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Non Ruminant Nutrition

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Assessment of visceral organ growth in pigs from birth through 150 kg

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Abstract

Visceral organs (VO) are essential for their role in the metabolism and distribution of consumed nutrients as well as other life functions in animals. Two experiments were conducted to assess the natural longitudinal changes that the VO undergo from birth through 150 kg body weight (BW). In Experiment 1, a total of 96 crossbred pigs were euthanized at birth (presuckle), d 1, 2, 3, 5, 7, 14, 21 (weaning), 22, 23, 24, 26, 28, 42, 49, and 63 of age. In Experiment 2, a total of 48 crossbred pigs were euthanized at 30, 50, 75, 100, 125, and 150 kg of BW. The absolute weight of VO, and the volume and length of the gastrointestinal tract (GIT) were measured. In both experiments, the absolute weight of VO, GIT length, and their volume increased (linear, quadratic, and/or cubic, $P < 0.05$) as BW and age increased. In Experiment 1, the relative weight of VO (liver, kidney, heart, and lung) decreased after initially increasing within the first week of life (linear, quadratic, and/or cubic, $P < 0.05$), whereas the relative weight of all VO decreased as BW increased in Experiment 2 (linear and/or quadratic, $P < 0.05$). The relative length of small intestine decreased and that of large intestine increased as age increased in Experiment 1 (linear and quadratic, $P < 0.05$), whereas the relative length of the small and large intestine in Experiment 2 were relatively constant at 80% and 20% of the total length of the intestine, respectively. As age and BW increased, the relative volume of the large intestine to the total volume of the GIT increased (linear and/or quadratic, $P < 0.05$), while the relative volume of the small intestine decreased (linear and/or quadratic, $P < 0.05$). In conclusion, results showed that both absolute and relative measurements (weight, volume, and length) of VO were dependent on the BW (age) of the pig.

Key words: development, pigs, viscera, visceral organs

Introduction

Visceral organs (VO) are crucial for life in all animals due to their essential role in all aspects of digestive physiology including the digestion of feedstuffs, absorption of nutrients, and metabolism of absorbed and circulating nutrients. Evaluation of VO size (e.g., mass, length, and volume) is typically assessed both on an absolute and relative (i.e., the absolute measure in proportion to the total body measure) basis. Relative VO weights, particularly

Abbreviations

BW	body weight
GIT	gastrointestinal tract
VO	visceral organs

those in laboratory animals, are widely used in nutritional studies for comparisons of VO across studies (Doornenbal and Tong 1981; Anugwa et al., 1989; Nyachoti et al., 2000). The use of pigs as a laboratory animal for biological research is increasing. Colin (1871; as cited by Argenzio, 1993) provided quite expansive information about different segments of the gastrointestinal tract (GIT) in multiple species. However, limited data are available about the VO of the contemporary pig phenotype. Especially lacking is the characterization of VO size from studies that employed similar size determination methods to assess change in measurements of the complete set of VO in response to BW gain within a single study.

Understanding the development of VO enhances evaluation of the physiological capacity of the animal, and associated differences in nutrient requirements to support different stages of growth (Shields et al., 1983). For example, it is becoming a common practice to select pigs that are leaner, resulting in a pig that has less fat at market (Theil et al., 2012; Cliplef and McKay, 1993); however, pigs that have less backfat and faster growth have been shown to have larger VO mass (Pond et al., 1988; Cliplef and McKay, 1993). Greater VO mass accounts for a large portion of body energy expenditure (Anugwa et al., 1989; Nyachoti et al., 2000) and oxygen consumption (Nyachoti et al., 2000), and may result in an increased maintenance energy requirement (Tess et al., 1986). The increase in oxygen consumption associated with increased VO size also reduces the growth efficiency in other tissues (Nyachoti et al., 2000). The objective of this study was to assess longitudinal changes that occur in VO size as pigs develop from birth through 150 kg BW.

Materials and Methods

The study was conducted at the University of Kentucky using protocols approved by the Institutional Animal Care and Use Committee of the University of Kentucky.

