Animal Science 2004, **79:** 73-83

1357-7298 / 04 /36260073$20·00

The relationship between the body shape of living pigs and their carcass morphology and composition

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Abstract

The conformation, tissue composition, and chemical composition of three types of pigs, given food ad libitum *and slaughtered over a nominal live weight range of 35 to 115 kg, was assessed in relation to data provided on the live animals by a visual image analysis (VIA) system. The pig types were named as '¾ Landrace', '½ Pietrain', and '¼ Meishan' types, representing 'attenuated', 'blocky', and 'flabby' types. Three analyses of the shape, conformation and composition data were performed. First, the relationship between conformation and age/size was assessed using linear regression of logarithmically transformed VIA and carcass data. In relation to age, '½ Pietrain' pigs were found by both VIA and carcass measurements to have the widest shoulders. Both analyses also found this type to have the widest ham, trunk, and shoulders in relation to body length across most of the body length range studied, although the greatest rate of increase in ham width in relation to body length was found in the '¼ Meishan' type pigs. Second, the relationship between composition and VIA shape was examined using linear regression of transformed and standardized data. Significant relationships were found between fat, lipid, muscle, and protein weight and VIA shape, although relationships were weaker for protein and muscle weight. For fat and lipid, the VIA shape measures from the trunk region proved the most informative, whereas the VIA ham measures proved the most informative for muscle and protein. Third, detrended measures of composition/conformation and shape were used to remove the effect of animal size from the data. Removal of the variation due to growth generally led to substantial decreases in the adjusted* R^2 *statistics and in the* R^2*-like statistics for prediction. Although in the models without detrending, relative fat and lipid weight had been found most strongly correlated with VIA shape, relative muscle was found most strongly correlated with shape in the detrended data. This was considered to result from the low between-animal variation in the data set combined with greater across-weight variation in fat and lipid weights than muscle and protein weights in the data without trend removal. Future trials with greater between-animal variation imposed would allow more precise determination of the relationship between conformation and shape.*

Keywords: *carcass composition, conformation, growth, pigs, visual image analysis.*

Introduction

The value of a pig carcass for meat production depends primarily on the carcass weight and on the relative proportions of fat and lean. As customer demands become more specific, the shape of retail cuts and thus the carcass conformation play an increasingly significant rôle in the meat production industry (Brown, 2004). Estimates of these carcass traits during a pig's lifetime are invaluable for the pig breeder, as they allow specification of a performance target, a management regime and genotype choice.

Present methods of obtaining estimates for the specified carcass traits involve labour-intensive weighing of the animals, measurement of backfat and back muscle depth using ultrasound and subjective condition scores. The inadequacy of body weight as an indicator of fat and lean content and body morphology has been commented on by various authors (Bastianelli and Sauvant, 1997; Emmans and Kyriazakis, 1997; Whittemore and Schofield, 2000), as has the potential of body shape indices for determining the relevant carcass characteristics (Brody, 1945; Whittemore and Schofield, 2000).

Until recently, accurate determination of live pig size and shape has been impractical. However, the development of a visual imaging system which provides daily size and shape measures from two-dimensional visual images of living pigs promises to overcome many of these difficulties (Marchant *et al.*, 1999). Previous analysis has already shown that live weight can be accurately determined from the size measures obtained by visual image analysis (VIA) (Marchant *et al.*, 1999). Furthermore, in addition to live weight, VIA can quantify other type- or animal-specific differences during the growth process (Doeschl *et al.*, 2004). For example, White *et al.* (2004) showed that pigs could be sorted according to their shape.

The present study investigates the potential of VIA to provide *in vivo* information about body conformation and composition in pigs of different live weights. For this purpose, three commercially available pig types with different body morphologies were studied and their shape characteristics during growth were related to their carcass conformation and composition after slaughter. The three pig types fall into the three categories 'attenuated and lean', 'blocky and muscular' and 'flabby and fatty' (Whittemore *et al.*, 2003). Previous analysis of the dissected carcasses of these pig types revealed significant differences in body conformation and composition. For some body parts, significant differences in the relative growth rates and composition changes of the body components between the individual types were observed (Fisher *et al.*, 2003). The aim of this study is to investigate whether VIA and carcass measurements provide a consistent description of shape and composition differences between the pig types.

Material and methods

Experimental animals

The trial involved 99 pigs of a live-weight range between 35 kg and 115 kg, which were progenies of female Large White/Landrace crosses and either a Landrace (progeny '$^3/_4$ Landrace'), a Pietrain (progeny '$^1/_2$ Pietrain') or a 50% Meishan (progeny '$^1/_4$ Meishan') male. The generated progeny could be classified into 'attenuated', 'blocky' and 'flabby' morphotypes, respectively. To reduce within-type variation compared with between-type variation, a single sire for each pig type was used.

Diet and environmental conditions for this trial were as described by Green *et al.* (2003). Briefly, pigs were housed in conditions designed to be thermoneutral and were offered *ad libitum* a cereal/soya-bean-based diet.

