Developments of carcass cuts, organs, body tissues and chemical body composition during growth of pigs

S. Landgraf, A. Susenbeth, P.W. Knap, H. Looft, G.S. Plastow, E. Kalm and R. Roehe

Animal Science / Volume 82 / Issue 06 / December 2006, pp 889 - 899
DOI: 10.1017/ASC2006097, Published online: 13 March 2007

Animal Science 2006, **82**: 889–899

ISSN 1357-7298
DOI: 10.1017/ASC2006097

Developments of carcass cuts, organs, body tissues and chemical body composition during growth of pigs

S. Landgraf[1], A. Susenbeth[2], P.W. Knap[3], H. Looft[3], G.S. Plastow[3], E. Kalm[1] and R. Roehe[1†]

[1]*Institute of Animal Breeding and Husbandry, Christian-Albrechts-University of Kiel, Hermann-Rodewald-Strasse 6, D-24118 Kiel, Germany*
[2]*Institute of Animal Nutrition, Physiology and Metabolism, Christian-Albrechts-University of Kiel, Hermann-Rodewald-Strasse 9, D-24098 Kiel, Germany*
[3]*PIC International Group, Ratsteich 31, D-24837 Schleswig, Germany*

[†]Corresponding author. E-mail: Rainer.Roehe@sac.ac.uk Present address: Sustainable Livestock Systems, Scottish Agricultural College, Bush Estate, Penicuik EH26 0PH, UK.

Abstract

A serial slaughter trial was carried out to examine the developmental change of physical and chemical body composition in pigs highly selected for lean content. A total of 48 pigs (17 females and 31 castrated males) were serially slaughtered and chemically analysed. Eight pigs were slaughtered at 20, 30, 60, 90, 120 and 140 kg live weight, (LW) respectively. The carcass was chilled and the left carcass side was dissected into the primal carcass cuts ham, loin, shoulder, belly and neck. Each primal carcass cut was further dissected into lean tissue, bones and rind. Additionally, the physical and chemical body composition was obtained for the total empty body as well as for the three fractions soft tissue, bones and viscera. Viscera included the organs, blood, empty intestinal tract and leaf fat. The relationship between physical or chemical body composition and empty body weight (EBWT) at slaughter was assessed using allometric equations ($\log_{10} y = \log_{10} a + b \log_{10} EBWT$)*. Dressing percentage increased from 69·4 to 85·2% at 20 to 120 kg and then decreased to 83·1% at 140 kg LW, whereas percentage of soft tissue, bones and viscera changed from 23·5 to 33·0%, 10·1 to 6·3% and 14·7 to 10·3%, respectively, during the entire growth period. Substantial changes in proportional weights of carcass cuts on the left carcass side were obtained for loin (10·5 to 17·5%) and belly (11·3 to 13·8%) during growth from 20 to 140 kg. Soft tissue fraction showed an allometric coefficient above 1 (*$b = 1·14$*) reflecting higher growth rate in relation to the total empty body. The coefficients for the fractions bones and viscera were substantially below 1 with* $b = 0·77$ *and 0·79, respectively, indicating substantial lower growth relative to growth of the total empty body. Lean tissue allometric growth rate of different primal cuts ranged from* $b = 1·02$ *(neck) to 1·28 (belly), whereas rates of components associated with fat tissue growth rate ranged from* $b = 0·62$ *(rind of belly) to 1·79 (backfat). For organs, allometric growth rate ranged from* $b = 0·61$ *(liver) to 0·90 (spleen). For the entire empty body, allometric accretion rate was 1·01, 1·75, 1·02 and 0·85 for protein, lipid, ash and water, respectively. Extreme increase in lipid deposition was obtained during growth from 120 to 140 kg growth. This was strongly associated with an increase in backfat and leaf fat in this period. Interestingly, breeds selected for high leanness such as Piétrain sired progeny showed an extreme increase in lipid accretion at a range of LW from 120 to 140 kg, which indicates that selection has only postponed the lipid deposition to an higher weight compared with the normally used final weight of 100 kg on the performance test. The estimates obtained for allometric growth rates of primal carcass cuts, body tissue and chemical body composition can be used to predict changes in weight of carcass cuts, determine selection goals concerning lean tissue growth, food intake capacity, etc. and generally as input parameters for pig growth models that can be used to improve the efficiency of the entire pig production system for pigs highly selected for lean content.*

Keywords: *allometry, body composition, carcass composition, growth, organs, pigs.*

Introduction

Growth, a complex and highly integrated process, was defined as the production of new biochemical units through metabolic and biological synthesis (Brody, 1945). In pigs, qualitative and quantitative changes in body composition are of increasing interest in the last years due to strong association of those traits with profit. Component pricing systems for pork have been developed reflecting the true carcass value more accurately (Akridge *et al.*, 1992; Tholen *et al.*, 2003). Using these systems, carcass value is strongly related to the amount of dissected lean of each primal cut. Knowledge of pig carcass composition and the development of body composition during growth are important to improve the efficiency of the production system and to increase the profit on present pig populations highly selected for lean tissue. In particular, the development of physical and chemical body composition of these pigs during growth is of high economic value in order to: (1) predict the development of carcass value during growth; (2) optimize the nutritional supply during growing and finishing; (3) determine selection objectives for optimal development of body tissue growth and food intake capacity; (4) refine alternative methods to identify optimal slaughter weights; and (5) provide parameters for description of growth and carcass composition for a pig growth model that can be used to improve the efficiency of the entire pig production system. To estimate body composition over the growth period the allometric model described by Huxley (1932) is of advantage because this function results in stable linear estimation function after log to log transformation, provides parameters with straight forward biological interpretation and stable first derivative estimates indicating the marginal growth. Seebeck (1968), Berg *et al*. (1978) in cattle, Evans and Kempster (1979) and Gu *et al.* (1992) in pigs have demonstrated that the allometric function appropriately describes the compositional changes throughout the growth period in meat animals. The objectives of the present study were to examine in a pig population selected for high leanness: (1) the development of primal carcass cuts and their dissected components during growth; (2) the growth of organs and minor carcass cuts; (3) the development of the chemical components of the total body of growing pigs; and (4) to identify indicator cuts for the development of the entire body composition.

Material and methods

Data were obtained in a three generation full-sib design and has been used to detect quantitative trait loci for protein and lipid deposition rate (Mohrmann *et al*., 2006a). The present analysis is based on the measurements of the F_1 generation that was generated from seven unrelated Piétrain boars (heterozygous at porcine ryanodine receptor locus, which are associated with stress susceptibility; Fujii *et al*. (1991)) of a sire line and 14 unrelated sows (Large White × Landrace × Leicoma) of a dam line. The experimental pigs were housed in identical straw-bedded pens (up to 15 pigs) with an electronic feeding station of the type ACEMA 48. The pigs were allowed *ad libitum* access to four pelleted diets designed to provide adequate nutrients for expression of their maximum protein accretion during the respective growth periods as described in detail by Landgraf *et al*. (2006) and Mohrmann *et al*. (2006b).

This study involved a total of 48 experimental pigs (17 females and 31 castrated males) serially slaughtered in six groups, covering a live weight (LW) range from 20 to 140 kg. Pigs were weighed weekly and pigs closed to the target weight were chosen for chemical analysis. At all weight classes (20, 30, 60, 90, 120 and 140 kg), eight animals were slaughtered in a nearby slaughter house. Organs, blood, empty intestinal tract and leaf fat were weighted separately and their weights were accumulated to the fraction viscera. The cold left carcass side was dissected (similar to DLG carcass cuts; Scheper and Scholz (1985)) at 24 h after slaughter as described in detail in Table 1. At first, the left carcass was dissected into the primal cuts like ham, shoulder, loin, belly and neck, and into the minor carcass cuts like thick rib, head, jowl, legs and tail. At second, the primal carcass cuts were dissected into the boneless and rindless component, bones, rind and other components. Then, the bones were pooled to the fraction ‘bone’ and the non-bone tissue to the fraction ‘soft tissue’. These fractions and the viscera of the entire body were then chemical analysed as described in detail by Landgraf *et al*. (2006) and Mohrmann *et al*. (2006b).

