model, compared with 59.9% in the model excluding muscle thickness.

Other more accurate objective means of assessing the lean content of carcasses are therefore required. Two approaches, primarily intended for beef carcass classification, but having possible application to pigs, have been developed at IFR. The first of these, video image analysis (VIA), enables carcass shape (conformation) to be quantified. Data on shape can be included along with the information obtained from an automatic probe to give a more accurate prediction of lean than provided

by the probe alone. With beef and lamb carcasses, subcutaneous fat development (fat cover) can also be assessed using VIA but this is not possible with pigs. Direct information on fatness can, however, be obtained by quantifying the area of subcutaneous fat exposed when the carcass is split.

Measurement of the velocity of ultrasound (VOS) through the loin and shoulder of beef carcasses gives as accurate a prediction of lean content as that provided by an experienced visual assessor using the EAAP 15-point scales for fatness and conformation. Preliminary work with pig carcasses shows that VOS measurements made across the hind limb are as useful in predicting percentage lean as they are in beef carcasses. The advantage over automatic probes is that both subcutaneous and intermuscular fat are assessed, not just backfat.

New techniques for classification should be robust and easily applied and should be capable of being integrated into a data capture system in the abattoir. This allows information to be returned to the producer who can then introduce changes to match production more effectively to market requirements.

<u>Use of objective techniques in pig carcass classification</u>

Throughout the world there has been considerable interest in moving towards objectivity in carcass grading, for the three major species but with the greatest practical advances being made in pigs. Within the pig industry, this move towards objectivity has been facilitated by a number of events - a combination of government legislation, increased industry awareness of the need to meet consumer requirements more precisely (based on price incentives) and the advance of dependable technology. The majority of Western countries have adopted deadweight classification systems with payments based, largely, on fat (and muscle) thickness but with some reference to other criteria such as sex and weight.

As fat and muscle thickness measurement plays such an important role, most of the technological developments have been concentrated in this area, with the greatest emphasis being on quantitative measurement of fat thickness at specific points. These points are usually chosen for ease of anatomical reference and access.

One of the first attempts at objectivity was the optical probe (Intrascope) which is inserted into the carcass to detect the interface between fat and muscle. From this concept a number of automatic probes have been developed. In Denmark, the electrical conductivity probe (MFA) of the early seventies was replaced a few years later by the automatic version KSA. This, too, has been superceded in the 80s by probes based on the principle of the different light-reflecting properties of fat and muscle tissues. These are the Hennesy Grading Probe (HGP) from New Zealand, the Fat-O-Meater (FOM) from Denmark and the Destron from Canada. These will not be described in detail as the subject has been adequately covered by Sack et al (1981), Sack (1983) and by others in this Symposium.

Whilst there is no question that the automatic probes have considerable advantages over subjective techniques they can be criticized on several grounds:

i) Reproducibility/repeatability

ii) Accuracy of predictive meat yield from one-dimensional data.

iii) The effectiveness of the site chosen as an accurate predictor of the total meat yield.

iv) Failure to accommodate conformation criteria.

Reproducibility and repeatability have been extensively investigated, for example for the FOM by Sack et al 1981, Casteels et al (1984), Matzke et al (1986); for the HGP by Adam & Hargreaves (1982) and all the instruments have been assessed in individual country official trials before adoption. However, because the instruments are manually operated, the ability to place them at the same reference point and the correct angle on every occasion will be important in determining accuracy under commercial conditions (Sack 1983).

The recent work of Matzke et al (1986), Blendl et al (1986) and Branschied et al (1987a,b,c,d) and others, have highlighted the problem of predicting percentage meat yield from fat thickness and muscle depth data. The problem is particularly significant with the 'blockier', more muscular meat-type pigs such as the Pietrain (compared with the less well developed 'white' breeds) where under-estimation of lean content by 1-3 percentage points can occur.

Work of Wood & Robinson (1988) has also shown that the introduction of muscle thickness data, often assumed to describe the effect of muscularity on lean content, does not improve prediction significantly. Table 1 shows the main traits in the two pig breeds under study. The standard deviation of 5.3% lean is larger than in other published studies

Table 1. Mean and standard deviation of main traits

	Both breeds		Large Whites		Pietrains	
	mean	sd	mean	sd	mean	sd
Lean (% of side)	57.3	5.30	56.0	5.10	61.6	3.39
Cold carcass weight (kg)	60.1	30.73	63.0	30.52	50.2	29.56
Fat thickness above m. longissimus (last rib) (C)	10.3	5.71	11.2	5.87	7.3	3.87
m. longissimus width (A, mm)	90.0	15.88	91.1	16.91	86.4	11.06
depth (B, mm)	48.0	10.11	47.5	10.05	49.6	10.26

Table 2. Regression of % lean on carcass measurements. Usefulness of measurements as predictors indicated by variation accounted for by regression (vaf) and residual standard deviation (rsd). Model 1 includes all pigs. Model 2 comprises separate regression lines (different intercepts, same coefficients) for the two breeds.

Predictor(s)	Model 1		Model 2	
	vaf	rsd (%)	vaf	rsd (%)
(sample standard deviation		5.30		
C	59.91	3.36	65.12	3.13
C + A	65.21	3.13	70.86	2.86
C + B	66.51	3.07	69.44	2.93
C + (AxB)	67.32	3.03	71.30	2.84

because the population included extremes of body weight. These extremes of pig type and weight were considered ideal to test the usefulness of carcass measurements as predictors.

Table 2 shows the combined effects of various measurements as predictors of percentage lean. Model 1 includes all pigs whereas model 2 fits separate lines for the two breeds. The reduction in residual sd using fat plus muscle thickness was not large enough in the whole population to allow the use of one equation. There were still important effects of breed. Similar trends were shown by Branscheid et al (1987 a, 1987 b). Therefore, other, more accurate methods of assessing the lean content of carcasses are required.

Use of video image analysis (VIA) and velocity of sound (VOS) in pig carcass classification

Two techniques, primarily intended for beef and sheep classification, Video Image Analysis (VIA) and Velocity of Ultrasound (VOS) have possible application to pigs. The principles of VOS have been extensively described by Miles and Fursey (1977), Miles et al 1983,a,b; and Miles et al 1984. Originally developed for live cattle, the authors have claimed that VOS could have tremendous economic implications for producers by indicating slaughter times for optimum yield.

Preliminary work with pig carcasses has shown that VOS measurements across the hind limb are as useful in predicting lean content as has already been demonstrated for beef carcasses.
The advantage of this technique over automatic probes is that subcutaneous and intermuscular fat are simultaneously assessed, not just backfat. Recent data showing the effect of including conformation score or breed effect with VOS or fat thickness measurements in a variable beef population (Miles et al, 1987) illustrate some important point with implications for generally less variable pig populations.

The results in Table 3 show that in the mixed beef population, the addition of conformation score and breed effect to the regression model

Table 3. *The Effect of Including Conformation Score or Breed with Fat Score, Fat Depth or Ultrasonically Measured Lipid Thickness on the Precision of Predicting Lean Percentage.*

	X(RSD)	X + conformation score		X + breed*	
		RSD	F!	RSD	F!
Lipid thickness, sites 2,3,4 [a]	(1.79)	1.80	0.29,NS	1.80	0.60,NS
Fat score	(2.18)	1.92	21.69,p<0.001	2.02	7.67,p<0.01
Fat depth	(2.20)	2.07	11.07,p<0.01	1.98	9.38,p<0.01

[a] Measured using VOS at 3 sites (2,3 and 4) on the carcass.
! Variance ratio attributable to additional term when added to simple regression including X.
* Fitting parallel lines. There was no significant improvement in fitting individual breed lines (separate slopes).

did not result in reduction in the RSD when used with ultrasound (VOS) measurement, but was highly significant when added to fat score (subcutaneous fat and internal fat such as medial thoracic wall) or fat depth (measured as mean fat depth over M. longissimus). No significant improvement was obtained by combining breed and conformation data; each alone produced a similar reduction in the RSD. This suggests that if a quantitative measure of conformation could be added to a quantitative fat measurement, accuracy in predicting percentage lean would be significantly improved.

Video image analysis (VIA) is being developed for just this purpose. Commercial VIA technology already developed is increasingly being used worldwide to measure fat/lean ratios 'on-line' in the meat products industry (Newman 1984a,b; 1987a,b). A VIA based system for detecting bone in raw materials and finished products will shortly be available.

With cattle and possibly sheep, where surface characteristics are known to be good indicators of total fatness, it should be possible to use VIA techniques alone for prediction of meat yield. This is not so with pigs. *In some parts of the world, automatic probes are already established in* abattoirs and are an integral part of producer payment schemes based in yield (eg Australia, Canada, New Zealand). In such cases, the introduction of VIA to assess shape, provide information on muscularity, distribution, lean:bone etc, would complement the probe-derived fatness measurement and therefore improve the prediction of yield. Sorenson et al (1988) have already indicated that Denmark is taking a similar approach for beef carcasses.

The SKG I and SKG II systems developed in Germany for pig classification,

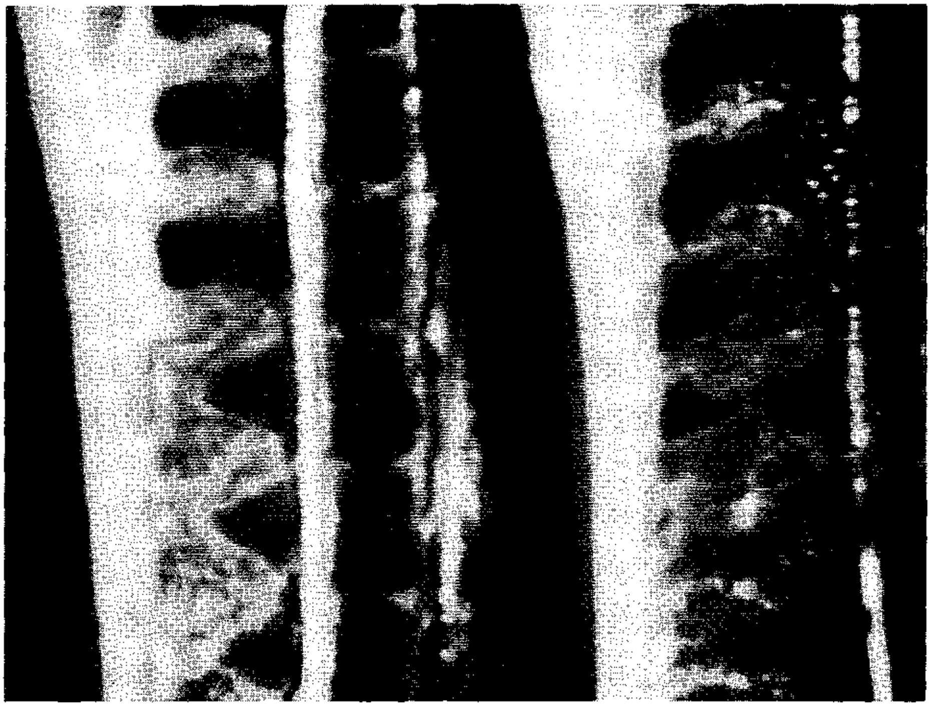

Plate 1: Video Image Analysis (VIA) generated images displaying subcutaneous fat thickness of Large White (left) and Pietrain at same anatomical site

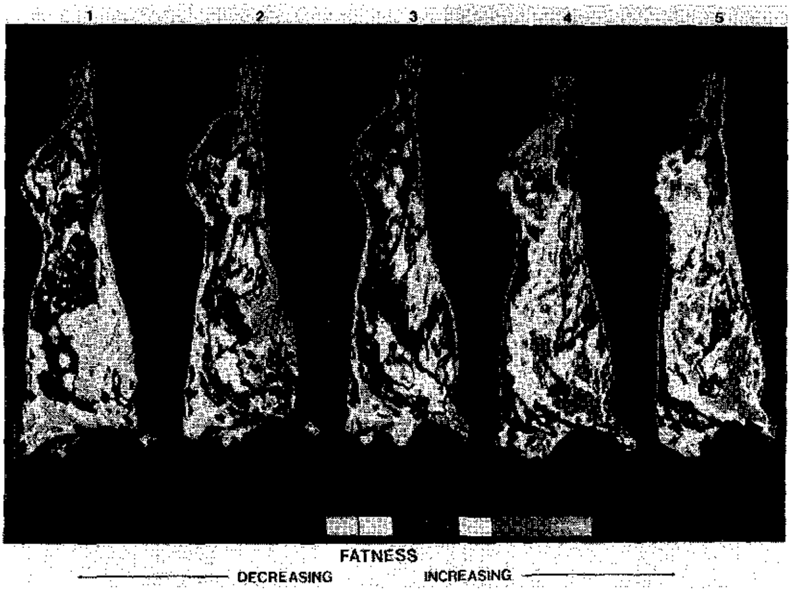

Plate 2: VIA generated external fat profiles on beef carcasses of different fat levels

is another approach to the objective measurement of conformation (Sack et al., 1981; Sack, 1983). These attempt to improve accuracy of meat yield prediction by measuring muscle thickness in the pelvic limb and combining this with a probe measurement of fatness.

Image analysis is also able to quantify fat at the cut surface, not just as a point measurement, but as a whole sector (Plate 1). Whilst there are logistical problems associated with orientation and interpretive problems with blood splash, they are being overcome with the development of more sophisticated 'intelligent' systems capable of interpreting colour. Plate 2 showing the change in external fat profile on beef carcasses of different fat levels illustrates this approach.

In some pig classification systems described, automatic probes are already established for the prediction of yield or carcass lean content.