The pigs were sequentially slaughtered at five approximately equidistant weight groups throughout the 35 to 115 kg nominal growth range. The three morphotypes were equally represented in each slaughter group. Variation in live weight at each slaughter point was sufficient to produce a continuum of live weights across the full weight range for each type.

Visual image analysis

During growth, a visual imaging system provided daily medians of seven linear (L1 to L7) and four area (A1 to A4) measurements of the pig (Figure 1). The measurements are defined as follows : L1 = width of shoulder at its widest point; L2 = width of body at the constriction between the shoulder and trunk; L3 = width of trunk at its widest point; L4 = width of body at the constriction between the trunk and ham; L5 = width of ham at its widest point; L6 = length of trunk between the L2 and L4 loci; L7 = total length of body, excluding head; A1 = plan area of shoulder, cranial to the L2 locus; A2 = plan area of trunk, between the L2 and L4 loci; A3 = plan area of ham, caudal to the L4 locus;

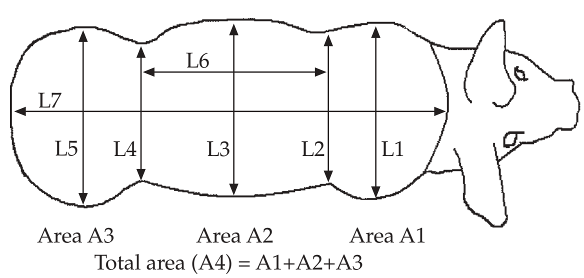

Figure 1 Linear and area measures from the visual image analysis (VIA) system.

A4 = total plan area of body, excluding head (A1 + A2 + A3).

Although pig shape is too complex to be described by a few linear and area measurements, these measurements can nevertheless serve as quantitative shape indices. Body shape indices were thus obtained by standardizing the linear VIA measurements L1 to L6 relative to the VIA body length L7 and the VIA area measurements A1 to A3 relative to the overall surface area A4. The standardized, non-dimensional measures are thus L1/L7 to L6/L7 and A1/A4 to A3/A4.

The shape indices of the living pigs were then compared with carcass measurements to determine whether they provide useful information about carcass conformation and composition during the animal's lifetime. The error in the VIA measurements was reduced by calculating the medians of the data from the 7 days prior to slaughter. In a few cases, where less than seven consecutive measurements were available, fewer measurements contributed to the calculation of the median. Pigs with less than four daily measurements within the 7 days prior to slaughter were removed from the analysis.

Slaughter and carcass dissection

The slaughter and dissection protocol has been described elsewhere (Fisher *et al.*, 2003; Green *et al.*, 2003; Whittemore *et al.*, 2003). The present analysis uses the cold carcass weight, as well as ham, trunk, and shoulder width measurements obtained by callipers on the hanging cold carcasses (defined as the maximum widths of the pelvic limb, abdominal and thoracic limb region, respectively). Body length, defined as the distance from the cranial edge of the pubic bone at its symphysis in the median plane to the cranial edge of the first rib at its junction with the sternum, was measured with a tape measure after splitting the carcass lengthwise into two sides.

A full side dissection was carried out on 40% of the pigs. The half-carcass was subdivided into a shoulder, foreloin, hindloin, belly, flank and pelvic limb. Each joint was separated into skin, subcutaneous fat, intermuscular fat, lean and bone as described by Brown and Wood (1979). The fat and muscle weights used in this study are the sums of the weights of the corresponding lean and fat tissues in all the joints.

For the remaining 60% of the pigs, the pelvic limb only was dissected. Estimates of carcass fat and muscle weights for these pigs were obtained from the corresponding weights in the pelvic limb. It has been stated that the pelvic limb composition is highly correlated with the composition of the entire carcass (Fisher *et al.*, 2003), and calculated R^2 statistics greater than 0·985 for all three pig types in the present study support this argument for the present data set.

Estimates of the chemical protein (Pt) and lipid (Lt) content of the whole body for each pig were derived from chemical analysis of the dissected lean and fatty tissues combined with estimates of the chemical composition of the bone and non-carcass components, derived from the data of Tullis (1982), as described by Whittemore *et al.* (2003).

Indices of carcass composition were obtained by standardizing dissected fat and muscle weights, and half of the carcass lipid and protein weights, relative to the dissected carcass side weights. Relative carcass fat and muscle weights are relevant for the meat market, whereas relative protein and lipid weights are more relevant for pig growth models and for genetic selection methods.

Statistical analysis

Statistical analysis was performed on logarithmically (base 10) transformed data for two reasons. First, preliminary analysis of the data showed that the relationships between body components and between shape and composition measurements were made more linear and residuals were normally distributed under this transformation. Second, by comparing the information about body morphology based on VIA and carcass measurements, the present analysis augments the previous analysis of the carcass morphology performed on the same pigs (Fisher *et al.*, 2003), which was carried out with logarithmic transformations of the data.