The following allometric equation was used to evaluate growth rate of each carcass component relative to carcass weight or empty body weight (EBWT):

$$Y = a X^{b}$$

where Y is weight of carcass component, X is weight of carcass or empty body weight, a is the intercept and b is the allometric growth coefficient relating the growth of Y to that

Table 1 *Primal carcass cuts (in bold) and their components after dissection*

Trait	Description
Ham	Ham separated from loin by cut between last and proceeding lumbar vertebrae, including rind, bones, hindquarter hock and tip of tenderloin
Ham trimmed	Ham boneless, rindless, without hindquarter hock and tip of tenderloin
Ham bones	Pelvis bone, femoral, tibial without hindquarter hock
Ham rind	Rind above ham without hindquarter hock
Tip of tenderloin	Tip of the filet
Hock	
Loin	Loin without neck, separated between 5 and 6 thoracic vertebrae and 5 and 6 lumbar vertebrae including tenderloin and bones
Loin trimmed	Loin boneless, without tenderloin and backfat
Loin bones	Bones of loin
Backfat	Fat above loin
Tenderloin	
Shoulder	Shoulder with shoulder meat, rind, bones and forequarter, without neck and thick ribs
Shoulder trimmed	Shoulder boneless, rindless without forequarter hock
Shoulder bones	Shoulder blade, humerus, radius, without forequarter
Shoulder rind	Rind above the shoulder without forequarter
Hock	
Belly	Belly with bones, flank and rind
Belly trimmed	Belly boneless, rindless, without flank
Belly ribs	Ribs of belly
Belly rind	Fat above belly
Flank	
Neck	Neck / spare rib with bones and rind
Neck trimmed	Neck rindless, boneless
Neck bones	Bones of neck
Neckfat	Fat above neck
Head	Head without jowl
Jowl	
Thick rib	First four ribs
Forleg	
Hindleg	
Tail	

of X. The statistical analysis was performed using SAS–procedure GLM (Statistical Analysis Systems Institute, 1992). The allometric equation $Y = a\,X^b$ was fit by linearizing the function as $\log_{10} Y = \log_{10} a + b \log_{10} X$. According to Gu *et al*. (1992) the following parameters were used to evaluate the goodness of fit of the allometric model:

(1) correlation (r) between the predicted values ($\hat{Y}_i$) and observed values (Y_i) for each component;
(2) the residual standard deviation (RSD) was calculated as follows:

$$\mathrm{RSD} = \left(\sum_{i=1}^{n} (e_i)^2 / n - p\right)^{\frac{1}{2}},$$

where e_i is the residual value for the ith observation, n = number of observations and p = degrees of freedom in the model.

Results

Growth of body components

At six target weights, LW, EBWT, carcass weight (CW), viscera of the entire body, carcass weight of the left side (CWl), weights of soft tissue and bones of the left carcass side, lean and fat tissue of the primal carcass cuts of the left carcass side were measured as presented in Table 2. Dressing percentage increased from 69·4 to 85·2% at 20 to 120 kg and thereafter decreased by 2·1 percent levels at 140 kg LW. Over the entire growth period, percentage of soft tissue of the EBWT increased continuously from 23·5 to 33·0%, whereas the corresponding ratios for bones and viscera decreased from 10·1 to 6·3% and 14·7 to 10·1%, respectively. The lean tissue of the primal cuts showed its highest increase between 90 and 120 kg LW, whereas fat tissue of these cuts increased extremely between 120 to 140 kg LW. However, it has to be considered that the percentage of fat tissue on the EBWT even decreased from 90 to 120 kg. The coefficients of variation were higher for traits at 20 kg compared with higher weight groups. In particular at high weights, viscera showed higher coefficients of variation than lean tissue.

Table 3 presents the developmental change of ham and its dissected components of the left carcass side during growth. Percentage of ham of the left carcass side increased from 27·1 to 30·7% at 20 to 30 kg and thereafter decreased to be approximately similar at 60 to 140 kg LW. Extreme increase in rind of ham occurred during growth from 120 to 140 kg LW. However, it has to be considered that the rind as percentage of the weight of entire ham was lower at 120 kg than at 90 kg LW. Weight of ham bones increased from 0·23 to 1·03 kg, but their corresponding proportion on the entire ham decreased from 11·9 to 6·5%. The percentage of tip of tenderloin on ham was about 3%, and showed very high variation among animals.

Loin percentage of the left carcass side rose from 10·5 to 17·5% (Table 4). The highest increase in loin growth of 2·86 kg was found between 90 and 120 kg LW. Backfat on the *longissimus dorsi* increased extremely by 1·35 kg between 120 and 140 kg LW. At LW of 140 kg, 30·3% of the entire loin consisted of backfat and there was substantial variation among animals as indicated by a coefficient of variation of 0·26. In contrast, bones and trimmed loin as percentage of the weight of entire loin decreased from 33 to 18% and 54 to 46% during growth, respectively.

Highest increase in shoulder weight (1·82 kg) was obtained between 60 and 90 kg LW (Table 5). The percentage of shoulder on the left carcass weight increased between 20 and 30 kg from 15·0 to 16·5%. Thereafter, the relative amount of shoulder decreased to 14·6% at 140 kg LW. Also, percentage of shoulder trimmed and rind on the entire shoulder weight rose from 56·9 to 61·9% and 14·3 to 16·4%,

Table 2 *Development of live weight (LW), empty body weight (EBWT), carcass weight (CW), carcass weight of the left side (CWl) and body fraction weights*[†] *of soft tissue, viscera and bones during growth*

	Weight class (kg)																	
	20			30			60			90			120			140		
Trait	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV
LW (kg)	20·2	2·25	0·11	32·8	2·14	0·07	62·6	2·60	0·04	92·8	3·46	0·04	116·5	1·91	0·02	141·9	4·32	0·03
EBWT (kg)	19·0	2·20	0·12	30·6	2·35	0·08	60·1	2·69	0·04	90·8	3·24	0·04	114·7	1·80	0·02	139·2	4·09	0·03
CW (kg)	14·0	1·96	0·14	23·6	1·27	0·05	47·5	2·53	0·05	71·9	1·90	0·03	99·2	3·43	0·03	117·8	2·79	0·02
CWl (kg)	7·1	1·11	0·16	11·3	0·64	0·06	22·9	1·16	0·05	35·1	1·21	0·03	47·7	1·98	0·04	57·0	1·75	0·03
Soft tissue (kg)	4·5	0·84	0·19	8·1	0·54	0·07	16·8	1·25	0·07	27·9	0·94	0·03	37·6	0·76	0·02	46·0	1·90	0·04
Lean tissue (kg)[‡]	3·1	0·47	0·15	5·7	0·30	0·05	11·7	0·99	0·08	18·2	1·52	0·08	25·5	1·22	0·05	29·2	1·72	0·06
Fat tissue (kg)[‡]	0·9	0·23	0·26	1·2	0·30	0·25	2·9	0·52	0·18	4·9	0·86	0·17	5·9	1·02	0·17	9·0	1·20	0·13
Viscera (kg)	2·8	0·44	0·16	4·6	0·36	0·08	7·4	0·56	0·08	10·2	0·70	0·07	12·0	1·23	0·10	14·1	1·40	0·10
Bones (kg)	1·9	0·23	0·12	2·8	0·18	0·06	4·6	0·32	0·07	6·4	0·37	0·06	8·0	0·59	0·07	8·8	0·47	0·05
CW:LW (%)	69·4	6·36	0·09	72·0	2·11	0·03	75·9	2·18	0·03	77·5	1·44	0·02	85·2	2·60	0·03	83·1	3·26	0·04
Soft tissue: EBWT (%)	23·5	3·08	0·13	26·5	1·74	0·07	28·0	1·70	0·06	30·8	1·08	0·04	32·8	0·73	0·02	33·0	0·60	0·02
Lean tissue: EBWT (%)	16·5	1·78	0·11	18·6	1·16	0·06	19·4	1·40	0·07	20·0	1·14	0·06	22·2	1·13	0·05	21·0	1·04	0·05
Fat tissue: EBWT (%)	4·6	1·15	0·25	3·9	0·78	0·20	4·9	0·82	0·17	5·5	1·05	0·19	5·1	0·86	0·17	6·5	0·82	0·13
Bones: EBWT (%)	10·1	0·77	0·08	9·1	0·72	0·08	7·6	0·47	0·06	7·0	0·54	0·08	6·9	0·56	0·08	6·3	0·35	0·06
Viscera: EBWT (%)	14·7	1·67	0·11	14·9	0·85	0·06	12·3	1·23	0·10	11·3	0·72	0·06	10·5	1·11	0·11	10·1	0·82	0·08

[†] Fraction of soft tissue and bones of the left carcass side.
[‡] From the primal carcass cuts of the left carcass side (ham, loin, shoulder, belly and neck).