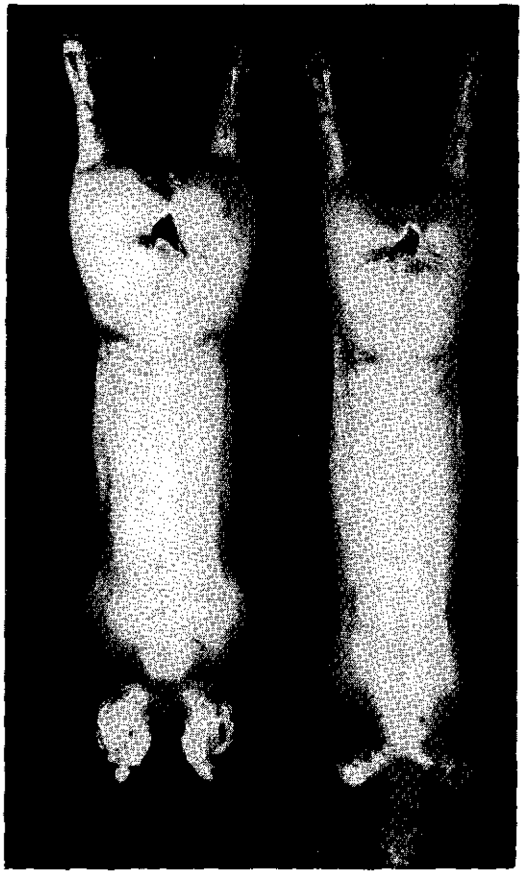

Plate 3: Examples of Large White and Pietrain carcass conformation used in VIA pilot study

Their deficiency appears to be the extent to which they are able to predict the contribution made by conformation. In a small-scale study, (plate 3 shows pig types used, plate 4 VIA derived images), VIA derived measurements of area, volume and roundness with reference to length (Table 4) were able to quantify differences between the two breeds. Also there are indications that when combined with probe data, it could be possible to explain differences in percentage lean at constant fat thickness.

Plate 4: Examples of VIA generated 2-dimensional profiles

Whilst the combined VIA/Probe system appears to work well, it is hoped that a totally independent VIA system could find favour with those plants yet to invest in probe technology. One major advantage of VIA is that it is non-contact and the system being developed requires little in the way of adaption to conventional carcass handling and carrying systems. With all the information on carcasses now available or capable of being generated within a slaughterhouse, techniques for transmission and centralised acquisition of those data are becoming increasingly important. Some of these data are obtained by subjective assessment, eg meat inspection, others, such as weight and fat measurement can be captured instrumentally.

Table 4 VIA Measurement of Selected Carcass Traits in two Pig breeds

(Mean values)	Total Area	Overall Length	Area Length	Overall Vol/Length	Roundness
Large White					
Dorsal	7221 ± 394	219.5 ±6.76	32.89 ± 1.34	mean	29.0 ±1.41
Lateral	7455 ± 297	218.3 ±5.85	34.16 ± 1.07	87058	27.0 ± 1.82
Post/Ant	14748 ± 526	229.75 ±5.06	77.271 ± 2.44	±8729	45.0 ± 4.90
Pietrain					
Dorsal	7324 ± 385	194.75 ±4.11	38.34 ± 1.34	mean	35.5 ± 1.91
Lateral	6876 ± 329	191.25 ±2.5	35.95 ± 1.43	120716	30.75± 0.96
Post/Ant	20342 ± 1199	228 ± 5.66	89.21 ± 4.39	±12716	58.5 ± 1.73

Throughout the world, there are a number of data capture systems at various stages of development. A system currently under development at IFR, Bristol is attempting to integrate the capture of instrumental data eg. VIA, VOS, grading probe, together with both live animal and carcass weight information, ear tag recognition and a computer voice recognition system for meat inspection data (Fig. 1). This is being generated as a discrete data file for each carcass through radio activated transponders, situated on the gambrel. The data is transmitted immediately it is gathered, and the file continually updated. In case of malfunction or failure, each data capture station retains a record of its own data. At the end of the information gathering cycle the files are read by the central computer and the information acted upon, eg. produces record, carcass price calculation, etc. Thus, the producer and the slaughterhouse can have ready access to the information and initiate changes in their own production techniques to mirror the changing market requirements. With improved video capture techniques, inexpensive hard copy pictures of the finished dressed carcasses can be provided with the digital data added to them, thus giving the producer a complete visual/data record.

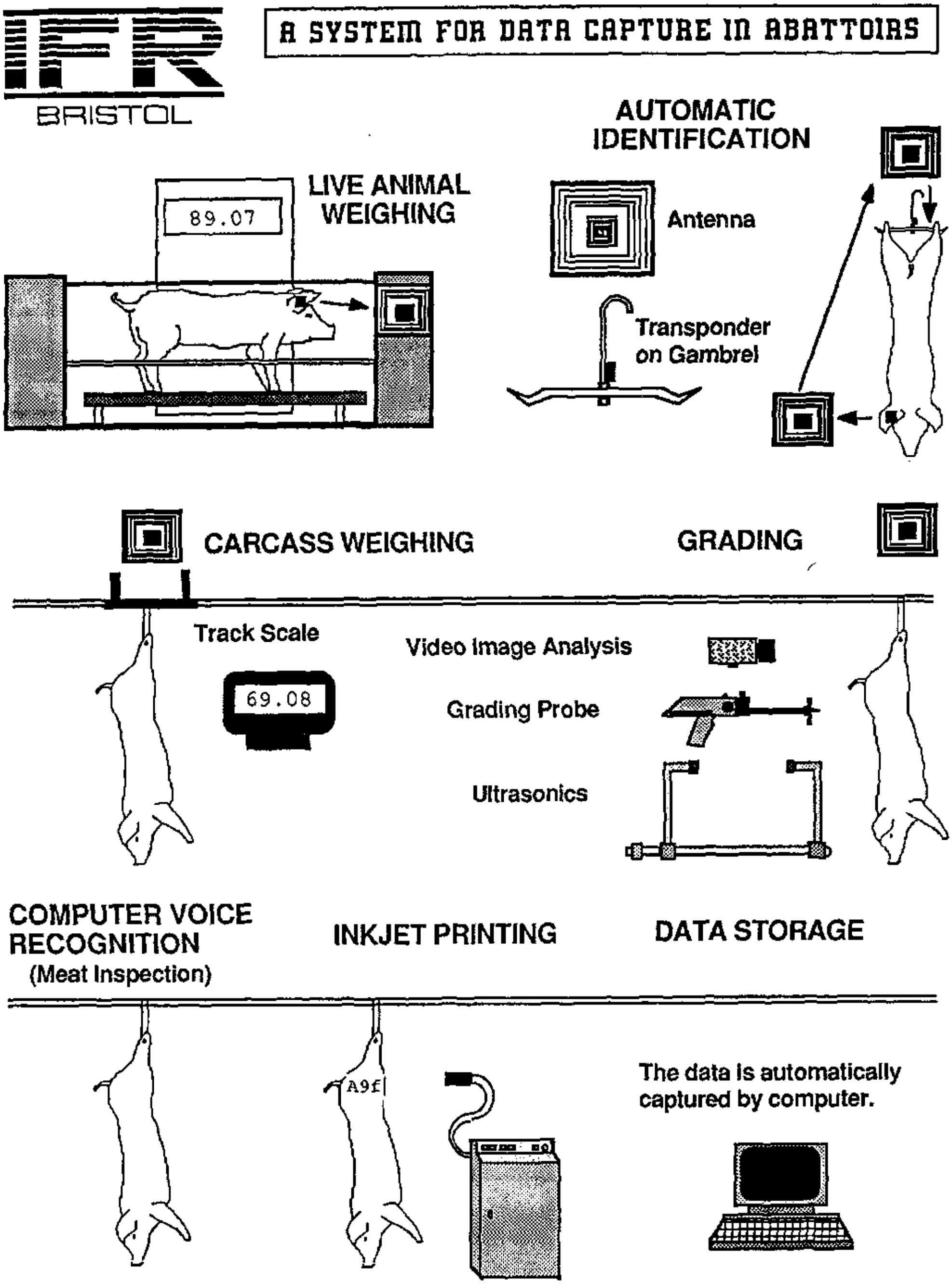

Figure 1: IFR-BL proposed system for Data Capture in Abattoirs

In this paper, two new technologies - Velocity of Ultrasound and Video Image Analysis - have been briefly described. It is believed that both can play an important role in producing objective measurement of carcass traits thereby improving prediction of carcass yield. Undoubtedly there will be others, but all are aiming to contribute to one of the major goals of the carcass industry, improved assessment of carcass quality. Better performance in this area will improve the perception of the product in the eye of the most discriminating of end users, the customer.

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INCORPORATING MEAT QUALITY IN GRADING SYSTEMS FOR PIGS

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Summary

The rapid conversion of glycogen to lactic acid within the nearest hour post mortem creates unfavourable changes in the structure, colour and water-holding properties of pig muscle. The possibility for an identification of these changes by means of internal reflectance already at time of grading is discussed. With modern grading equipment, the internal reflectance is used in the estimation of the lean meat percentage. The same equipment can therefore be utilized for assessing meat quality on the day of slaughter. This early estimate of PSE does not, however, give the ultimate quality, but can be used as a feed-back for checking the handling and optimize the environment in connection with transport and slaughter. (Keywords: swine, grading, meat quality, PSE, internal reflectance.)

Introduction

The valuation of carcasses is of great concern for the whole production chain from the producer through the wholesaler and retailer to the single consumer. To optimize this, both the meat content and the meat quality should be included.

For many years this valuation of pig carcasses has been directed to the assessment of the content of lean meat and fat while the quality of the meat has not been taken into consideration. The possibility to incorporate meat quality in the classification system depends both on the classification techniques used and on the possibility to get an early assessment of meat quality. With new grading equipment, the situation has changed during the last five years.

The aim of this paper is to describe and discuss the possibility of including meat quality in the classification systems. The principles of the carcass grading systems used as well as the possibilities for an early evaluation of meat quality characteristics will also be discussed.

Classification systems in use

The classification systems used in different markets has been described by Kempster et al. (1982), and recently by Pedersen (1988). In most countries, the estimate of carcass composition is based on a measure of the backfat thickness. The high correlation (r=-0.75) between the linear measurement of backfat thickness and the lean meat percentage is the base for the system. In some countries (Hansson & Andersson, 1984; Walstra, 1987; Pedersen, 1988), the thickness of the loin muscle is included in the estimate. In markets with a great variation in the types of the pigs, the objective measurements are supplemented with a subjective scoring of type or conformation. The linear measurements can be made with a simple ruler or with a more or less sophisticated electronic device. These devices use the principle that a probe is pushed through the carcass at the sites of interest. The linear measurements are evaluated in different ways, e.g. millimeter of fat, classes or lean meat percentages, and used as base in the payment system. The intention in most markets is to express the carcass composition in lean meat percentage units. In the EG market this will come inte force on 1st of January, 1989 (Pedersen, 1988).

Meat quality characteristics of interest

During recent years, interest in the quality of the meat has been increasing. The concept of pig meat quality may include tenderness, taste, fat content and nutritive value but the most important characteristics of quality are the pH-dependent paleness, softness and exudation (Swatland, 1988). The latter quality characteristics of meat are largely dependent on the biochemical processes that take place during the first hours after slaughter. The structure, colour and water-holding properties of the muscle changes. Very fast changes create the problem of pale, soft and exudative meat (PSE), which is regarded by the market as the most serious of the meat quality problems.

Ways of identifying quality

The changes that give the final quality are not always established until the day after slaughter, and the main problem is to find a valid technique that already at time of grading gives an estimate of the ultimate quality. It is therefore necessary to know which proportion of carcasses with PSE on the day after slaughter have developed changes in structure that can be measured already at the time of grading. We also need to know if it is possible to register these changes rapidly and with high reliability.

One parameter commonly used to identify early alterations in muscle consists of measuring the muscle pH 45 minutes after slaughter (pH_1). It is used as a means of identifying PSE and paying for good quality in one abattoir in Switzerland (Micarna AG, Bazenheid), but when large numbers of carcasses have to be assessed on rapidly moving lines, pH measurements are difficult to use routinely.

Some experiments have been performed with the intention to estimate the possibility for early identification of PSE. Barton-Gade (1981) reported from experiments with Danish pigs that measurements of pH_1 and colour/structure alone or in combination cannot give a good prediction of the ultimate quality. Seidler et al. (1987) found that the MS-Tester, measuring the complex electrical conductivity, was clearly superior to FoM (see below) for discriminating between PSE and normal muscle. Schmitten et al. (1987) using electrical conductivity stated that it is a method that can be used for predicting meat quality already on the slaughter line. A drawback is, however, that this instrument must be used as a complement to ordinary grading. Most experiences with early identification of meat quality have been performed with instruments utilizing internal reflectance, and these will be summarized below.

Evaluation of internal reflectance

The development of the increase in internal reflectance postmortem is poorly understood. The translucent muscle structure will change to an opaque structure depending on the drop in pH, and in severe cases on the denaturation of the sarcoplasmic and myofibrillar proteins. As discussed by Tarrant & Long (1986), the conditions causing very early increase in internal reflectance need to be rather extreme causing low pH when the muscle temperature is still high. According to MacDougall (1984), the muscle changes from tranlucent to slightly opaque at about pH 5.9. The relative contribution of the rigor bonds on the internal reflectance in pig muscle does not appear to be known. Jeacocke (1984) showed on beef muscle that the increase in scattering due to rigor was related to the extent of bonds between the thin and thick filaments. As recently shown by Larsson & Tornberg (1988), PSE muscle can have both the longest sarcomeres as well as the shortest.

The internal reflectance will increase about two-fold from early measurements until the following day (Lundström et al. 1987). However, we have recently found (unpublished) that some loin muscles will develop an early high internal reflectance that will not increase substantially until the next day, giving approximately normal ultimate values.

New grading instruments for measuring fat and muscle thicknesses use probes that measure the internal reflectance in order to identify the borders between the tissues of interest. The instruments available on the market at present are the Fat-o-Meater, FoM, (SFK, DK-2650 Hvidovre, Denmark), Destron Pork Grader PG-100 (International Destron Technologies, Markham, Ontario, Canada) and the Hennessy Grading Probe, GP2 (Hennessy Grading Systems, Ltd. Auckland, New Zealand).

The probes are equipped with light emitting diodes. As mentioned above, the probes are pushed through the carcass at the site of interest, usually in the back part near the last rib. When the probe eye passes the tissues, fat and muscle, the reflected light signal is sent to the computer and a profile is stored. Fat gives high signals and muscle gives lower values. The profiles can then be used to identify the borders between the backfat and underlying muscles, normally the loin muscle, and a measure of the thickness of muscle and fat can be obtained. As the level of the signal in the muscle portion of the profile is dependent on the reflected light, the profile can be evaluated to give an estimate of the internal reflectance of the muscle. The profile capture systems in the instruments mentioned above seem to be principally the same even if the evaluations of the profile differ. As GP2 uses a light diode emitting light at 570 nm, the internal reflectance of the muscle may be influenced by the variation in myoglobin. Our results so far indicate that the myoglobin influence on the internal reflectance is rather low (Lundström et al., 1988).