Logarithmic transformations of the data lead to a linear form of Huxley's conventional allometric equation (Huxley, 1932) for the relation between two body components *X* and *Y*, i.e.

$$\log Y = a + b \times \log X \quad (1)$$

Based on equation (1), changes in the body shape during growth and differences between pig types are indicated by the regressions of $\log_{10}$ of shoulder, ham and trunk width, respectively, on age and on $\log_{10}$ body length, which is an index of the animal's size. Since these four size measures are available from VIA of living pigs as well as from the dissected carcasses, they serve as a base to determine to what degree shape monitoring of living pigs delivers reliable estimates of carcass conformation.

The regression analysis was carried out with a general linear model using the SAS procedure PROC

GLM (Statistical Analysis Systems Institute (SAS), 1999). The first model fitted used different slopes and intercepts for each pig type. Using a 95% confidence level, pig types with non-significant differences in the slopes were then pooled in the slope calculations, and the intercepts were re-calculated for each pig type. The final model used pooled slope and intercept values for pig types for which no significant differences ($P < 0{\cdot}05$) in both measures were found.

The relationship between VIA body shape and carcass composition was assessed with a multiple linear regression analysis, which was carried out with the SAS procedure PROC REG (SAS, 1999). Only those VIA shape indices that showed a significant relationship with the corresponding composition measure in the pair-wise correlation matrix ($P < 0{\cdot}05$) were considered in the model. Next, variable selection in the regression model followed a stepwise regression procedure. Co-linearity between the shape indices was assessed using the variance inflation factors and condition indices as diagnostic tools (Montgomery and Peck, 1992). Errors in the regression coefficients and variance inflation due to multi co-linearity were minimized by including only shape indices which resulted in variance inflation factors less than two and condition indices less than 50 in the final models.

As an indication of the predictive capability of the regression models the PRESS statistic was calculated as an approximate measure of how much variability in new observations the model might be expected to explain (Montgomery and Peck, 1992). The PRESS statistics yields an R^2-like statistic for prediction (R^2_{pred}) provided by the following formula (Montgomery and Peck, 1992):

$$R^2_{pred} = 1 - \mathrm{PRESS/SST},$$

where SST is the total sum of squares of the regression model.

Detrending via *shape and carcass composition measures*
Since the present data stem from pigs at different growth stages, the relationship between the VIA body shape indices and the standardized carcass composition measures is affected by changes in pig shape and body composition due to growth. Removal of growth trends in the indices for body shape and carcass composition is important for understanding the true relationship between shape and composition for pigs at similar growth stages. To remove the growth effects in both data sets, changes in shape and composition due to growth were assessed according to the linearized allometric equation (1). For the assessment of shape changes, the VIA measures L7 body length and A4 surface area were substituted as X values and the linear and quadratic VIA measures L1 to L6 and A1 to A3 as Y values. Likewise, the change of body composition due to growth was assessed with the carcass side weight as X value and the composition measures muscle, fat, protein and lipid weights, respectively, as Y values. The analysis was carried out for all pig types combined and for each individual pig type. Pig types for which the slope b was not significantly different at a 95% confidence limit, were assigned a common slope coefficient. The regression analysis for the relationship between body shape and carcass composition was then repeated with the detrended shape and composition indices

$$sY = \log (Y/X^{b}) = \log Y - b \times \log X, \qquad (2)$$

where b is the growth coefficient calculated from the above relationship. These new indices were free from growth trends.

Results

Body conformation according to VIA and carcass dissection
Differences in the body dimensions of living bodies and cold carcasses, as well as slight differences in the definitions of the body length as measured with and without VIA (**Material and methods**), caused ranges of the body dimensions to differ between VIA and carcass measurements (Table 1). VIA body length L7 generally exceeded the body length measured on the corresponding carcass. Differences between the VIA and carcass measurements in the shoulder, trunk and ham widths were less pronounced (Table 1).

For the linear VIA size measures, statistical analysis revealed no significant differences between body length, ham width and trunk width between the three pig types, when assessed in relation to age. The '½ Pietrain' type pigs however had significantly wider shoulders than the '¼ Meishan' and '¾ Landrace' type pigs at a given age. Performing the same analysis on the carcass measurements, the '½ Pietrain' type pigs again had the widest shoulders relative to age, but also the shortest bodies. The '¼ Meishan' type pigs had significantly narrower hams

Table 1 *Range of dimensions of body components according to visual image analysis (VIA) and carcass measurements (mm)*

Measure	VIA range	Carcass measurement range
Body length	580-1080	520-870
Shoulder width	190-370	200-385
Trunk width	190-360	210-360
Ham width	200-370	180-350

Table 2 *Intercepts* (a) *and slopes* (b) *of log regression relationships between linear visual image analysis* (*VIA*) *measurements for the three pig types, together with the root mean squared error* (*RMSE*) *and* R^2 *statistics* (*standard errors of parameters are shown in brackets*)