Animals

Two experiments were conducted to determine the change in size of VO in response to BW gain. Experiment 1 was conducted to obtain the weight, volume, and length of VO from birth to 25 kg BW. In Experiment 1, 96 crossbred pigs (involving various crosses of Large White, Yorkshire, Landrace, and Duroc) were euthanized with sodium pentobarbitol over 16 time points (*n* = 6, 3 gilts and 3 barrows, per time point) from birth (pre-suckle) through d 42 postweaning (ca. d 63 of age; average ~25 kg BW). The times in which pigs were euthanized included: birth (pre-suckle), d 1, 2, 3, 5, 7, 14, and 21 of age (this was the suckling period, and weaning occurred on d 20.8 ± 0.48), and d 1, 2, 3, 5, 7, 14, 28, and 42 postweaning (ca. d 22, 23, 24, 26, 28, 42, 49, and 63 of age, respectively). At the time of euthanasia, six pigs were randomly chosen from the pig pool to account for natural variation that occurs within a group of pigs. At weaning, pigs were blocked by BW and housed in raised-deck nursery pens (1.22 × 2.44 m^2) with 4–5 pigs per pen. After weaning, pigs had ad libitum access to common diets in two phases (Phase I: d 0–14 postweaning; Phase II: d 15–42 postweaning) that met or exceeded all NRC (2012) requirement estimates (Table 1).

In addition to pigs of suckling and postweaning phases, reported are data from 6 collection time points on gestation days 108, 109, 110, 111, 112, and 113 (*n* = 6, 3 barrows and 3 gilts). Although the data collected from the fetuses were not statistically analyzed because the 6 fetuses collected per gestation day came from a single sow, they are presented because they are rare and of interest to the growth biology community.

Experiment 2 was conducted to obtain the weight, volume, and length of VO from ~30 to 150 kg BW. In Experiment 2, 48 crossbred pigs (involving various crosses of Large White, Yorkshire, Landrace, and Duroc) were selected from a larger group of 116 pigs that were housed in half-concrete slatted floor

Table 1. Postweaning diet formulation and calculated nutrient composition of basal diets (as-fed; Experiment 1)

	Basal diet	
Ingredient, %	Phase 1 (d 0–14 postweaning)	Phase 2 (d 15–42 postweaning)
Corn	51.05	61.33
Soybean meal, 48%	29.59	34.00
Fish meal (Menhaden)	2.00	0.00
Spray-dried animal plasma	2.00	0.00
Whey dried	10.00	0.00
Choice white grease	2.60	1.50
L-Lysine HCl	0.23	0.28
DL-methionine	0.17	0.18
L-threonine	0.08	0.12
Dicalcium phosphate	0.56	0.88
Limestone	1.08	1.07
Salt	0.50	0.50
Trace mineral premix[1]	0.06	0.06
Zinc oxide[2]	0.01	0.01
Iron sulfate[3]	0.02	0.02
Vitamin premix[4]	0.04	0.04
Santoquin[5]	0.02	0.02
Calculated composition		
Metabolizable energy, kcal/kg	3,401	3,348
NDF, %	7.08	8.38
SID[6] Lysine	1.35	1.23
Total Ca, %	0.80	0.70
Total P, %	0.60	0.56
STTD[6] P, %	0.40	0.33

[1]The trace mineral premix supplied the following per kilogram of diet: 27.5 mg of Mn as manganous oxide, 60.5 mg of Fe as ferrous sulfate monohydrate, 60.5 mg of Zn as zinc sulfate, 9.9 mg of Cu as copper sulfate, 0.39 mg of I as calcium iodate, and 0.17 mg of Se as sodium selenite.
[2]The zinc oxide supplied 50 mg/kg Zn.
[3]The iron sulfate supplied 50 mg/kg Fe.
[4]The vitamin premix supplied the following per kilogram of diet: 9,359 IU of vitamin A, 2,341 IU of vitamin D_3, 62.3 IU of vitamin E, 6.9 mg of vitamin K, 0.03 mg of vitamin B_{12}, 7.32 mg of riboflavin, 20.84 mg of pantothenic acid, 41.46 mg of niacin, 1.72 mg of folic acid, 4.16 mg of vitamin B_6, 1.15 mg of thiamin, and 0.23 mg of biotin.
[5]Santoquin (Monsanto, St. Louis, MO) supplied 130 mg/kg ethoxyquin.
[6]SID, standardized ileal digestible; STTD, standardized total tract digestible.

grow-finish pens (1.8 × 3.0 m[2]) with 6–8 pigs per pen. For the entire experiment, pigs had ad libitum access to water and a common diet that met or exceeded all NRC (2012) requirement estimates (Table 2) over five different growth phases (25–50, 50–75, 75–100, 100–125, and 125–150 kg BW). All diets contained 20% corn distillers dried grains and solubles. When the overall mean BW of the pigs was close to the BW of interest (30, 50, 75, 100, 125, and 150 kg), 8 pigs (4 gilts and 4 barrows) with BW closest to the weight of interest were euthanized.