The intramuscular fat in the muscle can also influence the internal reflectance. Streaks of fat give peaks in the profile and if these streaks are thick the influence of fat must be taken into consideration. The content of fat in the loin muscle is low in most carcasses and if there exist small peaks they can be neglected.

The evaluation of the profile can be made in different ways. The principle is that an average level of the profile within the central part of the muscle is calculated and displayed (see Fig. 1). As result of our experiences in the development of the Hennessy Grading System we have suggested that about 30 mm of the muscle part of the profile is used, starting 8 mm from the border between subcutaneous fat and the loin muscle (30 percent of the total carcass thickness).

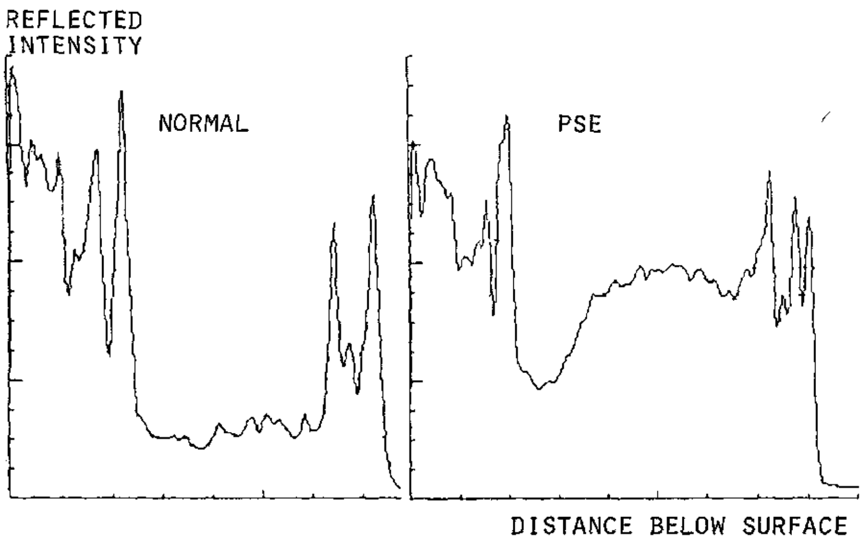

Fig. 1. Reflectance profiles captured at time of grading 45 min post mortem from normal and PSE loin muscles.

Results from the literature, as well as our own experiences, show a wide variation in the relationships obtained between early measurements of internal reflectance and ultimate meat quality. The automatic Danish meat quality probe is mainly used on chilled carcasses and Barton-Gade & Olsen (1984) found a high correlation between internal reflectance values and water holding capacity of the meat, when the measurements were made on the day after slaughter. This instrument is of special interest, because the probe will be used in the Danish grading system (Pedersen, 1988). Experiments made in Germany by Sack et al. (1984), showed that the reflection value obtained with the Fat-o-Meater provided reliable information on the PSE-condition. Somers et al. (1985), reported that the FOP value 1h postmortem was superior to pH_1 for predicting ultimate reflectance. However, Tarrant & Long (1986) found that FOP-measurements made 35 min postmortem were a less good predictor of drip loss than pH_1. At 4h, the same authors found pH_1 and FOP to be equally useful for prediction of drip loss, while the FOP value was superior 24h after slaughter.

Fortin and Raymond (1987), used the three instruments FoM, Destron and GP2 mentioned above for assessing meat quality on Canadian pigs on the slaughter line. Their results indicated a low prediction value of an early assessment. In the Netherlands the Hennessy Grading Systems have been used for carcass grading since 1987 (Walstra, 1987). In the about 60 systems installed, the instruments are equipped with programs that evaluate the profiles giving an estimate of the internal reflectance at the time of grading. In a series of experiments on carcasses from Dutch pigs (van der Wal., 1986; van der Wal et al., 1986; van der Wal et al., 1987), low correlations were obtained between different methods of early reflectance measurements and ultimate quality.

Grading and quality assessment with probes in Sweden

The Hennessy Grading System with the instrument version GP2 has been used for pig carcass grading at all abattoirs in Sweden since April 30, 1984. As the slaughter amounts to about 4 million annually, the system has been used on about 15 million carcasses. The system was developed in close cooperation with the Swedish slaughter industry and we have had good possibilities to influence the function of the system. The idea to use the profile for assessment of the internal reflectance of the muscle arose four years ago when we first discussed the possibility to obtain an early estimate of the quality of the meat. Changes were made in the software, to evaluate the profile according to the average level within the muscle portion. The internal reflectance value obtained by the probe is sent to the computer and also displayed on the instrument. In the Swedish grading system, measurements are made at two sites along the back. The profiles from the two sites are evaluated and an average of the two is displayed.

The instruments with the internal reflectance function have been used in the ordinary grading system, including more than 50,000 carcasses. The instrument has also been used on chilled carcasses the day after slaughter. Some of the results have been published (Hansson et al., 1986; Lundström et al., 1987; Lundström et al., 1988). The main results and experiences from our work can be summarized in the following points:

1. The software evaluation of the profile will give an estimate of the internal reflectance of the muscle at the site of measurement.

2. Carcasses with PSE at time of grading give a high internal reflectance which seems to be possible to identify by the instrument.

3. In most carcasses the peaks originating from streaks of

intramuscular fat are too small to influence the value obtained. If very fat muscles are measured, the software needs to be changed in order to minimize the influence of fat.

4. The incidence of PSE was found to differ considerably between abattoirs but also between days within the same abattoir. About 50 percent of carcasses with ultimate PSE were identified with high values of internal reflectance already at time of grading. Late development of PSE in some carcasses makes it difficult to include this early estimate in a payment system.

Proposed use of the system in the near future

Based on our results and experiences, the slaughtering industry is recommended to use grading probes with a profile evaluation system (PSE-option) in abattoirs where the incidence of PSE is known to be high. The Hennessy Grading Systems, approved for ordinary grading and equipped with this PSE-option, will give an estimate of the internal reflectance besides the lean meat percentage. This value will be displayed on the instrument and as an option printed out on the connected printer. The operator of the instrument can easily indicate the estimated quality on the carcass.

The main intention of this program is to use the information from the instrument to find the causes for the PSE-development. The information can also be used for pre-selection of carcasses according to quality. A repeated measurement must, however, be done at the time of cutting if the intention is to find all carcasses with PSE. When the probe is used on all pigs slaughtered, it will give an estimate of the average incidence of early PSE in the abattoir. This early quality assessment cannot be used as a base for payment to the producer.

In conclusion, we thus have a wide variation in the time pattern for the development of the final internal reflectance. Considering that, we do not find it meaningful at present to use an early measurement of internal reflectance as predictor of final meat quality. Instead, we recommend the use of early measurements as a means of finding environmental reasons behind high values detectable already at grading. The meat quality assessment on the day of slaughter can thus be used as a feed back for checking the handling. It may then be possible to optimize the environment in connection with transport and slaughter, and reduce some parts of the problems causing PSE. The part due to very stress-susceptible pigs has to be controlled by breeding, in order to get a reduction of the frequency of the halothane gene. However, it still has to be proved if all pigs subjected to a poor environment may develop very early PSE, or if it applies mostly to halothane sensitive pigs.

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NEWER TECHNIQUES IN LIVE EVALUATION OF PIGS

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Summary

Ultrasound pulse-echo techniques have been used to measure backfat depth in live pigs for more than twenty years. Such measurements have moderately high correlations with carcass composition traits. More advanced ultrasound scanners permit area measurements of muscle in addition to subcutaenous fat, but without large increases in predictive ability. Real-time scanners may offer the possibility of greater precision. X-ray computed tomography is a considerably more sophisticated and costly technique but prediction equations for composition traits have been developed with very high coefficients of variation. This probably arises from the fact that all fat and lean tissues in whole cross sections contribute to the prediction equation rather than just the subcutaneous fat and underlying muscle. Its application will probably be limited, however, by cost and complexity to large scale breeding schemes and research purposes. Nuclear Magnetic Resonance scanning is a technique of similar complexity with probably even greater potential for basic research since it measures parameters closely related to biochemical function. Practical applications are probably even more limited, however.

Whole-body electrical conductivity has been evaluated as an *in vivo* method of measuring pig carcass composition with conflicting results. It may be better than ultrasonics for predicting lean content and may be useful in combination with other methods. Neutron Activation Analysis may be used to measure elemental composition but facilties are so expensive as to be of use only in basic research. Dilution techniques may be as accurate in predicting composition as ultrasound methods but are considerably less practical for most situations. Ultrasonic methods will continue to be predominant for most practical situations while CT and NMR are likely to make major contributions to basic and applied research.

Introduction

There is a widespread recognition of the need to reduce the average fat content of the carcasses of meat producing species. In the short term changes may be brought about by modifications to management practices including a more critical assessment of readiness for slaughter. In the long term improvements in the

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genetic potential of slaughter stock for efficient lean meat production will result from selection of breeding stock based on in vivo assessment of composition. The efficiency of lean meat production will also be raised by a more thorough understanding of the mechanisms of growth from basic research. While a need for in vivo methods is common to all these areas each will impose its own set of restrictions so that a range of methods varying in cost and complexity will be needed.

The application of in vivo methods to pigs has been more successful than in cattle and sheep. This arises from the relatively larger subcutaneous fat depot in pigs which may be measured more repeatably due to its evenness, and also from the quicker return on investment in developing methods due to the larger number of offspring that can be reared. The application of ultrasound probes for in vivo assessment of composition is long-established. This paper will review recent developments in ultrasound techniques and others such as X-ray computed tomography, nuclear magnetic resonance, electrical conductivity and dilution techniques.

Ultrasound pulse-echo techniques

The principles of ultrasonic techniques have been described by Miles (1978). In brief, boundaries between tissues of different acoustic impedance produce an echo when high frequency sound waves (ultrasound) are propagated through a body. From a knowledge of the velocity of ultrasound in fat and muscle tissues it is therefore possible to map the boundaries between these tissues from the echo picture and take linear and area measurements. Simple probes (A-mode) have been used with moderate success for taking 'spot' fat depth measurements on live pigs since the 1960's. More recently B-mode scanners and real-time scanners have been used to take area measurements to see if greater accuracy of prediction of carcass paramaters can be achieved. The application of ultrasonic techniques to predicting composition in livestock has been reviewed most recently by Thwaites (1984), who concluded that the differences in predictive accuracy of the instruments that had been evaluated were small despite considerable variation in complexity and cost. Residual standard deviations for percentage lean predicted from one or more backfat depths have been reported in the range 1.3 to 2.7 (Table 1). No improvement in accuracy is generally found from inclusion of muscle area measurements in the prediction equation. Molenaar (1984) obtained residual standard deviations in the range 0.9 to 1.9 with a Kontron real-time scanner and conlcuded that these more complex machines offered the possibility of greater precision. A further real-time scanner (Pie-Data) was found to give higher coefficients of determination for predicting percentage lean than a simple linear backfat machine (Renco LM) (Molenaar, 1985).

X-Ray Computed Tomography (CT)

A detailed description of the principles of CT may be found in textbooks (e.g. Hamilton, 1982). In brief, a two-dimensional cross-sectional image is produced by rotation of an X-ray source

TABLE 1: Prediction of percentage lean with different ultrasonic machines

Reference	Instrument	Best rsd for lean %
1. Kempster et al., 1979	Sonatest	2.72
	Scanogram	2.18
	Danscanner	2.03
	Ilis	2.61
2. Alliston et al., 1982	Sonatest	1.29
	Scanogram	1.35
	Danscanner	1.33
3. Sather et al., 1982	Krautkramer	1.72
	Scanoprobe	1.71
4. Sather et al., 1987	Krautkramer	1.66
	Scanoprobe	1.63
	Renco	1.62
5. Molenaar, 1984	Kontron	0.84
6. Molenaar, 1985	Pie-Data	1.33

around the body through 360°. An arc-array of highly sensitive detectors measures the attenuation of radiation pulses as it rotates in synchrony with the source. Attenuation data from a large number of crossing pathways are processed by the computer and resolved into a square matrix of density values (CT numbers) which is displayed on a screen using either a grey-scale or colours. By convention water has a density of 0 Houndsfield Units, fat tissues have negative values and muscle tissues have positive values.

The image matrix data may be stored and used to reproduce the image for later evaluation or for manipulation of the data to generate prediction equations for carcass compositional traits. The first step in data manipulation is to exclude non-carcass parts by drawing a region of interest. The remaining data are then used to produce a frequency histogram of CT numbers. Since fat and lean pigs have characteristically different histograms, particularly for the ranges equivalent to fatty tissues and muscle, parameters of these histograms are likely to be closely related to carcass composition. Even after eliminating values outside the soft-tissue range (say -200 to +200) a large number of frequency values (400) per scan remain as potential predictors of compositional traits. Much of the effort in developing the use of CT as an *in vivo* method of predicting composition has been devoted to the optimum use of these frequency data and to combining data from scans taken at a number of locations.

Results from CT

The potential of CT for measuring composition in pigs was first reported in 1981 (Skjervold et al., 1981), who found R^2 values in the range 0.80 to 0.89 for the prediction of chemical compositional traits in 23 pigs (Table 2).

TABLE 2: Prediction of carcass composition and energy content from the distribution of CT numbers (From Skjervold et al., 1981)

	R^2 values for prediction of:			
Chemical analysis of:	% fat	% protein	% water	energy content
The slice	0.89	0.80	0.85	0.85
The whole carcass	0.89	0.83	0.82	0.85

Using a Siemens Somatom 2 a larger scale trial was reported by Vangen (1984). R^2 values in the range 0.76 to 0.95 were achieved for the prediction of chemical composition and energy content of boars from equations using CT number frequency data from one or two scans (Table 3).