	'3/4 Landrace' type	'1/4 Meishan' type	'1/2 Pietrain' type	RMSE	R^2
L1 *v.* L7†					
a	–0·395 (0·092)	–0·980 (0·138)	–0·362 (0·091)	0·018	0·944
b	0·973 (0·032)	1·179 (0·048)	= '3/4 Landrace'‡		
L3 *v.* L7†					
a	–0·314 (0·099)	–0·742 (0·149)	–0·296 (0·099)	0·019	0·927
b	0·942 (0·035)	1·093 (0·052)	= '3/4 Landrace'‡		
L5 *v.* L7†					
a	–0·337 (0·007)	–0·700 (0·107)	–0·314 (0·072)	0·014	0·962
b	0·957 (0·025)	1·084 (0·202)	= '3/4 Landrace'‡		

† See Figure 1.
‡ The notation = '3/4 Landrace' means that the corresponding coefficient was not statistically significantly different from the coefficient for the '3/4 Landrace' type pigs.

than the other two types; no significant difference between the three types occurred in the trunk width. The results suggest that, relative to age, carcass measurements show differences between the pig types more clearly than VIA.

Tables 2 and 3 show the results of regressing $\log_{10}$ shoulder width, $\log_{10}$ trunk width and $\log_{10}$ ham width on the body size index $\log_{10}$ body length for VIA measures (Table 2) and carcass measures (Table 3). Figure 2 shows the predicted regression lines for each pig type. Since body length is generally larger when derived from VIA than carcass measurements, VIA consistently yields lower relative shoulder, trunk and ham widths. VIA and carcass measurements both predicted different intercepts for the three pig types in shoulder, ham and trunk width, indicating that both methods detected significant shape differences between the pig types. Residuals were similar for both methods, except for ham width, where VIA provided a better fit than the carcass measurements, as is indicated by the root mean square error (RMSE) values in Tables 2 and 3.

Both methods of shape assessment classified the '1/2 Pietrain' type pigs as the type with the widest hams and widest shoulders for almost the entire body length range (i.e. less than 1000 mm) and as the type with the widest trunks for body length less than 740 mm. Neither of the other two types consistently had the highest values for any of the three width measurements across the body length range examined, nor were the rankings consistent between the methods.

Both VIA and carcass measurements showed a similar rate of increase of ham width relative to body length for the '3/4 Landrace' and '1/2 Pietrain' type

Table 3 *Intercepts* (a) *and slopes* (b) *of log regression relationships between linear carcass measurements for the three pig types, together with the root mean squared error* (*RMSE*) *and* R^2 *statistics. Standard errors of parameters are shown in brackets*

	'3/4 Landrace' type	'1/4 Meishan' type	'1/2 Pietrain' type	RMSE	R^2
Ham width *v.* body length					
a	–0·144 (0·116)	–0·817 (0·173)	–0·120 (0·115)	0·022	0·905
b	0·922 (0·041)	1·153 (0·063)	= '3/4 Landrace'†		
Trunk width *v.* body length					
a	–0·595 (0·090)	–0·584 (0·090)	–0·125 (0·125)	0·017	0·943
b	1·065 (0·031)	= '3/4 Landrace'†	0·905 (0·044)		
Shoulder width *v.* body length					
a	–1·199 (0·140)	–0·782 (0·105)	–0·740 (0·105)	0·020	0·945
b	1·263 (0·050)	1·116 (0·037)	= '1/4 Meishan'†		

† The notations " = '3/4 Landrace'" and " = '1/4 Meishan'" mean that the corresponding coefficients were not statistically significantly different from the coefficients for the '3/4 Landrace' and '1/4 Meishan' type pigs, respectively.