Table 3 *Developmental change of the ham and its dissected components of the left carcass side during the growth period*

	Weight class (kg)																	
	20			30			60			90			120			140		
Ham component	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV
Ham (kg)	1·92	0·36	0·19	3·47	0·24	0·07	6·58	0·42	0·06	10·22	0·83	0·08	12·99	0·66	0·05	15·97	0·79	0·05
Ham trimmed (kg)	1·23	0·21	0·17	2·18	0·18	0·08	4·36	0·39	0·09	6·70	0·70	0·10	9·09	0·70	0·08	10·28	0·86	0·08
Ham bones (kg)	0·23	0·06	0·28	0·30	0·04	0·14	0·53	0·06	0·11	0·69	0·09	0·13	0·89	0·13	0·14	1·03	0·17	0·17
Ham rind (kg)	0·19	0·04	0·19	0·31	0·05	0·17	0·74	0·08	0·11	1·38	0·25	0·18	1·49	0·25	0·17	2·53	0·53	0·21
Tip of tenderloin (kg)	0·05	0·01	0·07	0·10	0·03	0·29	0·20	0·04	0·21	0·31	0·07	0·24	0·39	0·24	0·60	0·43	0·08	0·19
Hock (kg)	0·19	0·07	0·42	0·36	0·05	0·15	0·55	0·15	0·28	0·81	0·12	0·15	1·02	0·09	0·09	1·31	0·32	0·25
Ham (%)†	27·1	2·23	0·08	30·7	0·67	0·02	28·8	1·03	0·04	29·1	1·97	0·07	27·3	1·41	0·05	28·0	1·07	0·04
Ham trimmed (%)‡	64·3	4·88	0·08	62·8	1·81	0·03	66·2	2·68	0·04	65·5	2·75	0·04	69·9	2·99	0·04	64·4	4·46	0·07
Ham bones (%)‡	11·9	2·67	0·19	8·5	0·91	0·11	8·1	1·00	0·12	6·8	1·18	0·17	6·8	0·80	0·12	6·5	1·25	0·19
Ham rind (%)‡	10·1	1·76	0·17	8·9	1·00	0·11	11·3	1·39	0·12	13·6	3·08	0·23	11·5	2·31	0·20	15·8	3·07	0·19
Tip of tenderloin (%)‡	2·8	0·63	0·23	2·9	0·66	0·23	3·0	0·57	0·19	3·0	0·67	0·22	3·0	1·70	0·56	2·7	0·54	0·20
Hock (%)‡	9·9	3·91	0·40	10·2	1·50	0·15	8·4	2·24	0·27	7·9	1·26	0·16	7·9	0·74	0·09	8·2	1·99	0·24

† Ham as percentage of the left carcass side.
‡ Components as percentage of the total weight of ham.

respectively. Highest decrease of a component of the shoulder was obtained for its bones from 27·5 to 8·9%. Weights of rind of shoulder and hock showed, in comparison with other shoulder components, high coefficients of variation between 0·13 to 0·42 and 0·12 to 0·56, respectively.

Weights of belly and dissected belly components are presented in Table 6. High variation among animals was estimated for weight of belly rind (0·27 to 0·57). Percentage of belly weight on the left carcass side increased from 11% at 20 kg to 15% at 90 kg LW and decreased thereafter. In contrast, the relative amount of rind on the entire belly decreased continuously from 37·5 to 11·8%. This corresponds with an increase in trimmed belly on the total carcass cut from 49 to 67%.

The smallest primal carcass cut was the neck (Table 7). The maximum weight was 5·01 kg; this was only 8·8% of the left carcass side weight. A linear increase in neck weight was obtained between 30 and 120 kg LW. Between 20 to 30 kg, gain in neck weight was lower, even when adjusting for the smaller weight difference between these groups. In comparison with fat tissue growth in the primal carcass cuts ham and loin, the neckfat showed no extreme increase during growth from 120 to 140 kg LW.

The changes in weights of minor carcass cuts during growth are given in Table 8. Increase in weights of thick rib, jowl and head showed large variation among weight groups. The relative amount of minor carcass cuts on the left carcass side weight did not change substantively during growth except for the head, for which the percentage decreased from 7·6 to 4·7%.

At slaughter day, organ weights were recorded as shown in Table 9. Weights of organs were three (lung), four (liver, kidney), five (heart) and six (spleen) times higher at 140 kg LW than those at 20 kg. However, the weight of organs as percentage of the EBWT decreased from 7·1 to 3·9% for all organs. Extreme increase in weight of leaf fat occurred at the end of the finishing period and was 2·6 times higher at 140 kg LW compared with those at 90 kg. Leaf fat was in this study a part of the viscera, which additionally consisted of blood, organs (liver, lung, kidney, spleen, heart and trachea) and empty intestinal tract.

Means, standard deviations and coefficients of variation of chemical components in the empty body for each weight class are presented in Table 10. Ash content was almost constant during growth, whereas protein content increased from 15·9 to 17·3% during growth from 20 to 30 kg and then

Table 4 *Developmental change of the loin and its dissected components of the left carcass side during the growth period*

	Weight class (kg)																	
	20			30			60			90			120			140		
Loin component	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV
Loin (kg)	0·74	0·16	0·21	1·32	0·08	0·06	3·34	0·35	0·11	5·42	0·46	0·09	8·28	1·05	0·13	9·98	1·02	0·10
Loin trimmed (kg)	0·40	0·09	0·23	0·73	0·05	0·06	1·84	0·21	0·11	2·89	0·26	0·09	4·31	0·58	0·14	4·62	0·43	0·09
Loin bones (kg)	0·24	0·04	0·19	0·36	0·07	0·18	0·72	0·11	0·15	1·06	0·12	0·12	1·49	0·22	0·15	1·83	0·19	0·10
Backfat (kg)	0·09	0·02	0·21	0·13	0·02	0·18	0·53	0·13	0·24	1·13	0·24	0·22	1·71	0·66	0·39	3·06	0·78	0·26
Tenderloin (kg)	0·05	0·003	0·08	0·09	0·02	0·20	0·22	0·06	0·28	0·30	0·06	0·20	0·41	0·06	0·16	0·41	0·09	0·21
Loin (%)†	10·5	1·66	0·16	11·7	0·98	0·08	14·6	1·46	0·10	15·4	1·19	0·08	17·4	1·99	0·11	17·5	1·93	0·11
Loin trimmed (%)‡	54·2	4·33	0·08	55·2	3·85	0·07	55·4	3·47	0·06	53·3	3·39	0·06	52·6	8·19	0·16	46·4	3·88	0·08
Loin bones (%)‡	33·2	6·14	0·18	26·9	4·12	0·15	21·5	2·00	0·09	19·5	2·23	0·11	18·1	2·99	0·16	18·4	1·63	0·09
Backfat (%)‡	12·4	3·45	0·28	9·6	1·59	0·17	15·6	2·94	0·19	20·6	2·97	0·14	20·7	7·12	0·34	30·3	5·01	0·17
Tenderloin (%)‡	3·8	1·43	0·21	6·8	1·49	0·22	6·4	1·29	0·20	5·6	1·24	0·22	5·0	0·78	0·16	4·1	0·75	0·18

† Loin as percentage of the left carcass side.
b ‡ Components as percentage of the total weight of loin.

Table 5 *Developmental change of the shoulder and its dissected components of the left carcass side during the growth period*

	Weight class (kg)																	
	20			30			60			90			120			140		
Shoulder component	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV
Shoulder (kg)	1·06	0·21	0·20	1·86	0·07	0·04	3·50	0·22	0·06	5·32	0·41	0·08	6·78	0·44	0·07	8·33	0·77	0·09
Shoulder trimmed (kg)	0·60	0·16	0·26	1·33	0·09	0·08	2·15	0·18	0·08	3·27	0·34	0·10	4·26	0·49	0·12	5·17	0·68	0·13
Shoulder bones (kg)	0·31	0·24	0·79	0·22	0·04	0·16	0·46	0·11	0·25	0·55	0·05	0·08	0·66	0·07	0·11	0·74	0·07	0·10
Shoulder rind (kg)	0·15	0·06	0·42	0·23	0·03	0·13	0·46	0·10	0·21	0·69	0·11	0·16	0·86	0·24	0·27	1·36	0·30	0·22
Hock (kg)	0·08	0·04	0·56	0·27	0·05	0·17	0·45	0·12	0·26	0·71	0·09	0·12	0·94	0·15	0·16	0·98	0·17	0·18
Shoulder (%)†	15·0	1·57	0·10	16·5	0·67	0·04	15·3	0·55	0·04	15·2	1·17	0·08	14·2	0·78	0·05	14·6	1·40	0·10
Shoulder trimmed (%)‡	56·9	11·93	0·21	61·1	4·32	0·07	61·2	1·82	0·03	61·3	2·95	0·05	62·8	6·07	0·10	61·9	3·14	0·05
Shoulder bones (%)‡	27·5	16·96	0·62	12·1	1·79	0·15	13·0	3·13	0·24	10·4	0·85	0·08	9·8	0·96	0·10	8·9	1·20	0·13
Shoulder rind (%)‡	14·3	5·07	0·35	12·5	1·48	0·12	13·2	2·87	0·22	13·0	2·14	0·17	12·6	3·52	0·28	16·4	4·16	0·25
Hock (%)‡	7·9	4·49	0·57	14·5	2·17	0·15	12·8	3·24	0·25	23·3	1·42	0·11	13·9	2·03	0·15	11·8	1·58	0·13

† Shoulder as percentage of the left carcass side.
‡ Components as percentage of the total weight of shoulder.

decreased by 1·4 percent levels at 140 kg LW. During the entire growth, lipid content increased substantially from 7·0 to 29·8%, this was mainly associated with a decrease in water content from 74·1 to 52·9%.