Experimental procedures

Experiment 1

Body weight was recorded weekly as well as at euthanasia. After euthanasia, the liver (sans gall bladder), kidney, heart, lungs, pancreas, and spleen were removed from the body and weighed. The stomach and cecum were collected and rinsed of contents using phosphate-buffered saline (NaCl: 137 mM, KCl: 2.7 mM, NA_2HPO_4:10 mM; pH 7.4 at 20–22°C), weighed, and then filled with the phosphate buffered saline until subjectively determined as "full." The weight of the saline was measured and using the density of the rinse solution (1.05 g/mL), the volume of the organ was calculated. The length of both the small and large intestine were measured using a wet pre-measured board and recorded. Segments of the small and large intestine of 10 mm in length were collected at pre-determined proportions of the total length (small intestine: 0%, 25%, 50%, 75%, and 100% of total length; large intestine: 0%, 50%, and 100% of total length), its circumference measured after cutting the segments longitudinally, and used for calculation of intestinal volume (see later sections).

Experiment 2

Pigs were weighed on a biweekly basis. On the days of euthanasia, pigs were weighed at the farm, transported to the University of Kentucky Meat Science Laboratory, stunned by electric shock, and then killed by exsanguination. The liver (sans gall bladder), kidneys, heart, pancreas, and spleen were removed from the body and weighed. The stomach and cecum were rinsed of contents with tap water (18–20°C) and the empty organ weight recorded. The volume of the stomach and cecum were then measured by filling the organs to their maximum capacity with the tap water, the water was then dumped into a graduated cylinder and volume was recorded. The intestines were measured for length, rinsed with tap water, weighed, and volume calculated using the same procedures as for Experiment 1. In addition, a segment of the small intestine at 0%, 25%, 50%, 75%, and 100% of the total small intestinal length, and a segment of the large intestine at 0%, ~67%, and 100% of total large intestinal length was collected and measured for circumference.

Computations and statistical analysis

To determine the volume of the intestines, the circumference and the length were used in a tapered cylinder formula assuming that the diameter of the intestinal lumen changed evenly throughout the GIT:

$$V = \frac{1}{3}\pi\left(r_1^2 + r_1r_2 + r_2^2\right)h.$$

In this equation, the parameters represent: V = volume, r1 = the first end of the cylinder, r2 = the second end of the cylinder, and h = length between each recorded circumference. Each circumference measurement was determined to be the end of the cylinder. In all, four volume measurements were determined for the small intestine and three volume measurements were determined for the large intestine. The volume of the stomach, small intestine, cecum, and large intestine were summed to yield the total volume. Total intestine length was determined

Table 2. Diet formulation and calculated nutrient composition of basal diets (as-fed; Experiment 2)

	Basal diet				
Body weight, kg	20–50	50–75	75–100	100–125	125–150
Ingredients, %					
Corn	47.58	53.02	58.1	62.35	65.82
SBM	29.70	24.40	19.50	15.40	12.05
Corn DDGS	20.00	20.00	20.00	20.00	20.00
Choice white grease	0.50	0.50	0.50	0.50	0.50
Dicalcium phosphate	0.60	0.50	0.40	0.35	0.30
Limestone	1.12	1.08	1.00	0.90	0.83
Salt	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[1]	0.15	0.15	0.15	0.15	0.15
Vitamin premix[2]	0.10	0.10	0.10	0.10	0.10
Calculated composition, %					
Metabolizable energy, kcal/kg	3,313	3,324	3,335	3,344	3,351
NDF, %	12.86	12.92	12.98	13.03	13.08
SID[3] Lysine	0.98	0.85	0.73	0.63	0.55
Total Ca, %	0.66	0.60	0.54	0.48	0.43
Total P, %	0.57	0.52	0.48	0.46	0.43
STTD[3] P, %	0.33	0.30	0.27	0.25	0.23

[1]The trace mineral premix supplied the following per kilogram of diet: 27.5 mg of Mn as manganous oxide, 60.5 mg of Fe as ferrous sulfate monohydrate, 60.5 mg of Zn as zinc sulfate, 9.9 mg of Cu as copper sulfate, 0.39 mg of I as calcium iodate, and 0.17 mg of Se as sodium selenite.
[2]The vitamin premix supplied the following per kilogram of diet: 9,359 IU of vitamin A, 2,341 IU of vitamin D_3, 62.3 IU of vitamin E, 6.9 mg of vitamin K, 0.03 mg of vitamin B_{12}, 7.32 mg of riboflavin, 20.84 mg of pantothenic acid, 41.46 mg of niacin, 1.72 mg of folic acid, 4.16 mg of vitamin B_6, 1.15 mg of thiamin, and 0.23 mg of biotin.
[3]SID, standardized ileal digestible; STTD, standardized total tract digestible.

by adding the length of the small and large intestine together. Relative weight of the VO is representative of the weight of the organ as a percent of the weight of the pig at euthanasia. Relative volume is the volume of the individual component of the VO as a percent of the total VO volume. Relative length of the GIT is the length of the individual intestine as a percent of the total length of both intestines.