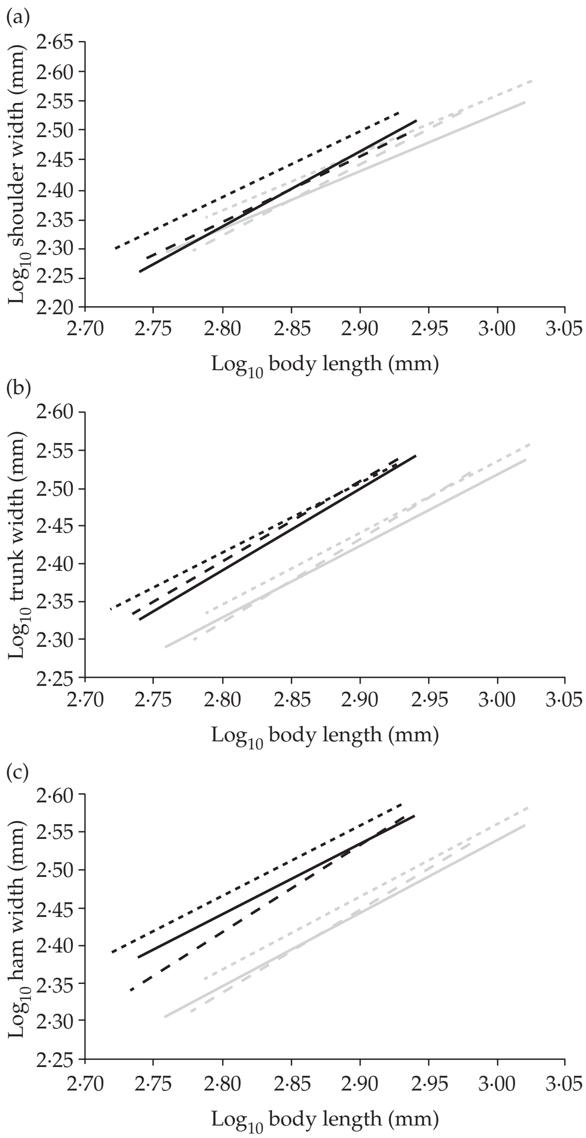

Figure 2 Regression relationships of (a) shoulder width, (b) trunk width and (c) ham width with body length for three pig types, as measured on the carcass (black) and using visual image analysis (VIA; measurements L1 *v.* L7, L3 *v.* L7 and L5 *v.* L7 respectively; grey). Predicted values for individuals are shown, indicating the three pig types as '$^3/_4$ Landrace' type (——), '$^1/_4$ Meishan' type (– – –) and '$^1/_2$ Pietrain' type (- - - -).

pigs and a greater increase for the '$^1/_4$ Meishan' type pigs. This difference was more significant in the carcass measurements.

For relative trunk and shoulder width, VIA and carcass measurements provided a less consistent picture of increase in width relative to increase in body length. VIA showed similar rates of increase in shoulder and trunk width relative to body length for '$^3/_4$ Landrace' and '$^1/_2$ Pietrain' type pigs and a larger increase for '$^1/_4$ Meishan' pigs; whereas carcass measurements showed a similar increase of trunk width relative to body length for '$^1/_4$ Meishan' and '$^3/_4$ Landrace' type pigs, but a smaller increase for '$^1/_2$ Pietrain' type pigs. Carcass measurements also showed a similar increase of shoulder width relative to body length for '$^1/_4$ Meishan' and '$^1/_2$ Pietrain' type pigs, but a greater increase for '$^3/_4$ Landrace' type pigs (Tables 2 and 3; Figure 2). As a consequence of the differences in the slopes, the pig types associated with the narrowest shoulders and trunks for a given body length differed between the methods.

Relationship between body shape and carcass composition

The ranges of carcass side weight (CW), carcass fat weight (FW) and carcass muscle weight (MW) were 8·7 to 51 kg, 0·96 to 13 kg, and 4·3 to 26 kg respectively. The respective ranges for whole body lipid weight (Lt) and protein weight (Pt) were from 2·0 kg to 31 kg and from 4·3 kg to 22 kg. The blocky '$^1/_2$ Pietrain' type pigs had the highest relative muscle and protein weights and the lowest relative fat and lipid weights; the fatty '$^1/_4$ Meishan' type pigs had the highest relative fat and lipid weights and the lowest relative muscle and protein weights.

The relationship between the body shape of the live pigs and the composition of their dissected carcasses was assessed by multiple linear regression models. The VIA shape indices log (L*i*/L7), for *i* = 1. . 6, and log (A*i*/A4), for *i* = 1…3, were used as independent variables and the four composition indices log (FW/CW), log (MW/CW), log (Lt/CW) and log (Pt/CW) were used as dependent variables. Table 4 shows the results for the three pig types, together with the adjusted R^2 statistics, the RMSE and the R^2-like statistics for prediction capability.

There was a strong relationship between body shape and relative carcass fat of live pigs respectively, as measured by VIA and lipid weights, as is indicated by adjusted R^2 values between 0·41 and 0·70 and RMSE of less than 10% of the dependent mean. The relationship between VIA body shape and carcass composition was most significant for the fatty '$^1/_4$ Meishan' type pigs and least significant for the attenuated '$^3/_4$ Landrace' pigs. Pooling all pig types resulted in less significant relationships. Adjusted R^2 values, RMSE and the shape indices that contributed to the final models were similar in the models for relative fat and lipid weight : only the shape indices

Table 4 *Multiple linear regression models with the standardized composition measures log (MW/CW), log (FW/CW), log(Pt/CW) and log(Lt/CW) as dependent variables and the standardized shape indices* Li *= log(Li/L7) for i = 1 ... 6, and* Ai *= log (Ai/A4) for i = 1 ... 3 as independent variables. All of the shown relationships were statistically significant at a 95% confidence limit. Other statistics shown are the dependent mean (dep. mean), the root mean square error (RMSE) and the adjusted* R^2 *statistic* (R^2_{adj}) *and* R^2*-like statistic for prediction* (R^2_{pred})†