Allometric growth

Correlations close to 1 indicate high goodness of fit of allometric growth of carcass fractions relative to EBWT as shown in Table 11. However, there were differences in RSD, which was lowest for bones (0·41 kg) and highest for lean tissue (1,14 kg). The soft tissue fraction grew relatively faster than the entire empty body. For fat tissue of the primal cuts, the estimate of allometric growth rate was only slightly higher than for lean tissue. Allometric growth rates (b) of the fractions bones and viscera were similar but substantially lower than 1 indicating a substantial lower growth rate relative to the empty body growth rate.

Table 12 shows the allometric growth of primal carcass cuts and their dissected components in relation to the EBWT. Relative growth of ham, shoulder and neck was only slightly faster ($b < 1·05$) than growth of the EBWT and those for shoulder and neck were not significant different from 1. In contrast, loin grew more rapidly than the EBWT ($b = 1·32$), whereas the allometric growth rate of the belly was less than those of the loin but higher than those of the other primal carcass cuts ($b = 1·14$). Backfat resulted in highest allometric growth rate with $b = 1·79$. The correlation between observed and predicted weights was mostly higher for the entire carcass cuts than for their dissected components.

Allometric growth of organs in relation to the EBWT is presented in Table 13. The relative accretion rate of organs was substantially less than 1 indicating that growth of organs was relatively lower than growth of the entire empty body. Lowest allometric growth rate was found for liver ($b = 0·61$) and highest for spleen ($b = 0·90$). Especially, leaf fat grew more rapidly ($b = 1·87$) than the empty body. For growth of organs, the goodness of fit of allometric functions was high, ranging from $r = 0·83$ to 0·96. These correlations were higher for liver and kidney than for heart, lung and spleen.

Allometric growths for the chemical body composition in relation to EBWT are presented in Table 14. Accretion of lipid occurred relatively more rapidly than EBWT as the coefficient of accretion rate exceeds 1 ($b = 1·75$). In contrast, accretion rate of water was reduced in comparison with EBWT as indicated by $b = 0·85$. Accretion rate of protein and ash were only slightly above 1 reflecting similar relative gains as EBWT.

Table 6 *Developmental change of the belly and its dissected components of the left carcass side during the growth period*

	Weight class (kg)																	
	20			30			60			90			120			140		
Belly component	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV
Belly (kg)	0·80	0·16	0·19	1·57	0·12	0·08	3·33	0·22	0·07	5·28	0·30	0·06	6·60	0·45	0·07	7·88	0·84	0·11
Belly trimmed (kg)	0·38	0·07	0·19	0·86	0·16	0·19	1·66	0·38	0·23	2·90	0·54	0·18	4·40	0·61	0·14	5·28	0·68	0·13
Belly ribs (kg)	0·16	0·07	0·47	0·25	0·05	0·20	0·52	0·11	0·21	0·73	0·11	0·15	0·99	0·14	0·14	0·99	0·14	0·15
Belly rind (kg)	0·31	0·13	0·42	0·40	0·23	0·57	0·82	0·23	0·27	1·03	0·55	0·54	0·83	0·32	0·38	0·95	0·47	0·49
Flank (kg)	0·09	0·01	0·16	0·10	0·07	0·71	0·40	0·17	0·43	0·74	0·29	0·39	0·79	0·21	0·27	1·19	0·23	0·19
Belly (%)†	11·3	0·95	0·08	13·9	0·94	0·07	14·6	0·54	0·04	15·1	0·90	0·05	13·9	1·06	0·08	13·8	1·52	0·11
Belly trimmed (%)‡	49·1	12·82	0·26	54·9	10·44	0·19	49·6	9·79	0·20	54·9	10·19	0·19	66·6	7·22	0·11	67·0	6·67	0·10
Belly ribs (%)‡	19·1	6·19	0·32	16·2	3·35	0·21	15·6	4·12	0·26	13·9	2·32	0·17	15·1	2·30	0·15	12·6	1·74	0·14
Belly rind (%)‡	37·5	11·53	0·31	25·5	13·90	0·55	25·0	7·63	0·31	19·3	10·07	0·52	12·5	4·36	0·35	11·8	4·44	0·38
Flank (%)‡	13·8	2·17	0·16	6·0	3·70	0·62	11·6	4·65	0·40	14·2	5·42	0·38	12·1	3·48	0·29	15·3	3·38	0·22

† Belly as percentage of the left carcass side.
‡ Components as percentage of the total weight of belly.

Table 7 *Developmental change of the neck and its dissected components of the left carcass side during the growth period*

	Weight class (kg)																	
	20			30			60			90			120			140		
Neck component	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV
Neck (kg)	0·69	0·16	0·24	0·98	0·11	0·11	2·06	0·28	0·14	3·19	0·36	0·11	4·33	0·42	0·10	5·01	1·07	0·21
Neck trimmed (kg)	0·43	0·12	0·28	0·59	0·07	0·11	1·25	0·14	0·11	1·83	0·19	0·10	2·59	0·30	0·12	3·03	0·32	0·10
Neck bones (kg)	0·22	0·05	0·21	0·25	0·05	0·18	0·41	0·09	0·23	0·62	0·15	0·25	0·83	0·10	0·12	0·95	0·29	0·31
Neckfat (kg)	0·13	0·04	0·30	0·14	0·05	0·33	0·39	0·12	0·31	0·73	0·26	0·36	1·01	0·15	0·15	1·16	0·33	0·29
Neck (%)†	9·8	1·40	0·14	8·7	0·86	0·10	9·0	1·13	0·13	9·1	0·97	0·11	9·1	0·95	0·10	8·8	1·76	0·20
Neck trimmed (%)‡	62·1	8·94	0·14	60·6	4·48	0·07	61·2	5·50	0·09	57·7	7·76	0·13	60·1	8·51	0·14	62·2	11·18	0·18
Neck bones (%)‡	31·5	4·32	0·14	25·6	3·14	0·12	19·7	3·47	0·18	19·3	4·04	0·21	19·3	2·78	0·14	19·4	5·33	0·27
Neckfat (%)‡	18·7	4·29	0·23	14·1	4·12	0·29	18·5	3·44	0·19	22·3	5·80	0·26	23·6	4·28	0·18	23·1	5·05	0·22

† Neck as percentage of the left carcass side.
‡ Components as percentage of the total weight of neck.

Table 8 *Developmental change of minor carcass cuts of the left carcass side during the growth period*

	Weight class (kg)																	
Minor carcass components (kg)	20			30			60			90			120			140		
	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV
Head	0·54	0·15	0·28	0·76	0·05	0·06	1·27	0·12	0·09	1·86	0·14	0·08	2·19	0·16	0·07	2·69	0·18	0·07
Jowl	0·23	0·09	0·38	0·46	0·09	0·19	0·83	0·21	0·25	1·21	0·16	0·13	1·76	0·24	0·14	2·22	0·15	0·07
Thick rib	0·24	0·08	0·36	0·38	0·07	0·17	0·94	0·08	0·08	1·18	0·30	0·26	1·89	0·50	0·26	2·08	0·35	0·17
Foreleg	0·08	0·03	0·34	0·13	0·02	0·15	0·25	0·04	0·14	0·52	0·19	0·37	0·41	0·15	0·36	0·39	0·08	0·22
Hindleg	0·16	0·05	0·29	0·29	0·04	0·15	0·55	0·06	0·11	0·53	0·26	0·48	0·76	0·21	0·28	0·89	0·14	0·15
Tail	0·11	0·06	0·57	0·17	0·05	0·32	0·26	0·09	0·35	0·46	0·17	0·37	0·42	0·09	0·22	0·51	0·29	0·56

Table 9 *Developmental change of organs, empty gastrointestinal tract and leaf fat during the growth period*

	Weight class (kg)																	
	20			30			60			90			120			140		
Organ (kg)	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV
Heart	0·11	0·01	0·09	0·17	0·05	0·28	0·31	0·14	0·46	0·37	0·04	0·11	0·40	0·16	0·40	0·51	0·05	0·10
Liver	0·54	0·07	0·12	0·88	0·10	0·12	1·27	0·10	0·08	1·56	0·20	0·13	1·72	0·20	0·11	2·02	0·26	0·13
Lung	0·35	0·13	0·37	0·48	0·09	0·18	0·77	0·13	0·18	0·85	0·15	0·17	1·08	0·14	0·13	1·15	0·41	0·36
Spleen	0·04	0·01	0·18	0·07	0·01	0·15	0·11	0·02	0·18	0·20	0·02	0·09	0·23	0·09	0·40	0·25	0·08	0·33
Kidney	0·10	0·02	0·17	0·16	0·02	0·13	0·28	0·03	0·10	0·32	0·04	0·13	0·40	0·05	0·13	0·44	0·03	0·06
Trachea	0·20	0·03	0·16	0·31	0·08	0·27	0·53	0·09	0·17	0·67	0·05	0·08	0·81	0·09	0·11	0·91	0·16	0·18
Intestinal tract	1·37	0·29	0·21	2·37	0·30	0·13	3·66	0·15	0·12	5·26	0·54	0·10	5·77	0·63	0·11	6·28	0·98	0·16
Blood	0·86	0·16	0·18	1·52	0·17	0·11	2·38	0·37	0·16	3·42	0·43	0·13	4·19	0·48	0·12	4·56	0·47	0·10
Leaf fat†	0·06	0·03	0·44	0·12	0·03	0·23	0·46	0·15	0·32	1·00	0·25	0·25	1·57	0·55	0·35	2·56	0·57	0·22

† Leaf fat is the entire tissue and not only lipid.