TABLE 3: Prediction of carcass composition and energy content from distribution of CT numbers or from ultrasonic backfat depth (from Vangen, 1984)

		R^2 (SEE) for estimation of:		
Dependent variables	d f	protein (kg)	fat (kg)	energy content (mj/kg)
Weight (w)	1	0.40 (0.72)	0.04 (1.79)	0.00 (69.1)
W + one scan	41	0.76 (0.65)	0.90 (0.79)	0.88 (31.6)
W + two scans (only signif. contributions)	16[1]	0.75 (0.52)	0.95 (0.47)	0.92 (21.3)
W + backfat	6	0.42 (0.74)	0.24 (1.61)	0.25 (60.2)

[1]df = 18 for fat model

Protein was predicted with lower accuracy than either fat or energy content. Ultrasonic backfat depth was no better than weight alone in predicting protein content and was considerably worse than CT at predicting fat and energy content (R^2 0.24 to 0.25). There was evidence that the poor performance of ultrasonics was in part due to a fall-off in precision at very low backfat values (average was 10.2 mm). CT does not seem to suffer from the same problem since it identifies all the fatty tissues in the cross-section rather than just the subcutaneous fat over the *longissimus dorsi* muscle. The superiority of CT over ultrasonics in this trial is emphasised in Table 4 which shows the residual variation in protein, fat and energy content explained by CT in addition to weight and in addition to ultrasonic backfat depth. CT explained 45% of the variation in protein content unexplained by ultrasonics and between 84 and 87% of the residual variation in energy content.

TABLE 4: Explanation of the residual variation in carcass composition and energy content by the distribution of CT numbers (From Vangen, 1984)

	Proportion of residual variation explained for:		
In addition to weight:	protein (kg)	fat (kg)	energy (mj/kg)
One scan	0.47	0.78	0.75
Two scans	0.58	0.95	0.92
Best equation	0.70	0.96	0.98
In addition to ultrasonic backfat depth:			
One scan	45	87	84

The stepwise regression approach when used with the large number of potential regressor variables that are available from even a small number of scans (e.g 40 per scan if the frequency data are summed over intervals of 10) leads to complex models with many degrees of freedom. Furthermore, differences between possible predictor variables in their contribution to reducing the SEE or increasing the R^2 value are small so that the order of selection may be rather arbitrary. This might be expected to lead to equations lacking robustness. Vangen (1985) used the cross-validation technique to determine standard errors for prediction and compare these with those for estimation for models with from 5 to 50 degrees of freedom (Table 5). Prediction errors compared favourably with those for estimation for both protein and fat with the best model in each case having as many as 40 degrees of freedom.

TABLE 5: Standard errors of estimation (SEE) and standard errors of prediction (SEP) for different regression models in prediction of carcass protein and fat content (From Vangen, 1985)

		Degrees of freedom for model						
		5	10	15	20	30	40	50
Protein, kg:	SEE	0.592	0.546	0.485	0.482	0.403	0.314	0.236
	SEP	0.594	0.588	0.567	0.528	0.548	0.506	0.586
Fat, kg:	SEE	1.063	0.934	0.833	0.746	0.599	0.419	0.350
	SEP	1.281	1.069	0.929	0.864	0.815	0.585	0.649

The stability or robustness of prediction equations is better tested on data sets totally unrelated to those from which the equations were derived. Vangen et al (1984) used equations from the trial reported above in three experiments to predict composition in a total of 18 Norwegian Landrace pigs and 19 pigs from a line selected for high backfat thickness. In the two experiments where the pigs were within the weight range of the original data (1 and 3) predicted values for protein and fat were quite close to those found by analysis. In experiment 2, however, where the pigs were lighter considerable bias was observed (Table 6). This suggests a need for specific equations for different weight ranges, possibly arising from changes in the chemical composition (and hence CT value) of the tissues with growth.

One advantage of CT over ultrasonic techniques is that information about the composition of individual tissues may be obtained. Allen and Vangen (1984) developed equations for predicting the chemical composition of samples of subcutaneous fat, the longissimus dorsi muscle and a mixed lean and fat sample (bacon side or streak) from the mean CT number of equivalent regions drawn on a scan image. Muscle and fat areas were also calculated and used in prediction euqations in an attempt to compare the predictive ability of CT and ultrasonics, since these areas could be measured with ultrasonic scanners, though probably with lower precision (Simm, 1986). For percentage water in the subcutaneous fat and chemical composition of the bacon side CT explained only 4 to 5 percent more of the residual variation than did area measurements (Table 7). For intramuscular fat content, CT explained no more variation than the base model (weight plus sex) whereas muscle area explained an additional 5 per cent. A more sophisticated regression analysis increased the proportion of the variation in intramuscular fat content explained from 0.25 to 0.39 (Vangen and Kolstad, 1986).

Nuclear Magnetic Resonance (NMR)

The principles of NMR imaging are given in detail in texts such as Gadian (1981) and Hamilton (1982). In brief when a body is subjected to a strong magnetic field atomic nuclei with an odd number of protons and neutrons spin at characteristic frequencies. The electromagnetic signals emitted yield information on the concentration and distribution of these nuclei which can be used to map and image the various tissues and organs. In fact a range of images may be formed by using different parameters of the emitted signals which are more closely related to the fundamental biochemical properties of the tissues than are CT images. Unlike CT there are no moving parts with NMR and the technique does not use ionising radiation. There is no known health hazard from the magnetic fields of the strength employed (typically about 2 tesla).

TABLE 6: Comparison between protein and fat content determined chemically and predicted from CT data in three experiments (from Vangen et al., 1984)

	live weight (kg)	protein (kg) by:- chemical analysis	C.T.	fat (kg) by:- chemical analysis	C.T.
Experiment 1:					
Fat line	97.4	8.0	7.7	24.5	24.5
Norwegian Landrace	107.7	10.4	9.2	15.8	13.4
Mean	102.1	9.1	8.5	20.6	19.5
Experiment 3:					
Fat line	81.9	6.9	6.3	20.5	19.1
Norwegian Landrace	85.0	7.5	7.0	12.2	9.4
Mean	83.5	7.2	6.7	16.7	14.7
Experiment 2:					
Fat line	63.7	7.4	5.6	23.4	12.3
Norwegian Landrace	60.3	10.1	5.3	12.5	5.5
Mean	62.3	8.5	5.5	19.1	9.6

TABLE 7: Prediction of composition of lean and fat samples from mean CT number and/or subcutaneous fat and LD areas (from Allen & Vangen, 1984)

	Model							
Dependent variable	Wt+Sex(S)		Wt+S+Areas(A)		Wt+S+CT		W+S+A+CT	
Bacon side:	R^2	RSD	R^2	RSD	R^2	RSD	R^2	RSD
% water	0.71	4.46	0.83	3.40	0.87	2.97	0.88	2.89
% fat	0.72	5.66	0.85	4.13	0.88	3.60	0.89	3.45
% protein	0.67	1.48	0.80	1.13	0.84	1.02	0.85	0.97
SCF:								
% water	0.59	4.12	0.77	3.13	0.82	2.75	0.82	2.75
LD:								
% fat	0.24	0.50	0.29	0.49	0.25	0.50	0.30	0.48

Results with NMR

Although there is little doubt that NMR has potential for measuring compositional traits in vivo no large-scale trials have yet been reported. Fuller et al (1984) using an NMR spectrometer showed that T_1 values for muscle and adipose tissues in vitro differed by a factor of 1.5, fat having the shorter relaxation time. Using the pulse-sequence technique and a powerful NMR imager Foster et al (1984) reported a contrast ratio of 6 between fat and muscle. Groen eweld et al (1984) scanned a single pig and a half-carcass by NMR and a single pig by CT and concluded that while CT gave greater fat-lean and fat-bone discrimination than NMR with a minimum contrast of 6 standard deviations for NMR, both systems gave sufficiennt discrimination. In the same study high correlations (0.97 - 0.98) between T_1 or T_2 values and fat:lean ratios for in vitro samples were reported.

Electrical Conductivity

Lean tissues being more ionic conduct electricity better than the less hydrated adipose tissues. Whole-body conductivity is therefore an indication of the lean:fat ratio. In contrast to most other techniques of in vivo assessment of body composition,, the technique was originally developed for use in pigs (Domermuth et al 1973) and has only recently been examined for use in human studies. The original equipment, known as electronic meat measuring equipment (EMME) consisted of a long solenoid coil driven by a 5MHz source generating an induced electrical field within a tunnel. The presence of a pig within the tunnel perturbates the induced field. The EMME measurement is an indication of the current needed to re-establish the field and is related to the whole-body conductivity of the pig. The method is quick to operate and totally harmless.

Results with Electrical Conductivity

As with many other techniques there have been conflicting reports of the usefulness of EMME readings in predicting body composition in pigs. Domermuth et al (1976) reported that three EMME readings were of about equal value to shrunk body weight for the prediction of either carcass protein or the weight of lean cuts, with only a minimal improvement when the two were used as co-predictors. However, there was considerable variation in liveweight in this experiment.

TABLE 8: Comparison of R^2 values for predicting carcass traits from EMME values and ultrasonic backfat with models including and excluding treatment (sex, diet, housing) (from Joyal et al., 1987)

	R^2	R^2 [1]	R^2 [1]	R^2 [1]
Base model includes treatment	1 Wt+treatment	2 1+EMME	3 1+backfat	4 1+EMME + backfat
Wt of lean	0.31	0.17**	0.09**	0.21
Wt of subcutaneous fat	0.19	0.08**	0.42**	0.44
Base model excludes treatment	1a wt	2a 1a+EMME	3a 1a+backfat	4a 1a+EMME + backfat
Wt of lean	0.20	0.11**	0.18**	0.14
Wt of subcutaneous fat	0.02	0.16**	0.58**	0.59

[1] R^2 = the increase in R^2 value over base model

In the most recently reported trial, Joyal et al (1987) found EMME number to be a better predictor of weight of lean in carcass than ultrasonic fat depth when weight and treatment (feeding level, sex, housing system) were included in the model, but the reverse was true for weight of subcutaneous fat (Table 8). When both were used in combination the R^2 value for the prediction of lean weight was significantly increased but the improvement for subcutaneous fat was only marginal. However, in most practical situations diet and housing conditions are unknown. When sex and treatment were excluded from the models, ultrasonic backfat was a better predictor of both lean and subcutaneous fat weights and there was no further significant increase in the R^2 value when both EMME and ultrasonic backfat depth were used in combination (Table 8). EMME may therefore be a technique with greater potential in experimental situations than in widespread practical applications.

Neutron Activation Analysis (NAA)

Neutron Activation Analysis has been developed as an important tool in human medicine with the ability to measure the total body content of a number of elements - calcium, phosphorus, sodium, cadmium, iron, iodine, chlorine, potassium, nitrogen, hydrogen, oxygen, carbon, aluminium and silver. Of these potassium is the only element with a naturally occurring radioisotope (40K) but other elements may be radioactive by exposing them to a source of neutrons. The induced isotopes may be measured by whole body counts. The data are translated into quantitative measurements of the elements of interest by comparing the spectra and counting-rates with those obtained from phantoms containing dispensed amounts of the appropriate elements.

The technique is very costly since it requires both a neutron source and a whole-body counting facility. Conventional whole-body counters employ a shielded room constructed of lead or steel to protect the detectors from background radiation. Animals would have to be anaesthetised and the limited penetration of neutrons imposes a size limit equivalent to a body weight of about 100 kg. Since muscle and adipose tissue differ considerably in elemental composition, in vivo NAA measurement of appropriate elements may provide a useful prediction of the lean: fat ratio in the body. Encouraging results have already been achieved for live rats and humans and for pig and sheep carcasses (Preston et al 1984). The same authors suggest that determination of total body protein and mineral content may be achieved with satisfactory precision from in vivo NAA measurement of nitrogen and clacium, but assessment of body fat by difference using NAA measurement of oxygen to give total body water may not be sufficiently accurate.

Tracer Dilution techniques

The basic theory of dilutiion techniques is that if a known amount of a biological tracer is injected into an animal it will become uniformly distributed throughout a compartment of the body (body water, fat etc). By measuring the concentration of tracer in the body pool after equilibrium is reached the size of the compartment can be calculated. Dilution techniques have most commonly been employed to measure total body water and from this to make predictions of body composition. Tritiated water, antipyrene and its derivatives and deuterium oxide have been used. Evans Blue has been used to estimate blood volume.

The main source of error in estimating carcass composition from tracer dilution in the body water arises from variation in the proportion of total body water contained in the gut contents and other non-carcass parts. A second source of error is the assumption of a constant ratio of water to protein in the lean body mass. Although this varies fairly predictably with maturity it may give rise to bias in breed comparison studies or when dietary or other treatments may affect this ratio.

Conflicting results have been reported in work on pigs. Ferrell and Cornelius (1984) used D_2O dilution to predict body composition in obese and normal pigs. They concluded that D_2O space was little better than liveweight for predicting body composition and was influenced by pig type. In one of the few studies where several dilution techniques have been compared, Houseman and McDonald (1976) found that D_2O dilution in body water, 42K dilution in lean body mass and Evans Blue dilution in blood all gave better estimates of body composition than liveweight and the first two were superior to ultrasonics (Table 9). Lipid weight was estimated with standard errors of 1.6 and 1.5 kg respectively when D_2O space or 42K was used in combination with liveweight. One reason for the high correlations achieved in this study, however, is the wide range of fatness. Shields et al (1983) also reported strong relationships between D_2O space and pig carcass composition, but the high R^2 values (0.97 - 0.99) reflect the very wide weight range (6.4 to 109 kg), and no comparison with a simpler technique is given.

TABLE 9: Correlation coefficients between individual predictors and body composition measurement in 24 pigs (weight range 72.3 - 92.3 kg) (Houseman and McDonald, 1976)

Method	total corr.	partial corr[1]	C V est (%)
Fat free wt			
Live wt	0.62	-	8.0
D_2O space	0.96	0.95	3.3
42K space	0.98	0.96	2.9
Evans Blue	0.83	0.72	7.2
Lipid Wt			
Live wt	-0.01	-	-
D_2O space	-0.66	-0.96	2.9
42K space	-0.77	-0.95	3.3
Evans Blue	-0.56	-0.71	7.4

[1] Live weight constant

Conclusions

There are several problems in making definitive statements about the relative merits of the techniques available for *in vivo* measurement of body composition in pigs. Not least of these is the small number of trials where a range of techniques have been compared on the same group of animals. Furthermore in many trials relatively complex methods have not been compared to simple, readily available indicators of composition such as liveweight, sex and growth rate.