Pig type	Model	Dep. mean	RMSE	R^2_{adj}	R^2_{pred}
log (MW/CW)					
Pooled	–0·55 + 0·34 L1 – 0·73 L4 + 1·02 L5	–0·29	0·03	0·37	0·33
'¾ Landrace'	–0·34 – 0·40 L2 + 0·29 A3	–0·29	0·03	0·35	0·26
'¼ Meishan'	–0·04 + 0·45 A1	–0·32	0·03	0·27	0·21
'½ Pietrain'	0·12 + 0·57 L5 + 0·25 A3	–0·26	0·02	0·41	0·31
log (FW/CW)					
Pooled	0·40 + 1·63 L4 + 0·82 L6	–0·77	0·08	0·48	0·46
'¾ Landrace'	0·74 + 2·76 L4	–0·77	0·07	0·58	0·55
'¼ Meishan'	0·85 + 3·05 L4	–0·74	0·07	0·69	0·66
'½ Pietrain'	–0·10 + 0·68 L4 + 0·92 L6	–0·80	0·05	0·60	0·53
log (Pt/CW)					
Pooled	–3·36 – 0·39 L4 + 0·35 A3	–3·33	0·03	0·30	0·28
'¾ Landrace'	–3·71 – 0·43 L4 –0·42 L6	–3·32	0·03	0·54	0·49
'¼ Meishan'		Not significant			
'½ Pietrain'	–3·32 – 0·34 L4 + 0·38 A3	–3·32	0·02	0·35	0·19
log (Lt/CW)					
Pooled	–2·19 + 1·58 L4 + 1·04 L6	–3·43	0·10	0·41	0·38
'¾ Landrace'	–1·72 + 3·10 L4	–3·41	0·08	0·58	0·55
'¼ Meishan'	–1·72 + 2·56 L4 + 0·79 L6	–3·36	0·07	0·70	0·66
'½ Pietrain'	–2·74 + 1·94 L6	–3·50	0·06	0·62	0·58

† CW = carcass side weight; MW = carcass muscle weight; FW = carcass fat weight; Pt = whole body protein weight; Lt = whole

log (L4/L7) and log (L6/L7) contributed to the final models for both relative carcass fat and lipid weight.

Compared with the relationships between VIA live body shape and relative carcass fat or lipid weight, the relationships between body shape and relative carcass muscle or protein weight were weaker, although still significant. This is most likely caused by the smaller variation in body muscle and protein weights than in body fat and lipid weights, as is also indicated by the smaller RMSE values relative to the dependent mean in the models shown in Table 4. Adjusted R^2 values in the models for relative carcass muscle and protein weights varied between 0·27 and 0·54.

Adjusted R^2 statistics, RMSE and the VIA live shape indices that contributed to the final models were different for relative muscle weight and relative protein weight. The relationship between body shape and relative muscle was strongest for the blocky, muscular '½ Pietrain' type pigs and weakest for the fatty '¼ Meishan' type pigs, for which type there was no significant relationship between body shape and relative carcass protein weight. For the '½ Pietrain' type pigs, the ham region was the body part for which the shape-muscle and shape-protein relationships were expressed most strongly. In contrast, '¾ Landrace' and '¼ Meishan' type pigs expressed the relationships through indices from various body regions. The R^2-like statistics for the predictive capabilities of the models were on average 0·875 of the adjusted R^2 statistics, indicating that the models have a relatively strong predictive power with regards to new observations.

Detrending VIA shape and carcass composition measures

The growth coefficients b for the VIA size measures and the four carcass composition measures relative to pig size (expressed by L7 and A4) and carcass weight, respectively, were calculated with equation (1). Coefficients b were derived for each pig type and for all types pooled, and implemented into equation (2) to yield the following detrended shape and composition measures:

$sLi = \log Li - b \times \log L7$ for $i = 1 \ldots 6$
$sAi = \log Ai - b \times \log A4$ for $i = 1 \ldots 3$
$sFW = \log FW - b \times \log CW$
$sMW = \log MW - b \times \log CW$
$sLt = \log Lt - b \times \log CW$
$sPt = \log Pt - b \times \log CW.$

This detrending removed all variation due to growth from the shape and composition indices and generally led to reductions in the between-animal variation in the indices. In particular, detrending

Table 5 *Multiple linear regression models with the detrended composition measures sMW = log MW-*b × *log CW; sFW = log FW-*b × *log CW; sPt = log Pt-*b × *log CW; and sLt = log Lt-*b × *log CW as dependent variables and the detrended shape indices s*Li = *log L*i-b × *log L7 for* i = 1·6, *and sA*i = *log A*i-b × *log A4 for* i = 1·3 *as independent variables. The coefficients* b *differed between the pig types and between the measures. All of the shown relationships were statistically significant at a 95% confidence limit. Other statistics shown are the dependent mean (dep. mean), the root mean square error (RMSE) and the adjusted* R^2 *statistic* (R^2_{adj}) *and* R^2*-like statistic for prediction* (R^2_{pred})†