Table 10 *Developmental change of the relative amount of chemical body composition on the empty body weight during the growth period*

	Weight class (kg)																	
	20			30			60			90			120			140		
Chemical component (%)	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV	Mean	s.d.	CV
Water	74·07	1·59	0·02	71·33	1·63	0·02	62·35	1·99	0·03	58·90	2·70	0·05	60·70	5·83	0·10	52·87	4·47	0·08
Lipid	7·04	1·11	0·16	8·39	1·49	0·18	17·40	2·26	0·13	21·49	2·84	0·13	22·86	5·35	0·23	29·75	4·61	0·15
Protein	15·91	0·82	0·05	17·32	0·70	0·04	17·15	0·85	0·16	16·58	0·30	0·02	16·07	1·08	0·07	15·88	1·16	0·07
Ash	3·01	0·25	0·08	2·99	0·39	0·13	3·13	0·22	0·07	3·06	0·22	0·07	3·14	0·22	0·07	2·91	0·34	0·12

Table 11 *Estimated allometric growth functions† relating weights of carcass fractions to empty body weight*

Components	*log a*	s.e.	*b*	s.e.	*r*	RSD‡ (kg)
Soft tissue	−0·084	0·032	1·137	0·014	0·99	0·884
Lean tissue§	−0·924	0·033	1·120	0·024	0·99	1·144
Fat tissue§	−1·637	0·076	1·185	0·037	0·96	0·876
Bones	−0·709	0·033	0·774	0·013	0·99	0·408
Viscera	−0·546	0·025	0·792	0·022	0·98	0·800

† Allometric functions were fitted by linearizing the functions as $\log_{10} Y = \log_{10} a + b \log_{10} X$.
‡ RSD = residual standard deviation.
§ of the primal carcass cuts (ham, loin, shoulder, belly and neck).

Allometric accretion rates of the chemical components of the fractions soft tissue, bones and their accumulated value as well as viscera in relation to the EBWT are given in Table 15. Highest allometric accretion rate of lipid ($b = 1{\cdot}85$) in relation to the EBWT was found in the soft tissue fraction but of almost similar rate in the viscera fraction. Substantial lower relative accretion rate of lipid ($b = 1{\cdot}25$) was obtained for the fraction bones, but this b value still exceeds 1 reflecting a more rapidly accumulating lipid than EBWT. Rate of accretion of protein ($b = 1{\cdot}15$) was above the rate of growth of the empty body in the soft tissue fraction and substantially lower in the fractions bones and viscera with $b = 0{\cdot}79$ and 0·70, respectively. Accretion rate of water was slightly lower than empty body growth rate in the soft tissue fraction, but substantively lower in the fractions bones and viscera at almost equal magnitude. Ash accretion rate was similar to those of the empty body in the fractions soft tissue and bones, however, much lower in the fraction viscera.

Table 12 *Estimated allometric growth functions† relating weights of carcass cuts and their dissected components to empty body weight*

Carcass cut	*log a*	s.e.	*b*	s.e.	*r*	RSD‡ (kg)
Ham	−1·040	0·026	1·047	0·012	0·99	0·448
Ham trimmed	−1·269	0·032	1·071	0·024	0·99	0·536
Ham bones	−1·664	0·056	0·776	0·025	0·94	0·107
Ham rind	−2·355	0·065	1·257	0·039	0·94	0·307
Tip of tenderloin	−2·589	0·103	1·044	0·063	0·81	0·104
Hock	−1·902	0·124	0·928	0·058	0·92	0·158
Loin	−1·826	0·051	1·318	0·034	0·98	0·686
Loin trimmed	−2·003	0·049	1·261	0·031	0·97	0·405
Loin bones	−1·951	0·058	1·022	0·027	0·97	0·154
Backfat	−3·447	0·122	1·789	0·064	0·92	0·482
Tenderloin	−2·685	0·082	1·097	0·038	0·91	0·063
Shoulder	−1·263	0·034	1·018	0·019	0·99	0·377
Shoulder trimmed	−1·559	0·047	1·061	0·033	0·98	0·356
Shoulder bones	−1·465	0·104	0·618	0·063	0·84	0·118
Shoulder rind	−2·199	0·101	1·050	0·045	0·91	0·193
Hock	−2·451	0·129	1·166	0·067	0·93	0·135
Belly	−1·520	0·036	1·138	0·023	0·99	0·453
Belly trimmed	−2·021	0·082	1·276	0·045	0·97	0·449
Belly ribs	−2·085	0·076	0·992	0·047	0·94	0·124
Belly rind	−1·332	0·177	0·621	0·101	0·55	0·368
Flank	−2·873	0·201	1·364	0·104	0·86	0·213
Neck	−1·514	0·063	1·032	0·027	0·96	0·461
Neck trimmed	−1·720	0·045	1·023	0·026	0·98	0·205
Neck bones	−1·720	0·089	0·774	0·052	0·89	0·148
Neck rind	−2·586	0·123	1·231	0·073	0·91	0·186

† Allometric functions were fitted by linearising the functions as $\log_{10} Y = \log_{10} a + b \log_{10} X$.
‡ RSD = residual standard deviation.

Table 13 *Estimated allometric growth functions† relating weights of organs, empty gastro-intestinal tract and leaf fat to empty body weight*

Fraction	*log a*	s.e.	*b*	s.e.	*r*	RSD‡ (kg)
Heart	−1·867	0·151	0·719	0·076	0·83	0·093
Liver	−1·010	0·054	0·614	0·025	0·95	0·165
Lung	−1·255	0·076	0·617	0·044	0·84	0·193
Spleen	−2·522	0·081	0·900	0·043	0·85	0·051
Kidney	−1·867	0·053	0·710	0·031	0·96	0·036
Trachea	−1·645	0·069	0·752	0·039	0·94	0·095
Blood	−1·053	0·067	0·804	0·036	0·95	0·468
Leaf fat	−3·657	0·122	1·867	0·055	0·93	0·367

† Allometric functions were fitted by linearizing the functions as $\log_{10} Y = \log_{10} a + b \log_{10} X$.
‡ RSD = residual standard deviation.

Discussion

Entire body and carcass composition

The coefficient of variation of LW was substantially higher at 20 kg LW than in other weight groups indicating the variation in growth during the adaptation period to the test station. Thereafter, the variation of LW was of small magnitude. Using commercial slaughter pigs, Ketels (1997) and Doedt (1997) estimated dressing percentages of 79·8% at about 110 kg LW, which is within the range of those obtained at 90 and 120 kg in the present study (Table 2). A developmental change of dressing percentage was shown by Wagner *et al.* (1999) with an increase from 68·1 to 76·2% when LW changed from 25 to 129 kg and thereafter decreased to 75·7% at 152 kg LW. In Table 2, dressing percentage increased from 69·4 to 85·2% in the weight range from 20 to 120 kg and decreased to 83·1% at 140 kg LW. Differences between studies may partly be due to the use of different cutting systems. In the half carcass of Large White × Landrace castrates, Davis and Pryor (1977) reported fat and lean tissue of 0·9 and 2·6 kg, respectively, at 19·8 kg LW and 5·8 and 9·7 kg at 62 kg LW. The accumulated weights of these two tissues were lower than the corresponding weights of soft tissue fraction in the present study with 3·5 *v.* 4·5 kg and 15·5 *v.* 16·8 kg for the corresponding weight groups, respectively. In Landrace, Davis and Kallweit (1979) reported for fat and lean tissue 0·9 and 3·2 kg at 17·5 kg LW and 17·2 and 24·0 kg at 121 kg LW. At 70 kg carcass weight, Gu *et al.* (1992) obtained for five different genotypes 21 to 24 kg fat tissue and 33 to 37 kg lean tissue of the entire carcass. This agrees well with the weight of soft tissue in the present study, which represents the accumulated fat and lean tisure and was 55·8 kg (two times the weight of soft tissue fraction of 27·9 kg of the left carcass side) at 72 kg carcass weight. The weight of bones at equivalent LWs were higher than

Table 14 *Estimated allometric growth functions† relating weights of chemical body components to empty body weight*

Chemical component	*log a*	s.e.	*b*	s.e.	*r*	RSD‡ (kg)
Water	0·033	0·023	0·850	0·011	0·99	3·570
Lipid	−2·172	0·069	1·749	0·035	0·97	3·576
Protein	−0·820	0·026	1·005	0·014	0·99	0·879
Ash	−1·590	0·041	1·024	0·023	0·98	0·267

† Allometric functions were fitted by linearizing the functions as $\log_{10} Y = \log_{10} a + b \log_{10} X$.
‡ RSD = residual standard deviation.