Many trials, particularly those involving new techniques, have been carried out using animals with much wider variation in age, weight and composition than would be the case in practice. While this may be justifed in order to check the linearity of relationships over a wide range, the high correlation coefficients reported can be misleading. Too often such studies have not been followed by validation exercises on more homogeneous groups of animals.

Making comparisons between techniques across different studies is also complicated by factors such as differences in the experience of operators, the choice of dependent variables, the size and variability of the sample and the presentation of the results.

TABLE 10: Comparison of *in vivo* techniques used to predict composition in pigs

Reference	Conclusion
Vangen, 1984	CT better than ultrasonics for protein, fat and energy
Joyal et al., 1987	Ultrasonics better than EMME for fat, EMME better for lean for experiments
Housemann & McDonald, 1976	Dilution techniques better than ultrasonics for all compositional traits
Domermuth et al., 1976	EMME and 40K dilution equal for lean weight and chemical composition
Fredeen et al., 1979	Ultrasonics better than EMME for fat, about equal for lean
Metz et al., 1984	Ultrasonics better than adipose tissue composition and fat cell size for lean and fat

The conclusions from some trials where more than one technique have been included are summarised in Table 10. All available evidence suggests that X-ray CT is more accurate at predicting composition than ultrasonic methods. Whether this increase in accuracy is justified by the higher cost will depend upon the partricular use of the *in vivo* measurements. Ultrasonics appear to be superior to EMME in predicting fat content but the reverse may be true for lean in situations where diet and rearing conditions are known. While dilution techniques may be more accurate than ultrasonics they are impractical for most situations. Ultrasonic techniques will undoubtedly continue to be important in most practical situations. CT may be justified for large scale breeding schemes particularly in populations where average backfat measurements are relatively low due to lower accuracy of ultrasonic measurements at low fat levels. CT, NMR, EMME, NAA and dilution techniques may all have future roles in basic research.

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ELECTRONIC GRADING OF PIG CARCASSES: THE CANADIAN EXPERIENCE

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Summary

After five years of research and development, Canada became on March 31, 1986, the second country to use electronic grading probes for grading pig carcasses. During that five year period, research included a scientific evaluation of the various electronic grading probes available, field tests to determine the reliability of these instruments under abattoir conditions and a study to estimate the impact of electronic grading on the Canadian pig population.

In 1987, close to 14 million pigs were graded electronically. The estimated lean yield was derived from the fat thickness and muscle depth measured on the left side of the carcass at the 3/4 last ribs, 7 cm lateral to the exposed surface of the split carcass. That measurement and the warm carcass weight were together converted into an index value (100 being the average index) which was then used for the financial settlement of the carcass.

An electronic probe is approved for use in Canada only after it has met strict specifications. These specifications were established through a collaborative effort of the Canadian Pork Council (the national organization of pork producers), the Canadian Meat Council (the national organization of slaughterers and processors) and Agriculture Canada. The specifications encompass three areas, firstly, a prediction equation to estimate the lean yield of the carcass is derived using approximately 220 carcasses. These carcasses are selected to be representative of the Canadian pig population. Secondly, a field test is conducted to verify the reliability of the probe under abattoir conditions and thirdly, a comparison test against the baseline probe is made to ensure that the grading information obtained is consistent with the grading information of the baseline probe.

Two electronic probes are currently approved for use in Canada: the Hennessy Grading Probe (GP-II) and Destron's Pork Grader (PG-100). A third one, the Fat-O-Meater (FOM), is in the final stages of the approval process. In addition to the specifications for approval, a monitoring procedure has been instituted to ensure that all probes and graders are operating within set specifications.

Introduction

In 1987, 14.2 million pigs were slaughtered in Canada, of which 14 million were classified or graded (Anonymous, 1988). Indeed, under federal legislation, all carcasses moving across provincial and/or national borders have to be classified. Furthermore, in all but one province, marketing boards have received the mandate under provincial legislation to market all pigs in their respective province, and these boards have elected to use the classification or grade derived from the national scheme as a basis for the financial settlement between the producer and the abattoir.

In Canada, pig carcasses are evaluated using the weight of the carcass and the lean yield of the carcass; the latter is estimated from the fat thickness and muscle depth measured at a location between the 3rd and 4th last ribs and 7 cm lateral to the mid-line. By using the weight and the estimated lean yield of a carcass, an index value is derived (Table 1).

According to De Boer's definition of classification systems and grading, the Canadian system has elements of both a classification and a grading scheme (De Boer, 1984). It has elements of a classification scheme because it objectively describes the carcass in terms of estimated lean yield and carcass weight. And it has elements of a grading scheme because it assigns, based on the estimated lean yield and the carcass weight, a yield class value and a weight class value to a carcass. These class values are used to derive an index representing the proportion of the bid price received for a carcass. The bid price is determined according to the supply and demand of pork within the North American continent. Thus, the index assigned to a carcass reflects the relative economic value of that carcass.

Table 1. The Canadian Hog Carcass Grading System*

		Weight class (Value/kg)									
		1	2	3	4	5	6	7	8	9	10
		40 - 59.99	60 - 64.99	65 - 69.99	70 - 74.99	75 - 79.99	80 - 84.99	85 - 89.99	90 - 94.99	95 - 99.99	100+
Yield Class	Estimated Lean Yield (%)										
1	≥ 53.6	80	100	106	112	114	113	111	108	100	81
2	52.8-53.59	80	98	105	111	113	112	109	107	98	81
3	52.0-52.79	80	97	103	109	112	111	108	105	97	81
4	51.2-51.99	80	95	101	107	110	109	107	103	95	81
5	50.4-51.19	80	93	100	106	108	107	106	102	92	81
6	49.6-50.39	80	92	98	104	107	106	104	100	90	81
7	48.8-49.59	80	90	96	102	105	104	102	97	87	81
8	48.0-48.79	80	89	95	101	103	102	101	95	83	81
9	47.2-47.99	80	88	93	99	102	101	99	92	82	81
10	46.4-47.19	80	87	91	97	100	99	97	90	82	81
11	45.6-46.39	80	86	89	96	98	97	96	88	82	81
12	44.8-45.59	80	85	88	94	97	96	94	85	82	81
13	44.0-44.79	80	83	87	92	95	94	92	82	82	81
14	43.2-43.99	80	82	86	90	91	90	91	82	82	81
15	42.4-43.19	80	82	85	88	89	88	87	82	82	81
16	41.6-42.39	80	82	82	87	88	87	86	82	82	81
17	< 41.6	80	82	82	82	82	82	82	82	82	81

*Anonymous, 1986

Development of the index table

Four factors were considered in arriving at the index table, namely, the lean yield of the individual cuts of the carcass, (ham, loin, picnic, butt and belly), the fat trim from each cut, the weight of each of the individual cuts, and finally the total weight of the carcass.

The lean content of the individual cuts and the fat trim for each yield-by-weight class combination were determined objectively in an across-Canada cutout test which took place at three geographical locations and involved a total of 3800 carcasses (Martin et al., 1981; Fortin et al., 1981). The monetary value for each of the individual cuts in each yield-by-weight class combination was determined according to the prevailing wholesale market. Fat trim as such was also valued according to the wholesale market for fat.

Because of its own weight, each individual cut can take on a unique value depending on the extent of its deviation from a market predetermined ideal weight. For example, a 5 kg ham may have, for marketing reasons, a different value than a 7 kg or 9 kg ham. The monetary factors as they relate to the variation in the weight of the individual cuts were arrived at through discussions among industry and producer representatives.

Finally, the weight of a carcass was also considered in assessing the overall economic value of a carcass since labour costs are expressed on a pig carcass basis. On that basis, a light carcass is processed at a higher cost per kilogram than a heavy carcass and is less valuable, therefore, to an abattoir. Thus, adjustments were made for the variation in value associated with the costs of production. Once again, these price adjustments were established through negotiations. In addition, light and heavy carcasses are descriminated against because it was believed that, because of the weight and/or quality of the cuts from these carcasses, they could not easily be marketed through the normal channels.

Over the years, the Canadian system has evolved through processes of objectivity in determining the lean yield of a carcass and of subjectivity in establishing the monetary value of the various components which make up the index table. This process, which involved participants from the scientific community, the meat industry and the producer organizations had both a scientific and a political component. The Canadian system was derived from a consensus of people often representing opposite opinions, interests and objectives. However, although the Canadian system is the product of a consensus, it is nevertheless administered by a third party to ensure its integrity and maintain a high level of credibility among the users. This third party has historically been Agriculture Canada which is the Federal Department of Agriculture.

Development of electronic grading

In its current format, the Canadian system was first introduced December 30, 1968. At that time, the index for a given carcass was derived from a weight class and a fat class (Anonymous, 1969). The fat class was defined as the sum of two ruler backfat measurements on the split carcass taken at the point of maximum thickness at the shoulder and maximum thickness at the loin. Weight classes were defined in 10 lb intervals. In 1981, the fat class was redefined as a single ruler backfat measurement on the split carcass taken at the point of maximum thickness at the loin (Anonymous, 1982). And finally, in 1986, with the implementation of electronic grading, the Canadian system was extensively revised (Anonymous, 1986). The weight classes were redefined and expressed in 5 kg intervals. Fat classes were replaced by lean yield classes. The lean yield of a carcass is now estimated from a fat thickness measurement and from a muscle depth measurement made with an electronic probe between the 3rd and 4th last ribs, 7 cm lateral to the mid-line. This estimated lean yield is converted into a yield class to provide an index value.

In 1986, when Canada became the second country, after Sweden, to convert completely to electronic grading of pig carcasses, two probes were certified for use in Canada: the Hennessy Grading Probe (GP-II) and the Destron's Pork Grader (PG-100). Currently, there are 28 plants across Canada using these probes. In 1987, these 28 plants slaughtered over 80% of the pigs marketed in Canada, while at the remaining plants, slaughtering less than 1000 pigs per week, pig carcasses are still graded using a ruler measurement of fat thickness. This measurement is converted into a yield class which uses the same index table (Anonymous, 1986). The ruler measurement is also used as a backup procedure in cases when probes become defective. However, most of the major plants have purchased two probes to cover this eventuality.

The research and development leading to electronic grading in Canada took six years. Indeed, early in 1980, members of the Canadian Meat Council (representing the interest of the meat industry), members of the Canadian Pork Council (representing the interest of the producers) and representatives of Agriculture Canada (the organization responsible for delivering the grading program to the Canadian pork industry) first met to discuss the possibility of using fully- or semi-automated probes for grading pig carcasses. The concept was readily accepted in principle by all three groups. This new concept was seen as a means to improve the accuracy of grading by allowing the use of alternative measurement sites, by making the measurement of muscle depth possible, and by reducing the extent of human involvement in the grading function. It was also seen as a means to reduce the cost of the grading settlement function. Finally, it was seen as a means to increase the operational flexibility of the grading function through automatic data capture.

Following this first meeting, a study was commissioned to investigate the feasibility of electronic grading under Canadian abattoir conditions. One of the major conclusions of the study was that probes using the principle of light reflectance for measuring fat and muscle thickness have the greatest potential for successful application.

Following this, a three-year action plan was prepared with a target date of early 1984 for implementation. However, this was overly optimistic and the plan very quickly became a five-year plan. The action plan consisted of a scientific evaluation of the available probes, a field evaluation of the probes, and a study to assess the impact of this new concept on the then current ruler grading system. Throughout the entire process, every decision taken was the result of a consensus among representatives of the Canadian Meat Council, the Canadian Pork Council and Agriculture Canada.

Scientific evaluation

Several questions remained unanswered about the probes. First of all, would the use of any of these probes be an improvement over the existing system which, at that time, was a ruler measurement of backfat at the loin? We know now that electronic grading is a better system than ruler grading, but the question, nevertheless, had to be answered. Once this was established, the location(s) and the number of measurements had to be determined. In addition, the relative performance of each of the available probes (the Danish Fat-O-Meater, the New Zealand Hennessy Grading Probe and later on, the Canadian Destron's Pork Grader) had to be evaluated.

A testing protocol, which is now appended to the grading regulations, was prepared (Anonymous, 1986). In this protocol, each carcass selected is measured by all probes. Each carcass is dissected to determine its lean content. Parameters such as the coefficient of determination and the residual standard deviation for the prediction equation of lean yield, derived from fat and muscle thickness measurements, are two of several parameters used to evaluate the performance of these probes.

In this testing protocol, 224 carcasses with equal number of barrows and gilts are used. Carcasses were selected to ensure that they represented a cross-section of those usually found in the Canadian pig population (Table 2).

Table 2. Sampling of carcasses for testing protocol.

Carcass weight (kg)	Number		
	barrow	gilt	total
<72.5	28	28	56
72.6-81.6	66	66	112
>81.7	28	28	56

For the original research project (Fortin et al., 1984), several probing locations were investigated, namely, the last rib, between the 3rd and 4th last ribs, between the 4th and 5th last ribs, and between the 5th and 6th last ribs. Also, at each of these locations, measurements were made 5, 7 and 9 cm lateral to the mid-line.

Based on the results of the scientific evaluation and on practical considerations, the probing site located between the 3rd and 4th last ribs, 7 cm lateral to the mid-line, was selected. For operational reasons, it was also felt that a single probing site had to be selected in order to accommodate the fast speed slaughter lines found in the Canadian abattoirs. And finally, because of the low percentage of left-handed graders, the decision was also made that only the left side of the carcass be probed.

When judging the performance of the probes in predicting the lean yield of a carcass from the measured fat thickness and muscle depth, the results of the scientific evaluation first of the Hennessy Grading Probe (GP-II) and the Fat-O-Meater (FOM) (Table 3) and later of the Canadian Destron Pork Grader (PG-100), the Hennessy Grading Probe and the Fat-O-Meater (Table 4), showed that none of the probes tested had a marked advantage over any of the others.

Table 3. Residual standard deviation (rsd) and coefficient of determination (r^2)*.