	Pig type	Model	Dep. mean	RMSE	R^2_{adj}	R^2_{pred}
sMW						
	Pooled	0·05 + 0·64 sL5 + 0·14 sA1	–0·12	0·03	0·14	0·10
	'3/4 Landrace'	–0·96 – 0·37 sL4 + 0·46 sA3	–0·12	0·02	0·29	0·23
	'1/4 Meishan'	–0·18 + 0·30 sA1	–0·16	0·03	0·09	0·01
	'1/2 Pietrain'	–0·44 + 0·63 sL5 – 0·28 sA2	–0·10	0·02	0·39	0·32
sFW						
	Pooled		Not significant			
	'3/4 Landrace'	–0·63 + 1·18 sL4	–2·30	0·06	0·16	0·07
	'1/4 Meishan'		Not significant			
	'1/2 Pietrain'	–2·78 – 1·12 sL1	–2·35	0·05	0·10	0·01
sPt						
	Pooled		Not significant			
	'3/4 Landrace'	–2·93 + 0·34 sA3	–2·71	0·02	0·14	0·04
	'1/4 Meishan'	–1·20 + 0·90 sL4	–2·47	0·05	0·09	0·00
	'1/2 Pietrain'		Not significant			
sLt						
	Pooled		Not significant			
	'3/4 Landrace'	–2·69 + 2·56 sL3	–5·26	0·13	0·23	0·19
	'1/4 Meishan'	–8·29 –2·26 sL4	–5·11	0·10	0·16	0·04
	'1/2 Pietrain'		Not significant			

† CW = carcass side weight; MW = carcass muscle weight; FW = carcass fat weight; Pt = whole body protein weight; Lt = whole body lipid weight.

resulted in significant reductions in the between-animal variation in the carcass fat weight sFW, but no change in between-animal variation in the carcass muscle weight sMW. Thus there was similar between-animal variation in both detrended measures. Between-animal variation in the detrended lipid weight sLt was still significantly higher then in the detrended protein weight sPt. Detrending did not affect the ranking of the pig types in terms of their composition : '1/2 Pietrain' type pigs still had, on average, the highest detrended muscle and protein weights and '1/4 Meishan' type pigs had, on average, the highest detrended fat and lipid weights.

At a 95% confidence level, few detrended VIA shape measures were correlated with detrended composition measures. In particular, for the '1/2 Pietrain' type pigs, no detrended shape measure correlated with detrended protein and lipid weights. Table 5 shows the multiple regression models together with the adjusted R^2 statistics, RMSE and R^2-like statistics for prediction for those cases for which the relationship between body shape and carcass composition was found statistically significant. Removal of the variation due to growth generally led to substantial decreases in the adjusted R^2 statistics and in the R^2-like statistics for prediction. Adjusted R^2 values varied between 0·09 and 0·39 and, apart from a few exceptions, the R^2-like statistics for predictions were less than 0·1, suggesting that the models have generally little predictive value for new observations. Nevertheless, for all pig types there remained a significant relationship between some VIA body shape indices and some indices of carcass composition.

In contrast to the models without detrending, which showed stronger relationships between VIA body shape and relative carcass fat or lipid weights than relative muscle or protein weights (Table 4), the highest adjusted R^2 values in the detrended models is generally associated with the detrended carcass muscle weight sMW, indicating that between-animal variation plays a significant rôle in the establishment of these relationships. Before detrending, standard deviations in the logarithmically transformed relative fat and lipid weights were about 4 times higher than those associated with relative muscle and protein weight. Detrending resulted in similar standard deviations for relative fat and muscle weights. Accordingly, upon detrending of the data, a greater reduction in goodness of fit was found for fat and lipid data.

Removal of variation due to growth affected which shape indices contributed to the models for carcass composition. In particular, the contribution of the VIA measures L4 and L6 reduced from 0·75 of the models associated with non-detrended indices (Table 4) to 0·25 of the models associated with detrended indices (Table 5).

For the '¾ Landrace' type pigs, the relationship between body shape and composition was statistically significant for all four composition indices, whereas for the other two pig types, only some relationships were statistically significant. In particular, removal of the growth effects made the highly significant relationship between body shape and relative carcass fat weight for the '¼ Meishan' type pigs not significant.

Discussion

The experiment was designed to generate substantial variation in body morphology and composition by slaughtering pigs of three morphotypes sequentially throughout a live weight range of 35 kg to 115 kg. Analysis by regression methods was therefore particularly apt for the assessment of body shape in this study. The range of data included body weights and body sizes that are useful for management and slaughter decisions.