Table 15 *Estimated allometric growth functions† relating weights of chemical components of the fractions soft tissue, bones and their accumulated value as well as viscera to empty body weight*

Fraction	Component	*log a*	s.e.	*b*	s.e.	*r*	RSD‡ (kg)
Soft tissue	Water	−0·725	0·044	0·984	0·016	0·98	1·457
	Lipid	−2·799	0·083	1·851	0·053	0·96	1·523
	Protein	−1·577	0·029	1·147	0·023	0·99	0·360
	Ash	−2·657	0·035	1·027	0·021	0·99	0·018
Bones	Water	−0·671	0·034	0·610	0·024	0·97	0·266
	Lipid	−2·496	0·051	1·250	0·026	0·98	0·095
	Protein	−1·493	0·042	0·794	0·019	0·98	0·105
	Ash	−2·093	0·035	1·058	0·027	0·97	0·110
Soft tissue + Bones	Water	−0·489	0·029	0·906	0·023	0·98	1·623
	Lipid	−2·545	0·071	1·750	0·044	0·97	1·566
	Protein	−1·315	0·033	1·063	0·015	0·99	0·383
	Ash	−1·985	0·041	1·052	0·023	0·98	0·118
Viscera	Water	−0·395	0·037	0·622	0·019	0·96	0·598
	Lipid	−3·300	0·103	1·822	0·055	0·93	0·650
	Protein	−1·289	0·044	0·695	0·021	0·96	0·122
	Ash	−2·399	0·061	0·666	0·032	0·88	0·014

† Allometric functions were fitted by linearizing the functions as $\log_{10} Y = \log_{10} a + b \log_{10} X$.
‡ RSD = residual standard deviation.

reported by Davis and Pryor (1977) and Davis and Kallweit (1979) because the present study additionally included bones of head, tail and digits.

Development of primal carcass cuts

Coefficients of variation of primal carcass cuts were mostly lower than their dissected components such as trimmed primal cut, rind and bones. At 110 kg LW, Doedt (1997) obtained weights of 12·97, 6·87, 6·48, 6·87, 4·21, 1·28 and 0·74 kg for ham, loin including backfat, shoulder, belly, neck including neckfat, backfat and neckfat weights, respectively. These correspond well with weights for ham, shoulder, belly and neck measured in present study, but were lower in weights for loin, backfat and neckfat. For five different genotypes grown from 59 to 127 kg, Gu *et al.* (1992) reported weights for ham, loin, shoulder, belly and neck from 6·5 to 12·7, 5·2 to 11·0, 2·4 to 4·7, 3·0 to 5·9 and 3·0 to 6·2, respectively. This corresponds with the weight of ham of the present study but had substantial higher weight for the loin and lower weight for the shoulder. This may partly due to the use of different cutting systems. Differences among genotypes for lean weight of the primal carcass cuts were found by Gu *et al.* (1992). Furthermore, Wagner *et al.* (1999) reported in a study using five different genotypes that the effect of genetic population was significant for all carcass measurements.

Amount of lean tissue in ham as percentage of the total lean tissue in all primal carcass cuts developed substantially different in pigs studied by Gu *et al.* (1992) compared with our experimental pigs. In the present serial slaughter trial, lean tissue in ham as percentage of lean tissue in all primal cuts decreased from 41·3 to 10·3% at 20 to 140 kg LW. In contrast, Gu *et al.* (1992) reported an increasing percentage of lean in ham on the total lean tissue of the carcass from 21·7 to 43·7 at 59 to 127 kg LW, respectively. In the present study, lean tissue of loin as percentage of the lean tissue in all primal carcass cuts increased from 14·5% at 20 kg to 18·5% at 120 kg LW and decreased thereafter to 17·2%. Gu *et al.* (1992) reported for lean tissue of loin on total lean of carcass an increase from 23·9 to 25·2% at 59 to 127 kg LW. Gu *et al.* (1992) obtained a consistent proportion of lean tissue of belly on the total lean of the carcass of 13·4% at 59 to 127 kg LW, whereas in the present study lean tissue of belly as percentage of total lean tissue in the primal cuts increased from 12·2% at 20 kg to 18·1% at 140 kg LW. Generally, highest growth of primal carcass cuts was obtained between 60 and 90 kg LW except for the loin that showed highest growth between 90 and 120 kg LW.

Growth of organs

At 140 kg LW, organs had three to six times higher weights than at 20 kg LW. During growth, heart (0·4%), spleen (0·2%) and kidney (0·4%) showed an almost constant percentage of the EBWT. In contrast, percentage of liver and lung of the EBWT decreased from 2·7 to 1·4% and 1·8 to 0·8%, respectively.

For 19 to 122 kg EBWT, Doornenbal and Tong (1981) reported in Lacombe pigs weights from 94 to 354, 644 to 1826, 452 to 1712, 52 to 183 and 116 to 330 g for heart, liver, lung (includes trachea), spleen and kidney weights, respectively. In the present study, all organ weights at 114·7 kg EBWT were higher than in the study of Doornenbal and Tong (1981) except for the liver that was 6% heavier than in our study. The higher organ weights may be due to the higher protein deposition of the animals examined in this study. For animals at 109 kg LW, Ketels (1997) obtained weights of 357, 1682, 848, 170 and 661 g for heart, liver, lung, spleen and trachea, respectively. The corresponding results of the present study were 370, 1560, 850, 200 and 670 g for heart, liver, lung, spleen and trachea, respectively. Differences may be due to the different genotypes and/or the presence or absence of blood in the organs, e.g. in this study the heart was cut to empty it of blood. Leaf fat increased exponentially above 120 kg and was associated with high variance among animals.

Chemical body composition

Different genetic potential of protein deposition and food intake capacity may be the reason for the high variation of lipid content among animals in particular at high weight. Growing animals above their normal slaughter weight may likely the reason for the high variation in lipid content. In a stress-free environment and with adequate supply of essential nutrients, the protein deposition depends on the energy intake above the maintenance. The protein deposition increases with increase in energy intake up to a genetic determined maximum (PD_{max}; Whittemore and Fawcett, 1976; Moughan and Verstegen, 1988). When this genetic determined PD_{max} was reached, additional absorbed feeding energy was used to deposit lipid (Möhn and De Lange, 1998). Therefore, depending on genetic determined PD_{max} and food intake capacity, the lipid deposition is expected to differ substantially among animals. This was shown in the present study especially for higher weights.

For five different genotypes, Wagner *et al*. (1999) found an increase in protein content as percentage of the EBWT from 13·8 to 14·7% at 25 to 45 kg LW and thereafter a continuous decrease to 13·2% at 120 kg LW. In present study, protein content of the empty body increased in the first growth phase (20 to 30 kg) from 15·9 to 17·3% and thereafter decreased to 15·9% at 140 kg LW. This increase in protein content can be explained by the development of protein content in the fat-free substance in comparison to the development of lipid content of the entire empty body. During the entire growth period, percentage of protein of fat free substance increased from 17·9 to 22·2%. During growth from 20 to 30 kg LW, the increase in protein accretion of fat-free substance was substantially higher than the accretion of lipid so that the protein content relative to the EBWT increased. After 30 kg LW, protein accretion in the fat-free substance was lower than lipid accretion. This resulted in a decreasing protein accretion in relation to the empty body in the growth phase from 30 to 140 kg LW. The increasing protein content was not found by Susenbeth (1984) but the development of the other chemical components of empty body composition was similar as in this study. Lipid content increased from 8 to 28%, water content decreased from 71 to 53% and protein content from 17 to 15% between 20 and 115 kg EBWT (Susenbeth, 1984). However, the high percentage of lipid and low percentage of water was obtained at a much lower EBWT than in the present study. This indicates the high emphasis of selection on lean content in the analysed population based on Piétrain sire. The increase in fat deposition seems to be only postponed to higher weight. In the present study, empty body lipid content increased from 7·0 to 22·9% during growth from 20 to 120 kg LW, whereas water content decreased from 74·1 to 60·7%. In comparison, Wagner *et al.* (1999) reported substantial higher lipid contents from 13·4 to 32·8% between 25 and 129 kg LW and lower water content from 66·5 to 49·3%. For semi-*ad libitum* fed Large White pigs, slaughtered at 70 kg LW, Möhn and De Lange (1998) reported lipid, protein and water contents of 21·5, 16·5 and 59·3%, respectively. This was similar to the values at 90 kg LW in the present study.