	GP-II	FOM
rsd	2.13	2.09
r^2	0.51	0.53

*Fortin et al. (1984)

Table 4. Residual standard deviation (rsd) and coefficient of determination (r^2)*.

	GP-II	FOM	PG-100
rsd	1.76	1.69	1.66
r^2	0.49	0.52	0.54

*Usborne and Fortin (unpublished)

Field evaluation

It was reassuring to find out that these probes could indeed perform satisfactorily under laboratory conditions but it was also necessary to know how well these probes could withstand the test of abattoir conditions.

As part of the field evaluation, the following criteria were employed: the frequency of breakdowns, the number of reprobes, the retention of calibration, the time required to take a measurement, ease of operation, ease of interface with North American computer technology and finally an overall subjective rating (1-10).

This field evaluation was conducted by experienced Agriculture Canada personnel. Once again, based on the field evaluation results, none of the three probes really stood out from any of the other two. Consequently, all three probes were judged to be adequate for use under Canadian abattoir conditions.

Impact assessment

The adoption of a new technology always means disruption to established systems and, of course, the introduction of electronic probing had that potential. Furthermore, at the time of implementing electronic grading, weight classes were also being redefined and fat classes were being eliminated and replaced by lean yield classes. It was then critical, in order for the Canadian pork industry to accept this new technology, to know exactly the effect of this new technology on grading. Hence, the need for a study to assess its impact.

It was felt by the Canadian industry that, for this new technology to be accepted, the overall average index for a given group of pig carcasses graded under this new technology should not be greatly different from the overall average index obtained using a ruler backfat measurement although it was recognized that, for individual pig carcasses, it might not necessarily be so. This was a requirement of both the Canadian meat industry and producers. The challenge was to gain acceptance for a new concept without markedly altering a ruler grading system that was well liked by the Canadian pork industry and had received great praise in the past. Although, there was great potential for improving the precision for assessing the 'TRUE' value of a carcass, it has not been fully fulfilled because of this industry requirement.

In the Fall of 1984, information consisting of a ruler measurement of fat at the loin and probe measurements of fat thickness and muscle depth taken between the 3rd and 4th last ribs was collected on approximately 160,000 pig carcasses. These carcasses originated from all pig producing regions of Canada. This information was used by the Canadian Meat Council and the Canadian Pork Council throughout their negotiations to arrive at an index table that would meet the basic requirement of similarity between the current and proposed systems. A table was agreed upon in the Fall of 1985 (Table 1). The Canadian industry was ready for electronic grading.

Monitoring program

Since March 1986, Agriculture Canada as the organization responsible for delivering the program, has been conducting a monitoring program to ensure that the integrity of the probes operating in the various plants is maintained and that the graders operating these probes are performing within acceptable levels.

Twice a year, each probe is tested against a benchmark probe. For each test, 100 carcasses are probed both with the plant probe and the benchmark probe. The deviation between the two estimated lean yields for each carcass is the criterion used to pass judgement on the integrity of the plant probe. Through consultation with the Canadian pork industry, tolerance limits have been established for the average deviation between estimated lean yields, overall and within each yield class. Tolerance limits have also been established on the extent of individual carcass variation as measured by the standard deviation of the deviation between estimated lean yields, overall and within each yield class. If any of these parameters fall outside the preset tolerance limits, the plant probe is then decertified and is recertified only when it meets the tolerance limits.

Graders are also monitored on a regular basis for correct probing angle and location. If the grader's rate falls below a certain level, the grader is then removed from the slaughter line and given further training. The grader is only allowed to return to grading after the rate reaches again the acceptable level.

Comparison of the Hennessy grading probe and Destron's pork grader

As mentioned previously, the major but somewhat misguided concern of the Canadian pork industry about the new technology for grading pig carcasses, was and still remains that the average index for the Canadian pig population under this new technology be similar to the average index that would have been assigned under the ruler grading system. Furthermore, with the current use of at least two different probes, and a third one in the near future, the same criterion of similarity is expected by the Canadian pork industry. In other words, whether a group of pig carcasses is classified using the Hennessy Grading Probe, the Destron's Pork Grader or any other probe the average estimated lean yield and the average index for that group of pig carcasses should be similar.

However, there is also a perception in a small segment of the Canadian pork industry that this concept further implies that, in addition to overall similarity, a given single carcass should also receive a similar estimated lean yield and consequently a similar grade regardless of the probe used. Because of the limits of precision associated with the prediction equation for each probe, this is not a realistic expectation. However, this concern by a small segment of the Canadian pork industry has forced Agriculture Canada to undertake an extensive education program to remedy the misconception.

The Canadian grading system is expected to accomplish several goals; namely, to estimate the lean yield of a carcass from a measurement of fat thickness and muscle depth, to convert that estimated lean yield into a yield class, and finally, to derive from this yield class together with the weight class an index value to be used for the financial settlement of that carcass. Therefore, the performance of a grading system, such as the Canadian system, where the use of probes from different manufacturers is permitted can be assessed in terms of the estimated lean yields derived from the various probes and in terms of the ultimate use of this estimated lean yield; in other words, the assignment of a given carcass to a yield class and a financially associated index value.

As part of the education program initiated by Agriculture Canada, grading data on pig carcasses, probed both with the Hennessy Grading Probe and the Destron's Pork Grader, were collected under abattoir conditions in two different regions of Canada during the latter part of 1987 and early part of 1988. This program is an attempt to demonstrate the extent of the inherent variation associated with the use of two probes under abattoir conditions.

Using the criteria of assessment previously described it is evident that, despite fairly tight tolerance limits on the average deviation between the estimated lean yields, overall and within each yield class (Table 5), there is still some degree of individual variation associated with the use of two probes as evidenced by a standard deviation of the order of 0.4 to 0.5.

Table 5. Mean deviation between estimated lean yields (PG-100 vs GP-II).

Overall: +0.03	(Standard deviation: 0.446)	
Yield class	Mean deviation	Standard deviation
2	0.06	0.408
3	0.01	0.410
4	0.02	0.389
5	0.06	0.386
6	0.00	0.442
7	0.04	0.471
8	0.03	0.404
9	0.02	0.516
10	-0.09	0.493
11	-0.02	0.494
12	0.06	0.511

The extent of this variation is further illustrated in Table 6. Converting the lean yields estimated from the two probes into the corresponding lean yield classes resulted in approximately 30% of all carcasses being assigned a different lean yield class. It is important to remember, however, that under the Canadian grading regulations (Anonymous, 1986) a lean yield class is defined as an interval of 0.8% of estimated lean yield.

Table 6. Percentage of carcasses assigned a similar or different yield class using the GP-II or PG-100.

	Same yield class	Different yield class
Overall	71.4	28.6
Yield class		
2	80.0	20.0
3	70.5	29.5
4	74.4	25.6
5	76.1	23.9
6	71.2	28.8
7	69.3	30.7
8	70.9	29.1
9	71.0	29.0
10	66.4	33.6
11	72.5	27.5
12	64.0	36.0

A similar comparison using two different Hennessy Grading Probes, provided some insight on the extent of the variation apparently inherent to this new technology in the Canadian context (Table 7). The variation associated with two probes from two different manufacturers appears to be no greater than the variation associated with two probes from the same manufacturer.

Table 7. Percentage of carcasses assigned a similar or different yield class using two different GP-II.

Same yield class	Different yield class
60.5	39.5
69.1	30.9
55.6	44.4
52.5	47.5
59.0	41.0

One can only conclude that the individual variation observed in a system such as the Canadian grading system where probes from two different manufacturers are used, is the price for a free enterprise philosophy whereby any manufacturer whose probe meets the technical specifications as specified by the Canadian pork industry can have a probe certified by Agriculture Canada for use in Canada.

Conclusions

During the last two years, major changes in the Canadian grading system have taken place. The general acceptance of these changes by the Canadian pork industry has only been possible because all users were involved throughout the entire process. Electronic grading has generally been accepted by the Canadian pork industry because it is the result of a consensus among the Canadian producers, the Canadian Meat Industry and Agriculture Canada.

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YUGOSLAV PIG CARCASS EVALUATION AND GRADING SYSTEM INCLUDING LEAN MEAT CONTENT
- Its characteristics and application -

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Summary

Creation and development of Yugoslav standards in grading of carcasses and sides of slaughtered pigs on the rail in the post war period are presented. The change of orientation towards breeding of meaty pigs in Yugoslavia started at the beginning of the fifties by importation of Large White pigs from Great Britain, and several years later Dutch and Swedish Landrace from Holland and Sweden, respectively. The first standards for pigs, with all characteristics of British standards for bacon, were established in 1960. The next standard for meat type pigs is completely domestic and it apeared after 7 years of research at the Institute of Novi Sad. In order to come to a reliable conclusion about the real meat yield in fattening pigs in the carcass weight range 65 to 113 kg, 5,500 pig sides have been dissected, according to the method of Weniger et al. The yields of meat, fatty tissue and bone have been determined in cuts of the carcasses (ham, loin, neck, shoulder and rib and belly) as well as total meat yield in the carcass. After statistical analyses of the results obtained, the respective tables have been elaborated concerning the yield of meat as kg and per cent, for the carcasses of pigs weighing 65-113kg. Backfat thickness (sum of mid back + loin measurements) ranged from 30 to 105 mm. A grid was developed giving yield of meat, expressed in kg and percent, for sixteen backfat measurement ranges and sixteen weight ranges. The meat from belly and ribs (processed part "Hamburger bacon") was not presented as lean meat, but it was included in yield of fatty tissue. That difference is significant in relation to European standards. These tables are included, besides the usual text in two standards for meaty pigs, JUS.E.CI 021 from 1969, and in current Regulation from 1985. By applying these standards, for 15 years of work, over 55 million fatteners have been graded in the industrial slaugherhouses in Yugoslavia.

Key-words: standard, regulation, carcass, side, Hamburger bacon, meat yield.

Introduction

Thirty years have passed since the first published review on grading of pig carcasses (Harrington,1958), so that it is now time to apprise as a whole what happened from that time in that field. Considerable progress has been achieved and the success was evident in the following directions:

- Mutual relationships between the basic components of carcass were better understood.
- The basic aims were clarified, and the exactness in grading, as one of the aims, became clearer and more reliable in relation to cost of grading for differecnt purposes.
- The existing techniques have been improved and automated and experience gained in their use.
- The relative possibility of the existing procedures for grading of meatiness and quality of carcasses has been better understood, as well as the scope and inter′ - relationship between procedures.

The research of many authors into these problems is complete and bery profound. Of many of them we mention papers of Hammond, 1955, Elsley et al., 1964, Zobrisky et al., 1958, Sreckovic, 1965, de Boer, 1984, Bichard, 1984, Walstra, 1987, Pedersen, 1984, Glodek, 1986, Nikolic, 1987, and others.

Aim and task

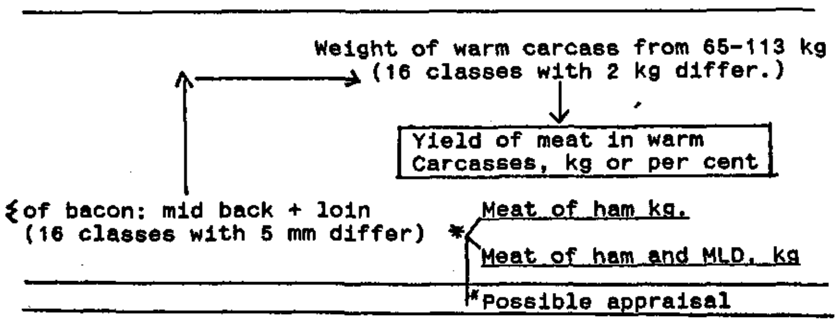
Grading of pig carcasses on the factory rail is a method of collecting direct and indirect measurements which influence carcass value. These comprise measurements of fat which allow prediction of lean meat yield but also subjective assessments such as carcass shape. Processing of data collected has allowed the development of standards which emphasise lean content of carcasses. Such standards are not perfect however and their shortcomings must be accepted. They are however the basis of properly organised breeding and selection schemes as well as the basis for many technical studies in feeding and management of pigs. These standards are not fixed and can be improved from time to time as new scientific knowledge, technical innovations and experience are accumulated.

In the post war period, considerable progress in improvement of pig production in Yugoslavia has been achieved up to the mid fifties. At that time, from Great Britain about 5,000 breeding gilts and sows, have been imported with the respective number of breeding boars of Large White breed, and several years later on, there was an importation of Dutch and Swedish Landrace from Holland and Sweden, respectively. The basic aim of these importations was a fundamental change of breed structure and gradual production of bacon for the British market.

Relatively quickly, by 1961, the first Yugoslav standard for meaty pigs was proclaimed, with the basic aim to grade by it the quality of pig carcasses intended for bacon production. However, bacon production was quickly abandoned, because the market was saturated by offers of higher quality bacon from Denmark and Poland. As a result in the secondhalf of the sixties there was a switch towards another method of fattening of pigs, weighing at slaughter 100-105 kg. These pigs had higher yields of meat in the ham and better conformation of carcasses. The aim of processing of the carcass is: canned ham for American market and other durable products from meat intended to export.

That change in breeding and housing of meaty pigs required the elaboration of new Yugoslav standard for meaty pigs. In research work, which was the basis for elaboration of standards, the biggest contribution has been by the Livestock Research Institute (Department for pig husbandry) in Novi Sad made both methodology and elaboration of the problem and in its realization. Basically, the start was from the oldest and still most correct method of total disscetion of the sides and their cuts to lean, fat and bone. In the course of seven years over 5,500 sides have been dissected, and the work performed in several large industrial slaughterhouses, using the standard teams of technicians and workers. By means of dissection the real yield of lean meat including intramuscular fat was determined in sides weighing from 65 -113 kg. Before slaughter of fatteners they were weighed, then the weighings performed on warm carcasses one hour after slaughter and 24 hours there-after. After that the disscetion of one side (right) has been done dividing the ham, loin, shoulder and neck, and belly and rib into lean fat and bone. The weight of side and its parts was taken before dissection and then the yield of individual tissues. The dissection was carried out according to Weniger et al. Before dissection, on warm and cooled sides the linear measurements have been taken, of length of side and back fat thickness on shoulder, mid back and three loin sites.