All data were subjected to ANOVA using PROC GLM in SAS 9.4 (SAS Inst., Inc., Cary, NC) with the individual pig as the experimental unit. The model included terms for age, sex, and age × sex interaction for Experiment 1, and slaughter weight, sex, and slaughter weight × sex interaction for Experiment 2. Orthogonal polynomial contrasts were used to determine linear, quadratic, and cubic effects of age (Experiment 1) or slaughter weight (Experiment 2) on response measures. The contrast coefficients were generated using PROC IML in SAS; Experiment 1 was broken up into two phases, suckling (birth to weaning using d 0–21) and postweaning (weaning to 42 d postweaning using postweaning day) for orthogonal polynomial contrasts. Polynomial contrast coefficients for Experiment 2 were based on BW category. Least squares means are reported in the tables. Effects were considered significant at $P < 0.05$. As noted above, data from late gestation (gestation day 108–113) were not evaluated statistically because, although each value represents six fetuses, they came from a single sow and, therefore, $n = 1$ for each day.

Results

Experiment 1

There was no observed sex effect or age by sex interaction ($P > 0.05$) for the relative weights, relative volume, or relative length of the VO in the suckling period. Additionally, there was no sex effect or age by sex interaction ($P > 0.05$) for the relative length of the GIT in the postweaning period. There was a sex effect for the absolute weight of the spleen ($P = 0.03$) where the barrows had heavier spleens than the gilts. There was a sex effect for the relative large intestine volume ($P = 0.02$) where the barrows had greater relative large intestinal volumes than the gilts.

In the suckling period, the relative weight of the liver, kidneys, spleen, heart, and stomach responded linearly, quadratically, and cubically to age (Tables 3 and 4; $P < 0.05$), whereas the relative weight of the pancreas, lung, and cecum had linear and cubic responses to age ($P < 0.05$). The relative weight of the liver increased from 2.99% at birth to 4.20% at d 5 postpartum. After d 5 postpartum, relative liver weight decreased to 2.73% at weaning. Similarly, the relative weight of kidney, pancreas, heart, lungs, and stomach all increased from birth to d 3 postpartum and then decreased until weaning; the spleen increased to d 7 before declining. The relative weight of the cecum increased through the entire suckling period from 0.09% to 0.13%, respectively.

Table 3. Absolute and relative weights of selected visceral organs from birth to 42 d PW (Experiment 1)[1]