Allometric growth of physical body composition

Allometric coefficients for lean growth rate presented in the literature ranged from $b = 0{\cdot}75$ to 1·06 and for fat growth rate from $b = 1{\cdot}16$ to 1·65 (Davis, 1974; Cole *et al*., 1976; Davis and Kallweit, 1979; Fortin *et al*., 1985 and 1987). In the present study an allometric growth coefficient of $b = 1{\cdot}14$ was estimated for the soft tissue fraction. The allometric growth rate of lean tissue of all primal cuts was only slightly lower than those of fat tissue. This showed that the allometric function was not able to reflect the extreme increase of fat tissue at 120 to 140 kg LW. Schinckel and de Lange (1996) discussed an augmented allometric function in order to be more flexible in fitting relative relationship of growth. Trimmed primal carcass cuts showed allometric b values close to 1 for lean growth in accordance with the literature (Kempster and Evans, 1979; Rook *et al*., 1987). Only loin and belly and their trimmed parts grew relatively faster ($b = 1{\cdot}1$ to 1·3) than the EBWT. There was high variation in allometric b values of fat deposition among primal carcass cuts ranging from $b = 0{\cdot}62$ (belly rind) to 1·79 (backfat). For trimmed carcass cuts nearly the same allometric growth rate was estimated as for the complete carcass cuts, except for belly and loin, for which the trimmed part grew faster or lower, respectively, than the complete belly or loin. This lower growth of the trimmed component of the loin was due to rapid growth in backfat ($b = 1{\cdot}79$). Interestingly, the allometric growth rate of backfat ($b = 1{\cdot}79$) and leaf fat ($b = 1{\cdot}87$) was similar to the allometric growth rate of lipid of the entire empty body ($b = 1{\cdot}75$). These two carcass cuts can therefore be used as indicator cuts for the development of lipid deposition. The high association between backfat thickness and lipid deposition may be expected because of its high part-whole correlation but not those of leaf fat and lipid deposition. Allometric growth rates of lean tissue and bones were higher in the primal carcass cuts loin and belly than in ham, shoulder and neck. This corresponds with results presented by Kempster and Evans (1979) who estimated allometric growth rates of lean tissue and bones in carcass cuts in relation to the total tissue weight for rump back of $b = 1{\cdot}05$ and 1·06, for rib back of $b = 1{\cdot}15$ and 1·10, for rib streak of $b = 0{\cdot}98$ and 0·91, for ham of $b = 0{\cdot}97$ and 0·93, and for shoulder of $b = 0{\cdot}96$ and 0·95, for collar of $b = 1{\cdot}03$ and 1·07, respectively. Growth of ham trimmed (b = 1·07) showed similar allometric growth rate in relation to EBWT than those of lean tissue growth in the entire body (b = 1·12) and growth of ham rind (b = 1·26) was similar to those of fat tissue growth in the entire body (b = 1·19). Therefore, the components of the ham can be used as good indicator for lean and fat tissue growth of the entire body.

Of all body fractions, the lowest growth coefficient was estimated for bones, indicating that this fraction was the earliest maturing tissue and thus decreased as proportion of carcass side weight during growth (Fortin *et al*., 1987). For growth of bones, Davis (1974), Cole *et al*. (1976), Davis and Kallweit (1979), Fortin *et al.* (1985 and 1987) estimated allometric b values from $b = 0{\cdot}63$ to 0·92 in relation to the carcass side weight; Davis (1983), Gu *et al*. (1992) estimated allometric b values from $b = 0{\cdot}60$ to 0·76 in relation to carcass weight and Whittemore *et al*. (1988) and Whittemore (1993) estimated allometric b values in Large White pigs of $b = 0{\cdot}83$ to 0·84 in relation to EBWT. In the present study, allometric growth coefficient of bones was estimated also in relation to EBWT but its magnitude was substantially lower with $b = 0{\cdot}71$ than given by the latter authors. There may be genotype differences, because Whittemore (1993) analysed purebred Large White, whereas in the present study crosses between Piétrain and a crossbred dam line were used. This corresponds with results of Fortin *et al*. (1987), who also obtained significantly lower allometric growth of bones for Piétrain than for Large White. This also indicates that different breeds reached maturity at different LW.

In this study, for viscera a growth coefficient of $b = 0{\cdot}73$ was estimated, which was similar to those ($b = 0{\cdot}69$) of Tess *et al*. (1986). All visceral organs grew slower than the empty body as indicated by allometric b values substantially less than 1. Doornenbal and Tong (1981) estimated that heart ($b = 0{\cdot}75$), lung ($b = 0{\cdot}80$) and spleen ($b = 0{\cdot}74$) grew, in relation to LW, faster than kidney ($b = 0{\cdot}69$), liver

($b = 0{\cdot}66$) and empty intestinal tract ($b = 0{\cdot}66$). In the present study, allometric growth rates were in general lower except for the spleen and empty intestinal tract. In particular, lung growth rate was substantially lower with $b = 0{\cdot}62$. This lung growth rate corresponds well with the rate obtained for a lowfat Duroc-Yorkshire line ($b = 0{\cdot}61$), but not with the rate of highfat Beltsville line ($b = 0{\cdot}44$) reported by Tess *et al*. (1986) and are slightly higher than the estimates of Rook *et al*. (1987) for Large White ($b = 0{\cdot}58$). Doornenbal and Tong (1981) obtained correlations for the fitted allometric growth functions between $r = 0{\cdot}93$ (spleen) to 0·99 (heart), whereas in the present study similar high correlations were obtained for trachea, liver and kidney (r = 0·94 to 0·96), but lower correlations for lung, spleen, and heart ($r = 0{\cdot}83$ to 0·85).

Allometric growth of chemical body composition

With increasing percentage of lipid in the empty body, a decrease in the percentage of water was almost inversely proportional (slightly higher increase in percentage of lipid). Based on the allometric relationship of these components to EBWT, accretion rate for lipid showed the highest deviation from 1, which was highly significant ($P < 0{\cdot}001$). In contrast, allometric accretion rates of protein and ash were almost 1 and non-significant different from 1 ($P > 0{\cdot}5$). In a weight range from 20 to 200 LW, Whittemore *et al*. (1988) estimated for Large White × Landrace pigs allometric *b* values for females of $b = 0{\cdot}93$, 0·83, 1·63 and 0·92 and for castrated males of $b = 0{\cdot}85$, 0·78, 1·67 and 0·90 for protein, water, lipid and ash, respectively, in relation to EBWT. While the water accretion rate was almost equal in both studies, protein and ash accretion were slightly higher, and lipid accretion substantially higher in the present study. Accretion rate of protein of the total body was almost equal to the growth of the EBWT, however, the accretion rates of protein in the fractions soft tissue, bones and viscera varied substantially between $b = 0{\cdot}70$ to 1·15. Interestingly, the accretion rate of lipid of the viscera fraction was almost as high as the accretion rate of lipid in the soft tissue. Although, the accretion rate of ash in total body ($b = 1{\cdot}02$) is almost equal to the growth rate of the EBWT, there was substantial slower accretion of ash in the viscera fraction ($b = 0{\cdot}66$).

General conclusion

In conclusion, the results indicate that lean tissue weight gain of the primal cuts per kg gain of the left carcass weight only slightly increased from 517 g/kg at 30 to 60 kg to 579 g/kg at 90 to 120 kg LW, but decreased to 398 g/kg at 120 to 140 kg LW. This decrease was associated with an extreme increase in fat tissue growth. This early change in body composition may indicate a very early maturity of these crossbred animals, which was sired by Piétrain. The results also showed that there is a necessity to estimate the growth rate of different carcass cuts separately because there was a substantial difference in growth rate, e.g. the fat tissue allometric growth rate was $b = 0{\cdot}62$ for belly fat but $b = 1{\cdot}79$ for backfat above the *m. longissumus dorsi*. The allometric growth rates of ham trimmed and ham rind were similar to rates of lean and fat tissue of the entire empty body, respectively, and thus, most usable as indicator cuts. Also, the growth of bones of the entire empty body was most appropriately reflected by the allometric growth rate of bones of the ham. As indicator cuts for accretion rate of lipid, protein and ash of the entire empty body, backfat above the *m. longissumus dorsi* or leaf fat, the trimmed ham and the loin bones, respectively, were most appropriate. However, lipid did not grow allometrically to EBWT above 120 kg. Generally, the estimated allometric growth rates of primal carcass cuts, body tissue and chemical body composition are essential input parameters of a pig growth model in order to estimate for example nutritional requirements of very lean pigs, the optimal slaughter weights based on the change of carcass cuts during growth, the determination of selection goals concerning lean tissue growth and food intake capacity as well as other issues to improve the efficiency of the entire pig production system (De Lange *et al*., 2003; Knap *et al*., 2003; Pomar *et al*., 2003). These relationships can be substantially influenced by the type of the pig (as difference in leanness) and has to be monitored in each line of interest. Therefore, the obtained estimates for growth of body composition are especially of interest for pigs highly selected for lean content.