Table 1. Appraisement of meat yield in the warm carcass.



The investigations aimed at three basic tasks:

1) Studies and finding of yield of meat and other tissues (fat, bone) in sides of meat breeds of pigs in a wide population and finding of reliable parameters for the most important slaughter characteristics (weight of carcass, back fat thickness, yield of meat).
2) Statistical processing of the results obtained from the dissection of sides into individual cuts and yield of meat in them, as well as of total yield of meat and other tissues in the carcass.
3) Elaboration of methods for appraisement of meatiness of pigs on the rail, as the basic part of the new standard. The control of exactness of the method and its reliability under conditions of industrial slaughterings of pigs.

The first task has provided reliable information about the real slaughter value of white meat type pigs and their crosses from the production of pigs organized by the society (large farms within the combines, private farmers).

The second task, on the basis of the results from the first one, enabled the elaboration of a reliable method for fast appraisement of meatines of sides on the rail (not more than 10 seconds). The principle of indirect determination of yield of meat (in kg and percentage) has been accepted on the basis of weighing or warm carcass (in kg) and back fat thickness (together with the shin) after splitting of carcass (in mm). Measurement of backfat has been done by means of steel tape. By estimation of correlation coefficients for backfat thickness and the amount of meat the following correlation figures have been obtained.

Backfat thickness, in mm on:

- shoulder	r = -0.64
- mid back + loin	r = -0.71
- shoulder + mid back + loin	r = -0.60

The most reliable indication for appraisement of meatiness was taken as the sum of measurement of mid back + loin.

The third task was to control the exactness of the method elaborated on large numbers of slaughtered fatteners, of different weight categories, choosen from representative production areas.

After these controls the standards for meat type pigs for industrial processing JUS E.CI.021 was declared in 1969, as well as the current Regulation about the quality of slaughtered pigs and categorization of pig meat from 1985.

Grading of carcasses by applying of standards

Under meaty pigs, in the sense of the Yugoslav standard (Regulation) are considered the pigs of improved meaty breeds, as well as their crosses, the weight of warm carcasses of which weighed 65-113 kg. According to the first Standard for meaty pigs, the carcasses in the class were classified as light meaty (65-75 kg) meaty (76-100) and heavy meaty (101-113 kg), and carcasses without class (lighter than 65 or heavier than 113 kg). According to new Regulation, that classification is not obligatory.

Under meatiness of carcass is considered the whole weight of lean meat, without that from belly and rib cuts and meat of head. That is an important difference in relation to European standards and that of EEC, because by that the yield of meat in the carcass is lower by 4-7 kg.

Meatiness of carcass is determined on the rail, one hour after slaughter and the measurements are done on warm carcass using measures of backfat thickness. The weight of carcass is taken on an automatic scale with the exactness of ± 0.5 kg. Fatty tissue with skin is measured on mid back, where it is smallest, between 13th and 15th vetebrae and on loin, where M.gluteus medius most embodies into fatty tissue.

The backfat thickness is measured by means of steel tape with the exactness of ± 1 mm, and it may be done also by other modern instruments.

For determination of meat yield in the carcass, on the basis of the measurement carried out, two tables are in use, which present the basic ingredient of the Standard. In one table the yield was presented in kilograms and in the other as percent, and on the basis of total yield of meat (as percent) and weight of carcass, their value is determined.

In Table 1. are presented schematically grading and finding of meatiness of carcass. On the basis of these measurements it is also possible to find out the yield of meat in the ham (kg) or the yield of meat in the ham and M.longissimus dorse (MDL), if special purposes are aimed at. The appraisement until now is not a constituent of the standard.

Table 2. Yield of meat in the carcass, percent or kg.

Σ of bacon mid back + loin, mm	Weight of warm carcass, kg		
	65-67	80-82	111-113
31 - 35	43.26% 28.55kg	2.31* 22.49	45.57% 51.04kg
56 - 60	14.49* 9.56	38.85% 31.47kg	14.47* 16.21
101 - 105	28.77% 18.99kg	2.33* 15.84	31.10% 34.83kg

*Difference

The bacon measured on two sites gives the sum of backfat thickness (mm). That sum in tables of the standard is divided into 16 vertical columns with a difference between colums of 5 mm. In the horizontal part of the table, in 16 horizontal parts the weight of carcass is shown, from 63-113 kg, with a difference of 2 kg.

On vertical and horizontal crossing there is the yield of meat as percent, or kilogrammes for both sides of each slaughtered fattener.

Because of uneasiness of showing the whole table about the appraisement of meatiness, in Table 2. are presented the basic principles and the respective extreme differences between the sides of highest and lowest quality with respect to meatiness, depending on backfat thichness and weight of warm carcasses. These differences are shown as percent or kilogrammes. The largest number of slaughtered pigs, fattened in our conditions have the weight of carcass of 80-82 kg with the sum of backfat thickness of 56-60 mm. The meatiness of such carcasses amount to 38.85 percent or 31.47 kg of meat, and we would like to note once more, without the meat from belly and rib cuts of the carcass.

In the course of 15 years by application of Standard in Yugoslavia, in industrial slaughterhouses, 58,598.00 pigs have been graded. The classification of the graded pigs is presented in Table 3.

Table 3. Grading of carcasses according to standard

Grade and meatiness	Weight of warm carcass		
	65-75	76-100	101-113
Carcass in grade, %	25.09	53.45	4.59
Meatiness of carcass, %	40.10	38.84	36.65
Total carcasses classified, Nº		58,598.000	
Carcasses in grade, %		83.13	
Without grade, %		16.87	

The largest number of graded carcasses was in the range of weights of 76-100 kg (meaty pigs), with the yield of meat of 38.84 percent. In the grade there were 83.13 percent and 16.87 percent of the total number of pigs slaughtered were out of grade.

By the work done until now we have gained certain experience, which has its positive but also some negative sides. Namely, every standard of one country presents certain averages of quality (meatiness) of carcasses. Those farms, which with respect to breeding and selection work achieved an obvious progress, are to a certain extent damaged by that appraisement of meatiness (for instance lower appraisement of meat by 1-2 percent in relation to real yield, found by means of dissection). In such farms, at least once a year the checking dissections are carried out, and if the higher yield of meat was found, they were paid so much percent more than it is appraised by standard, for the next six months. In the course of work, all changes and comments are noted, in order to make certain corrections of standard.

At the next correction of standard we intend to include the meat from belly and rib cut into total yield of meat. That until now has made a wrong impression amond researchers and in relation to standards of other countries with respect to real meat yield of Yugoslav meaty pigs.

There is an important work on automation of the whole process of appraisement of meatiness of carcasses in several large industrial (exporting) slaûghterhouses, as well as on other technical and technological innovations.

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PIG CARCASS CLASSIFICATION USING AUTOMATIC PROBES IN SPAIN

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Summary

This paper deals with some sapects of the application of the new pig carcass classification scheme in Spain according to EEC regulations. The decision has been taken in favour of using the following automatic classification probes: Fat-o-Meater (FOM), Hennessy Grading Probe (HGP) and Destron PG-100 (DST). Biological and experimental bias that cause problems in the standarization of the new scheme across member countries are discussed. It is necessary to minimize these differences with further coordinated studies in order to avoid discrimination in competitivity within and between countries.

Introduction

The main objectives of using carcass classification schemes are to make the meat trade transactions more transparent and also for administration price reporting purposes. Therefore, the use of a common language able to be understood by all the meat chain using a carcass characteristic of commercial relevance, is the basic requirement for a classification system to be highly creditable. All the historical aspects of grading and classification have been correctly and comprehensibly reviewed by Kempster, Cuthbertson and Harrington (1982).

Pig carcass classification in the EEC

The carcass lean meat percentage has been the payment characteristic chosen by the EEC for their pig carcass grading scheme (Regulations 2676/75 and 3220/84). This is due to consumer demand for leaner fresh meat and meat products over the last decades. The estimation of lean percentage was carried out in the abattoirs using two mid-line fat thicknesses (minimum loin or mid-back) in combination with notes of the visual assessment of conformation (Regulation 2760/75). However, an amendment was accepted to allow some countries (Denmark, Ireland and the United Kingdom) to use their individual techniques for estimating the carcass lean percentage determining grades.

The subjectivity of the use of visual assessment of conformation created producer dissatisfaction because of its relative importance in determining grades. Moreover, scientific evidence demonstrated the higher precision of fat depth measurements taken over the m.longissimus by probes than mid-line fat depths (Kempster et.al., 1982).

A coordinated study was conducted to determine the linkage between carcass dissection methods with the reference lean percentage devised by the German Meat Research Institute (Commission of the Eurpean Communities, 1979). Although this study was carried out with a reduced sample, the results highlight no overall regression formula fits all groups. This means that no common classification system is possible to predict the lean percentage in all categories of carcasses.

The situation explained previously led to Council Regulation 3220/84 which outlined the scale for grading pig carcasses, as well as Commission Regulation 2667/85 which laid down specific rules for the application of the Community scale for grading. It should be implemented in all member states by Jan. 1st. 1989 and comprises the following principles: a) standard carcass presentation, b) individual carcass identification and c) the use of objective measurements to predict the reference lean percentage. The lean meat percentage will define grades in terms of 5% ranges and will be indicated by the letters E ($\geq$ 55), U ($\geq$ 50 to $<$ 55), R ($\geq$ 45 to $<$ 50), O ($\geq$ 40 to $<$ 45) and P ($<$ 40). A special grade for carcasses with 60% or more will be designated by the letter S.
The estimated lean percentage will be determined by approved methods which must observe certain statistical requirements. The information should be based on a representative sample of at least 120 dissected carcasses. Each of the methods should predict carcass lean percentage with a minimum correlation of 0.8 and a maximum residual s.d. of 2.5%.

Present situation in Spain

The commercial classification of pig carcasses has been bases on the old EEC Pig Grading Scheme whereby estimated lean percentage was determined by the visual assessment of conformation and back-fat depths taken in the mid line. The system is applied by the abattoir employees and obviously creates a feeling of limited confidence in the producers. Also, an important proportion of pigs are sold on a live weight basis.
During the last year a trial was conducted by our Institute to evaluate different pieces of equipment available for pig classification (Diestre, Gispert and Oliver, 1988). The final decision taken was to use the three automatic pig grading probes: Fat-o-Meater (FOM) (manufactured by SFK Ltd., Hvidovre, Denmark), Hennessy Grading Probe (HGP) (manufactured by Hennessy and Chong Ltd., Auckland, New Zeland) and Destron PG-100 (DST) (manufactured by Destron Technologies Inc., Ontario, Canada). One equation for each equipment with three predictors was submitted to Brussels and approved for use in the Spanish application of the EEC Grading Scheme
The following measurements can be recorded with the automatic probes 60 mm from the mid-dorsal line:
Last rib fat depth (LR): fat thickness (mm) measured over the m.longissimus at the head of the last rib.
3 to 4 last rib fat (34 LR fat): fat thickness (mm) between the third and fourth ribs counting from the last rib.
3 to 4 last rib muscle depth (34 LR muscle): m.longissimus thickness measured during the some operation to obtain 3 to 4 last rib fat depth.
In Table 1, the residual s.d. for the prediction of reference lean percentage from individual measurements taken with the three probes and the combination of two measurements, 34 LR muscle plus fat (one point measurement) and LR fat (two points measurement) are presented.

Table 1. Residual s.d. for the prediction of EC reference lean percentage from predictors taken with automatic probes.

	FOM	HGP	DST
LR	2.97	2.90	3.06
34 LR fat	2.91	2.95	2.53
34 LR muscle	4.12	4.18	4.27
34 LR fat, 34 LR muscle	2.48	2.63	2.31
LR, 34 LR fat, 34 LR muscle	2.23	2.45	2.25

For commercial classification there are two possible ways to estimate lean concentration using one point measurements (i.e. 34 LR fat and 34 LR muscle). and two point measurement (i.e. adding LR). In our results DST was slightly better in the first option and FOM was better in the second. Taking into account Danish experience in using automatic probes, we think that if a two point measurement is used, the system can be used without problems in the Spanish abattoirs (Pederson and Busk, 1982).

Bias in estimating carcass lean percentage

There is clear scientific evidence that carcasses from blocky breeds (Pietrain and Belgian Landrace) are underrated when shape or conformation is not evaluated. The CEC 1979 study showed that with the same fat thickness these carcasses were 7% leaner. The bias appears to be less when visual assessment of shape is added to predict lean percentage. In a recent experiment at IFR Bristol, it was found that the application of the best prediction equation to a sample 310 Pietrain and Large White pigs using fat and muscle thickness caused lean percentage in blocky carcasses to be underestimate by about 2% units. (Wood, 1988).
In Table 2, the degree of bias (predicted-actual lean percentage) is presented when the commercial equation of each grading probe is applied to three classes of conformation.

Table 2. Predicted minus actual reference percentage of lean in carcass when grading probe equations are applied to three classes of conformation

Conformation classes	Grading probes	Lean percentage estimated	actual	Differences
1 Good	FOM	50.5	51.4	-0.9
	HGP	50.5	51.5	-1.0
	DST	50.7	51.4	-0.7
2 Medium	FOM	49.0	49.2	-0.2
	HGP	49.4	49.2	+0.2
	DST	49.4	49.2	+0.2
3 Poor	FOM	50.0	49.8	+0.2
	HGP	50.0	49.5	+0.5
	DST	50.6	49.8	+0.8

The results show that in good conformation carcasses (class 1), the estimation of lean percentage is underestimated whereas in poor conformation carcasses (class 3), it is overestimated. This biological bias should be minimized with new technological developments. The Video Image Analysis can accurately measure conformation and should be tested as a way of classifying pig carcasses. For more details see the information presented by P.B.D. Newman and J.F. Wood in this book.
In addition to the biological bias there is also experimental bias creating problems within and between member countries. Permission to make the necessary adjustments of national dissection methods to the reference method using equations established ten years ago, is, of course, one aspect that should be taken into account. It is well known that lipid content has been reduced drastically over the last years (Kempster, Cook and Grantley-Smith 1986 a). On the other hand, the selection procedures des-

cribed in the different working documents submitted to Brussels are consistently different (For a detailed explanation, see the paper of A.J. Kempster and G. Cook). This biological and experimental bias in predicting carcass lean between member countries is, in some cases, over one class of the system (5%). Therefore, it is necessary to study all these aspects in order to avoid discrimination in competitivity within and between countries.