The description of carcass conformation and composition resulting from this study are in general agreement with the results of other studies. The '½ Pietrain' type pigs were previously classified by their wide hams and shoulders in comparison to white breeds and 'Meishan' types (Fisher *et al.,* 2003). Various independent studies performed on purebred pigs with carcass weights within the range examined in this study have found that Pietrain pigs are generally associated with higher lean content and Meishan pigs are generally associated with higher fat percentages (Davies, 1974; Fortin *et al.,* 1987; Quiniou *et al.,* 1996; Mueller *et al.,* 2000).

The use of crossbred progenies originating from the same dam pig type, which was justified on commercial grounds to maximize the usefulness of the results to industry practice, led to only moderate variations in body shape and composition for pigs of similar weights or sizes. The low between-type variation in this study may have been responsible for some of the disagreement in the description of conformation through VIA and carcass analysis, and the relatively weak correlations between shape and composition. The use of purebred animals would have produced pigs with increased between-type and decreased within-type variation in body form and composition. For the analysis of change in body conformation across size, this might have resulted in more pronounced differences between types, and better agreement between VIA and carcass analyses. To detect the relationship between shape and composition at a given weight, variation in environment and diet could be used to compensate for the reduction in within-type variation in shape and composition caused by the use of purebred animals.

Body conformation

Relative to age, carcass measurements describe differences in body conformation between the pig types more clearly than VIA. A separate analysis of pig growth relative to age, which used daily VIA size measurements over a prolonged growth period, showed however, that VIA could identify significant growth differences between pig types better than body weight (Doeschl *et al*., 2004).

Both VIA and carcass measurements classify the '½ Pietrain' pigs as the type with widest hams and shoulders over almost the entire size range and also as the type with the widest trunks for short body length. VIA and carcass measurements also show good agreement for the increase of ham width relative to body length. However, the methods disagree with respect to the relative increase of shoulder and trunk widths. Table 2 shows that the relative VIA ham width measure log (L5/L7) is associated with a higher adjusted R^2 statistics and a lower RMSE than the VIA shoulder and trunk width measures log (L1/L7) and log (L3/L7). Visual inspection of the daily linear VIA measurements for individual pigs indicated that the L5 measures had less scatter around their regression lines than other linear measures, suggesting that L5 measures were more reliable in this trial than the L1 and L3 measures. Continuous improvement of the visual imaging system and thus in the accuracy of the measurements would likely result in a better agreement of the shape descriptions provided by VIA and carcass measurements. It is possible that animal posture is in part responsible for the lower variation in L5; for example, changing level of gut fill my affect trunk width as measured by L3.

Relationship between body shape and carcass composition

The analysis described here has shown that there are important and significant relationships between the body shape of the living pigs studied immediately prior to slaughter and the composition of their dissected carcasses. Shape indices related to the trunk region of the pig appear to be relevant descriptors for relative fat and lipid weight, whereas shape indices related to the shoulder and ham region play a significant rôle for the description of relative muscle and protein content.

Detrending shape and carcass indices generally resulted in weaker relationships between shape and composition indices, at least partly due to the low within-type variation in shape and composition measures. That there is a statistically significant relationship between the detrended body shape and carcass composition despite the small variations in relative composition and shape indices after removal of growth trends is supportive of a need for further development work. It is hoped that a subsequent trial, in which variations in body conformation and composition are generated by different diets and more shape information is returned by the VIA system, will provide more definite answers about the relationship between body shape and carcass conformation.

Conclusion

The present study reveals the potential of VIA for obtaining *in vivo* estimates of carcass conformation and composition of pigs. The results of this analysis are encouraging as they show that VIA and carcass measurements generally lead to a similar description of body conformation characteristics for three pig types and that the shape indices provided by VIA explain a substantial amount of variation in the carcass composition. This study used commercially available pig types in order to be relevant to industry practice. In consequence, the variation in shape and composition was mainly achieved through staggered slaughter weights and less through different genetic material. Thus, the design of the trial did not maximize the possibilities for determining regression relationships between VIA body shape and body composition for pigs of a specific body length or body size. The observed significant link between VIA determined live body shape and composition in this study calls for further investigation of this relationship, as the prediction of carcass characteristics during a pig's lifetime offers great benefits to the production market.

Acknowledgements

The experiment was conducted at the Barhill research farm of BOCM PAULS in Cheshire. Physical carcass dissection was completed at the University of Bristol, Division of Farm Animal Science. Chemical analyses were undertaken at the laboratories of BOCM PAULS, Ipswich. The authors gratefully acknowledge the assistance of Mr F. Sandberg in the analysis of the data. This work is part of the UK LINK Sustainable Livestock Production Programme LK0614 Integrated Management Systems for Pig Nutrition Control and Pollution Reduction. The authors acknowledge the support of the sponsors : UK Department for Environment, Food and Rural Affairs (formerly Ministry of Agriculture, Fisheries and Food), UK Meat and Livestock Commission; and the industrial partners BOCM PAULS Ltd, Pig Improvement Company (UK) Ltd and Osborne (Europe) Ltd.

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(*Received* 19 *November* 2003—*Accepted* 24 *February* 2004)