Acknowledgements

We wish to thank the Landwirtschaftskammer Schleswig-Holstein for using their performance test station as well as PIC-Germany for providing the animals. This work was supported by Deutsche Forschungsgemeinschaft (DFG) and Sygen International.

References

Akridge, J. T., Brorsen, B. W., Whipker, L. D., Forrest, J. C., Kuei, C. H. and Schinckel, A. P. 1992. Evaluation of alternative techniques to determine pork carcass value. *Journal of Animal Science* **70:** 18-28.

Berg, R. T., Andersen, B. B. and Liboriussen, T. 1978. Growth of bovine tissues. 1. Genetic influences on growth patterns of muscle, fat and bone in young bulls. *Animal Production* **26:** 245-258.

Brody, S. 1945. *Bioenergetics and growth*. Reinhold Publishing Corp., New York.

Cole, D. J. A., White, M. R., Hardy, B. and Carr, J. R. 1976. Tissue growth in the pig. *Animal Production* **22:** 341-350.

Davis, A. S. 1974. A comparison of tissue development in Piétrain and Large White pigs from birth to 64 kg live weight 2. Growth changes in muscle distribution. *Animal Production* **19:** 377-387.

Davis, A. S. 1983. Growth and development in pigs: a reanalysis of the effects of nutrition on body composition. *Journal of Agricultural Science, Cambridge* **100:** 681-687.

Davis, A. S. and Kallweit, E. 1979. The effect of body weight and maturity on the carcass composition in pig. *Zeitschrift für Züchtungskunde und Züchtungsbiologie* **96:** 6-17.

Davis, A. S. and Pryor, W. J. 1977. Growth changes in the distribution of dissectable and intramuscular fat in pigs. *Journal of Agricultural Science, Cambridge* **89:** 257-266.

De Lange, C. F. M., Morel, P. C. H. and Birkett, S. H. 2003. Modeling chemical and physical body composition of the growing pig. *Journal of Animal Science* **81:** (suppl. 2) E159-E165.

Doedt, H. 1997. Qualitative und wirtschaftliche Aspekte der Schweineproduktion unter Berücksichtigung von Handelswert und Gesundheitsstatus. Doctoral thesis, University Kiel, Germany.

Doornenbal, H. and Tong, A. K. W. 1981. Growth, development and chemical composition of the pig. IV. Relative growth of visceral organs. *Growth* **45:** 279-285.

Evans, D. G. and Kempster, A. J. 1979. The effect of genotype, sex and feeding regimen on pig carcass development. 1. Primary components, tissues and joints. *Journal of Agricultural Science, Cambridge* **93:** 339-347.

Fortin, A., Wood, J. D. and Wehlehan, O. P. 1987. Breed and sex effects on the development and proportions of muscle, fat and bone in pigs. *Journal of Agricultural Science, Cambridge* **108:** 39-45.

Fortin, A., Wood, J. D. and Wehlehan, O. P. 1985. Development of carcass tissues in entire male and female Large White, Piétrain and Iron Age pigs. *Animal Production* **40:** 541-542 (abstr.).

Fujii, J., Otsu, K., Zorzato, F., de Leon, S., Khanna, V. K., Weiler, J. E., O'Brien, P. J. and Maclennan, D. H. 1991. Identification of a mutation in porcine ryanodine receptor associated with malignant hyperthermia. *Science* **153:** 448-451.

Gu, Y., Schinckel, A. P. and Martin, T. G. 1992. Growth, development and carcass composition in five genotypes of swine. *Journal of Animal Science* **70:** 1719-1729.

Huxley, J. S. 1932. *Problems of relative growth*. Methuen, London.

Kempster, A. J. and Evans, D. G. 1979. The effects of genotype, sex and feeding regimen on pig carcass development. 2. Tissue weight distribution and fat partition between depots. *Journal of Agricultural Science, Cambridge* **93:** 349-358.

Ketels, O. 1997. Zerlegekalkulation bei Jungbullen und ökonomische Bewertung der Schlachtnebenprodukte bei Jungbullen und Mastschweinen. *Doctoral thesis, University Kiel, Germany*.

Knap, P. W., Roehe, R., Kolstad, K., Pomar, C. and Luiting, P. 2003. Characterization of pig genotypes for growth modeling. *Journal of Animal Science* **81:** (suppl.2) E187-E195.

Landgraf, S., Susenbeth, A., Knap, P. W., Looft, H., Plastow, G. S., Kalm, E. and Roehe, R. 2006. Allometric association between *in vivo* estimation of body composition during growth using deuterium dilution technique and chemical analysis of serial slaughtered pigs. *Animal Science* **82:** 223-231.

Möhn, S. and De Lange, C. F. M. 1998. The effect of body weight on the upper limit to protein deposition in a defined population of growing gilts. *Journal of Animal Science* **76:** 124-133.

Mohrmann, M., Roehe, R., Knap, P. W, Looft, H., Plastow, G. S. and Kalm, E. 2006a. Quantitative trait loci associated with AutoFOM grading characteristics, carcass cuts and chemical body composition during growth of *Sus scrofa*. *Animal Genetics* (In press).

Mohrmann, M., Roehe, R., Susenbeth, A., Baulain, U., Knap, P. W., Looft, H., Plastow, G. S. and Kalm, E. 2006b. Association between body composition of growing pigs determined by magnetic resonance imaging, deuterium dilution technique, and chemical analysis. *Meat Science* **72:** 518-531.

Moughan, P. J. and Verstegen, M. W. A. 1988. The modelling of growth in the pig. *Netherlands Journal of Agricultural Science* **36:** 145-166.

Pomar, C., Kyriazakis, I., Emmans, G. C. and Knap, P. W. 2003. Modeling stochasticity: dealing with populations rather than individual pigs. *Journal of Animal Science* **81:** (suppl.2) E178-E186.

Rook, A. J., Ellis, M., Whittemore, C. T. and Phillips, P. 1987. Relationship between whole-body chemical composition, physically dissected carcass parts and backfat measurements in pigs. *Animal Production* **44:** 263-273.

Scheper, J. and Scholz, W. 1985. *DLG-Schnittführung für die Zerlegung der Schlachtkörper von Rind, Kalb, Schwein und Schaf*. Arbeitsunterlagen DLG, Frankfurt am Main.

Schinckel, A. P. and de Lange, C. F. M. 1996. Characterization of growth parameters needed as inputs for pig growth models. *Journal of Animal Science* **74:** 2021-2036.

Seebeck, R. M. 1968. Developmental studies of body composition. *Animal Breeding Abstracts* **36:** 167-181.

Statistical Analysis Systems Institute. 1992. *SAS user's guide, version 6*. SAS Institute Inc., Cary, NC.

Susenbeth, A. 1984. Berechnung der Körperzusammensetzung von Schweinen aus dem mit Hilfe von D_2O bestimmten Körperwassser. Doctoral thesis, University Hohenheim, Germany.

Tess, M. W., Dickerson, G. E., Nienaber, J. A. and Ferrell, C. L. 1986. Growth, development and body composition in three genetic stocks of swine. *Journal of Animal Science* **62:** 968-979.

Tholen, E., Baulain, U., Henning, M. D. and Schellander, K. 2003. Comparison of different methods to assess the composition of pig bellies in progeny testing. *Journal of Animal Science* **81:** 1177-1184.

Wagner, J. R., Schinckel, A. P., Chen, W., Forrest, J. C. and Coe, B. L. 1999. Analysis of body composition changes of swine during growth and development. *Journal of Animal Science* **77:** 1442-1466.

Whittemore, C. T. 1993. Growth and body composition changes in pigs. In *The science and practice of pig production*, *2nd ed*. pp. 53-86. Blackwell Science Ltd, Oxford.

Whittemore, C. T. and Fawcett, R. H. 1976. Theoretical aspects of a flexible model to simulate protein and lipid growth in pigs. *Animal Production* **22:** 87-96.

Whittemore, C. T., Tullis, J. B. and Emmans, G. C. 1988. Protein growth in pigs. *Animal Production* **46:** 437-445.

(*Received* 22 *September* 2005—*Accepted* 19 *July* 2006)