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COMPUTER TOMOGRAPHY, A NON-DESTRUCTIVE METHOD OF CARCASS EVALUATION

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Summary

Computer tomography has shown to give very accurate in-vivo predictions of carcass composition. In order to evaluate this method in evaluation of pig carcasses, 187 halves were scanned in the computer tomograph at the Agricultural University of Norway. The accuracies seem to be of the same magnitude as those achieved for in-vivo CT. Meat percentage was estimated with an R^2-value of .96 and residual standard deviation of 1.02 (sample sd:4.75). The method does not give significant biases with respect to sex, breed and live weight. CT is a faster and cheaper method of measuring meat percentage than dissection.

Key-words: Computer tomography, meat percentage, carcass evaluation techniques.

Introduction

In the recent years there has been a trend towards a pig carcass classification based on meat percentage. In the EEC member countries this will be obligatory by 1. Jan. 1989 (Daumas 1987). Hence, meat percentage will become an increasingly important parameter in future pig production. The classification system will mainly rely on grading instruments such as Hennesey Grading Probe, Fat-O-Meater, Destron etc. The accuracy with which these instruments predict meat percentage is probably sufficient for commercial grading purposes. For experimental purposes, however, there are often a demand for more accurate methods. The most common method up to now has been carcass dissection. Several dissection standards which differ in amount of labour required per carcass exist. The accuracy of the different standards are roughly proportionate to the amount of labour put into it, even the most laborious dissection methods will not measure meat percentages without errors. The most important dissadvantages of dissection methods are related to their time consumption and that they reduce the economic value of the carcasses.

Computer tomography (CT) of live pigs has shown to give prediction of carcass composition of high accuracy (Vangen 1985). The method was expected to give even better results when applied directly on carcasses since positioning of scans is easier, no anaesthetics are needed and there are no problems due to movement of object during exposure. If there are no restrictions on food which has been X-rayed, use of CT will not reduce the economic value of the carcasses. This paper deals with evaluation of CT in terms of accuracy, lack of bias and capacity.

Material and methods

A computer tomograph is an X-ray instrument which reconstructs an image of a crossectional slice of the body examined. The CT-image is a 256 by 256 elements matrix. Each element represents a CT-value expressed in Houndsfield Units which expresses the X-ray absorption in the corresponding area of the cross sectional slice.

In this experiment, 187 half carcasses (left halves) were scanned in the computer tomograph at the Agricultural University of Norway. Additionally, bacon side sale cuts from the right half of 116 of the 187 pigs were scanned. Totally 6 crossectional scans on the half carcass were taken. These scans were perpendicular to a line through the spinal column and located at the following positions: 1) between 1st and 2nd thoracic vertebra, 2) between 4th and 5th thoracic, 3) between 10th and 11th thoracic, 4) between 2nd and 3rd lumbar, 5) head of femur, 6) through meatiest part of the ham. For the bacon side sale cut, 4 scans were taken. These were located at: 1) between 5th and 6th rib, 2) between 10th and 11th rib, 3) caudal edge of last rib, 4) half distanse between (3) and caudal edge of the sale cut.

The 187 CT-scanned carcasses derive from a total of 232 carcasses in an experiment carried out by the Norwegian Meat Marketing Board with the purpose of calibrating grading instruments for meat percentage prediction. Most of the carcasses (173) were dissected. On 128 carcasses both CT- and dissection data were available (Table 1). Most of the animals were purebred Norwegian Landrace, but crossbreds with Duroc and Yorkshire were also represented (Table 2).

Table 1. Number of animals with data on dissection and computer tomography (CT)

	Not dissected	dissected	Totally
Without CT	0	45	45
CT of half carcass	33	38	71
CT of half carcass + bacon side	26	90	116
Totally	59	173	232

Table 2. Distribution of breed combinations

	n
L	128
LD x L, LD x Y, LY x LD	34
LY x L	70

L: Norwegian Landrace D: Duroc Y: Yorkshire

The dissection was carried out on the right half of the carcass. Meat content was recorded as total amount of dissected meat from this half. Meat percentage was calculated as the ratio of meat content to total dissected (meat, fat, bone and remainder). No corrections were made to adjust for unequal weights of the left and right halves. Together with the fact that one half was CT- scanned and the other half was dissected, this introduces a source of error which set the limit of the correlation between meat percentage and CT-records to a value less than one. Means and standard deviations of some carcass characteristics are given in Table 3.

Table 3. Means and standard deviations for some carcass characteristics.

Trait	n	$\bar{x}$	sd
Carcass wt.kg[1)]	232	74.1	8.0
Meat content, kg	173	19.4	2.3
Meat percentage	173	57.0	4.8
Meat % in bacon side	170	47.6	6.6

1) whole carcass, all others: half carcass.

Results and discussion

To establish the relationship between meat characteristics as dependent variables and carcass weight and x-ray absorption values obtained by computer tomography as independent variables, the following multiple regression model was analysed:

Model 1: $$Y = \beta_o + \sum_{j=1}^{k} \sum_{i=1}^{40} \beta_{ji} P_{ji} + e$$

where Y = Dependent variables

β_o = Intercept

β_{ji} = regression coeffisients

P_{ji} = Absorption value no i from j-th CT-scan, j = 1-6 for carcass, 1-4 for bacon side

e = random error

For comparison, the relationship between the same dependent variables and some carcass measurements were analysed according to the following multiple regression model:

Model 2: $$Y = \beta_o + \sum_{i=1}^{8} \beta_i X_i + e$$

where: β_i = regression coeffisients
X_i = carcass measurement no i (see text)

The carcass measurements in model 2 were four different midline backfat thicknesses,backfat thickness 7 cm from midline at last rib, percent ham and loin, eye muscle area and carcass weight. For both models, stepwise regression approach with the maximum R^2 improvement variable selection method was used. The models with the highest number of significant covariates were chosen, with the restriction that not more than 20 variables should enter the model. The results from analyses of models 1 and 2 are given in Table 4.

Table 4. Estimation of meat percentage and meat content in carcass and meat percentage in bacon side by computer tomography (estimation by carcass measurements in brackets).

Dependent variable	Sample SD	Estimation		
		d.f.	Residual SD	R^2
Meat %	4.75	20 (7)	1.02 (1.92)	.96 (.85)
Meat content, kg	2.27	20 (5)	.40 (.73)	.98 (.90)
Meat % in bacon side	6.56	15 (5)	2.22 (3.78)	.90 (.68)

There is a substantial reduction from sample standard deviations to residual standard deviations by fitting models with CT- covariates. The best fit is for meat content in carcass, followed by carcass meat percentage and meat percentage in bacon side. The better fit for amount than for the percent-variables is probably due to the fact that the CT-variables express amounts through areas with different x-ray density. Carcass weight entered the model only for meat content, which also indicates the different nature of the two types of dependent variables analysed. The least successful estimation is shown for meat percentage in bacon side. One possible reason is the difficulty of defining standard anatomical positions for cross sectional CT-scans.

The residual standard deviations obtained from model 1 are in the magnitude of 53-59% of those obtained by model 2. This strongly indicates that CT is far more efficient in prediction of meat than simple carcass measurements. The relative high number of covariates in model 1, however, introduces a possible overfitting problem. The true residual standard deviations are therefore somewhat higher than those given in Table 4. On the other hand, the accuracy of dissection is less than 100%, which will affect the true residual standard deviations in the opposite direction.

The value of a CT-based prediction of meat percentage would be somewhat limited if the method gives bias for effects such as breed, sex and carcass weigth. To investigate this on the present data the following model was analysed:

Model 3 $(\hat{Y}_{ct} - Y)_{ijk} = \beta_o + a_i + b_j + \beta_1 X_{ijk} + e_{ijk}$

where: $\hat{Y}_{ct}$ = CT-estimate of Y (see Model 1)

Y = meat characteristic

$(\hat{Y}_{ct} - Y)$ = residual from fitting Model 1

β_o = intercept

a_i = fixed effect of sex nr i(i=1:gilt,i=2:castrate)

b_j = fixed effect of breed or breed combination j

β_1 = regression coeffisient

X_{ijk} = carcass weight of individual k, sex i and breed j.

e_{ijk} = random error term.

Results from analysis of residuals by model 3 are given i Table 5. There were *no significant* effects of any of the independent variables. This indicates a negligible bias introduced by the method with respect to sex, breed and carcass weight.

Table 5. Analysis of variance on residuals (CT estimated-observed)

Residual	F-value	R^2	Effect of		
			breed	sex	carcass wt.
Meat percentage	.39	.02	ns	ns	ns
Meat % in bacon side	.50	.03	ns	ns	ns

Applications

The present experiment was financed by the Norwegian Meat Marketing Board. Their primary interest in the project was to reduce costs connected to calibration and recalibration of carcass grading instruments. The cost reduction by use of CT compared to carcass dissection is due to two factors, the higher capacity and no reduction in value of the carcasses. It is possible to scan max. 50 carcasses per day, demanding a staff of three persons (16.7 carcasses per person and day). The dissection method used had a capacity of 1-2 carcasses per person and day.

CT has up to now been applied in the evaluation of 3 grading instruments. In addition the Norwegian Pig Breeding Association has plans for using the method in an evaluation of different ultrasonic equipment for backfat thickness measurements in their field test.

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INDIRECT METHODS FOR ESTIMATION OF PER CENT LEAN MEAT IN PIG CARCASSES OF DIFFERENT BREEDS

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In pig carcass grading important biases have been found by using the same equation for different types of pigs. As part of experiments concerning meat and slaughter quality, 754 randomly chosen pigs from the testing stations were totally dissected into meat, fat and bone. Before dissection, fat depth and muscle depth were measured on different locations on the carcass (fig.1)

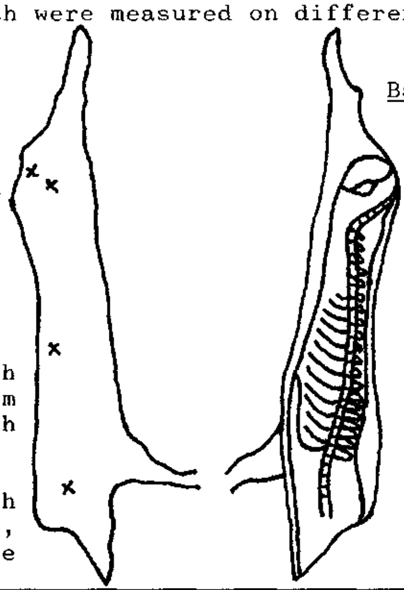
Sidefat depth

x_7: 4 cm above the edge of os pubis, 5 cm from backbone

x_6: At the top of os pubis, 9 cm from backbone

x_5: Between 3rd and 4th last rib, 7 cm from backbone (fat depth and muscle depth

x_4: Between 3rd and 4th cervical vertebrae, 11 cm from backbone



Backfat depth

x_3: Loin

x_2: Middle

x_1: Shoulder

Table 1. AVERAGE (x) AND STANDARD DEVIATION (SD) FOR % LEAN IN CARCASS FROM DIFFERENT BREEDS

	L		Y		D	
	x	sd	x	sd	x	sd
Number	247		266		241	
EEC Carcass weight, kg	74.9	4.50	76.7	4.60	75.8	3.88
EEC % lean in carcass	56.9	2.80	58.2	2.77	54.4	2.76

For comparison of the different breeds, some slaughter quality traits are corrected to the same slaughter weight and % lean in the carcass (table 2).

Table 2. AVERAGE FOR DIFFERENT CARCASS QUALITY TRAITS IN DIFFERENT BREEDS AFTER CORRECTION TO SAME SLAUGHTER WEIGHT (75.8 KG) AND % LEAN IN THE CARCASS (56.5%)

	L	Y	D
% Lean in:			
Fore-end	66.8[a]	65.9[bc]	65.9[bc]
Belly	61.6[a]	64.0[bc]	64.6[bc]
Loin	62.4[a]	60.9[b]	61.8[c]
Ham	69.2[a]	70.9[b]	70.0[c]
Backfat depth, mm:			
x_1	33.0[a]	37.6[bc]	36.4[bc]
x_2	14.8[a]	18.2[b]	16.5[c]
x_3	13.5[a]	16.9[b]	14.3[c]
Sidefat depth, mm:			
x_4	13.1[a]	14.6[bc]	14.1[bc]
x_5	15.8[abc]	16.2[abc]	16.2[abc]
x_6	17.4[a]	16.0[b]	14.4[c]
x_7	10.0[ac]	9.4[b]	10.2[ac]
Muscle depth, mm:			
x_5	47.1[ac]	50.5[b]	47.5[ac]

Numbers with different letters are significantly different

Landrace differs significantly from the two other breeds for all slaughter quality traits except for some sidefat depths and muscle depth. Yorkshire and Duroc only differ for measurements in loin and ham. With different equipments, e.g. F.O.M. and Hennessy probe, it is possible to measure sidefat depth without cutting the carcass. In this experiment the sidefat and muscle depth are measured with F.O.M.

At completion of the equation for calculation of % lean in the carcass it was found that sidefat depth contributes more to an exact determination than backfat depth (table 3)

Table 3. DETERMINATION OF COEFFICIENT (R^2) AND RESIDUAL STANDARD DEVIATION (RSD) BY DETERMINATION OF % LEAN IN CARCASS ON BASIS OF DIFFERENT FAT DEPTHS

	R^2	RSD
3 Backfat Measurements	0.41	2.44
3 Sidefat Measurements	0.64	1.91

A regression analysis showed that there was no effect of sidefat depth within breed and none on the b-value for the same traits in the various equations were significantly different.

In table 4 the bias is % estimated lean in carcass is shown when breed is not included in the equation.

Table 4. BIAS IN % LEAN IN CARCASS WITH USE OF ALL MEASURED SIDEFAT AND MUSCLE DEPTHS

	4 sidefat depths + 1 muscle depth
L	0
Y	0.55
D	0.64

To have an unbiased estimate for % lean in the carcass it is necessary to include a constant for each breed.