		Organ weight, absoluting and as (% BW)			
Age, days	BW, kg[2,6,7]	Liver[2,3,4,5,6,8,9]	Kidneys[2,4,5,6]	Spleen[2,4,5,6,7,9]	Pancreas[2,4,6,7,8,9]
Gest.108	1.15	31.20 (2.67)	8.37 (0.73)	1.38 (0.12)	1.37 (0.12)[10]
Gest.109	1.42	38.29 (2.67)	8.84 (0.62)	1.69 (0.12)	1.66 (0.12)
Gest.110	1.50	42.80 (2.86)	10.30 (0.69)	1.88 (0.13)	1.63 (0.11)
Gest.111	1.51	54.18 (3.58)	8.97 (0.61)	1.68 (0.11)	1.61 (0.11)[10]
Gest.112	1.24	45.81 (3.69)	8.93 (0.72)	1.34 (0.11)	1.35 (0.11)
Gest.113	1.36	50.99 (3.73)	9.16 (0.67)	1.44 (0.10)	1.66 (0.12)
0 (Birth)	1.55	47.28 (2.99)	8.78 (0.57)	1.47 (0.09)	2.38 (0.14)
1	1.57	41.73 (2.55)	11.88 (0.78)	1.95 (0.12)	2.32 (0.14)
2	1.74	61.88 (3.54)	13.22 (0.76)	2.28 (0.13)	2.94 (0.17)[10]
3	1.67	68.08 (4.09)	13.53 (0.82)	2.97 (0.18)	3.52 (0.21)
5	2.47	103.00 (4.20)	19.38 (0.79)	5.52 (0.22)	4.20 (0.17)
7	2.67	98.72 (3.71)	21.37 (0.80)	7.23 (0.27)	4.35 (0.16)
14	5.26	166.25 (3.16)	30.70 (0.59)	12.63 (0.24)	6.98 (0.13)
21 (W)	6.40	176.17 (2.73)	35.93 (0.55)	14.58 (0.23)	7.63 (0.12)
22 (PW1)	5.62	130.07 (2.31)	31.10 (0.56)	12.25 (0.22)	7.53 (0.13)
23 (PW2)	6.27	159.55 (2.54)	32.00 (0.51)	13.13 (0.21)	7.53 (0.12)
24 (PW3)	5.77	159.13 (2.76)	29.17 (0.50)	14.47 (0.25)	7.40 (0.13)
26 (PW5)	6.34	182.65 (2.83)	33.60 (0.53)	12.23 (0.20)	9.62 (0.16)
28 (PW7)	6.69	195.17 (2.91)	39.53 (0.58)	14.72 (0.22)	13.98 (0.21)
35 (PW14)	9.55	302.57 (3.17)	57.32 (0.59)	16.42 (0.17)	20.72 (0.22)
49 (PW28)	18.55	586.25 (3.15)	94.42 (0.51)	30.93 (0.17)	47.5 (0.26)
63 (PW42)	28.12	800.68 (2.86)	137.38 (0.49)	54.75 (0.20)	67.77 (0.24)
SEM[11]	0.40/ 0.94	13.47/28.42 (0.18/0.08)	2.67/5.47 (0.04/0.02)	1.02/2.23 (0.01/0.01)	0.75/1.62 (0.02/0.01)

[1]Values in the parentheses represent the relative weight to body weight. PW, postweaning; Gest., gestation day; W, weaning; gestation day means are reported but not included in the statistical analysis, statistical analysis was assessed from birth to weaning (the suckling period) and from weaning to 42 d PW (the postweaning period); $n = 6$ per mean unless otherwise noted.
[2,3]Linear or quadratic response ($P < 0.05$) to age for absolute weight, respectively, suckling.
[4]Linear and cubic response ($P < 0.05$) to age for relative weight suckling.
[5]Quadratic response ($P < 0.05$) to age for relative weight suckling.
[6–8]Linear, quadratic, or cubic response ($P < 0.05$) to age for absolute weight, respectively, PW.
[9]Linear and quadratic response ($P < 0.05$) to age for relative weight PW.
[10]$n = 5$.
[11]SEM values are presented as absolute weights suckling period SEM/PW period SEM (relative weights suckling period SEM/PW period SEM).

Table 4. Absolute and relative weights of selected visceral organs from birth to 42 d PW (Experiment 1)[1]

		Organ weight, absoluting and as (% BW)			
Age, days	BW, kg[2,7,8]	Heart[2,5,6,7,8,9,10]	Lungs[2,3,4,5,7,8,9,10]	Stomach[2,5,6,7,8,11,12,13,16]	Cecum[2,5,7,8,11,12,13,16]
Gest.108	1.15	7.77 (0.67)	30.83 (2.67)	6.22 (0.52)[14]	0.67 (0.06)[14]
Gest.109	1.42	11.76 (0.82)	36.93 (2.59)	9.00 (0.63)	0.90 (0.06)
Gest.110	1.50	11.95 (0.80)	36.70 (2.43)	8.50 (0.57)	0.97 (0.06)
Gest.111	1.51	9.90 (0.66)	47.05 (3.10)	9.42 (0.62)	0.82 (0.06)
Gest.112	1.24	8.81 (0.71)	29.09 (2.36)	7.20 (0.58)	0.68 (0.05)
Gest.113	1.36	9.25 (0.68)	34.46 (2.53)	7.74 (0.57)	0.64 (0.05)
0 (Birth)	1.55	11.08 (0.72)	27.67 (1.86)	7.18 (0.56)[15]	1.25 (0.09)
1	1.57	10.80 (0.69)	26.72 (1.77)	8.95 (0.59)	1.52 (0.10)
2	1.74	12.48 (0.73)	32.00 (1.88)	12.10 (0.67)[14]	1.55 (0.09)
3	1.67	13.55 (0.81)	33.63 (2.01)	11.17 (0.67)	1.70 (0.10)
5	2.47	18.28 (0.74)	42.75 (1.73)	15.48 (0.62)	2.12 (0.09)
7	2.67	17.30 (0.66)	45.78 (1.74)	16.60 (0.62)	2.85 (0.11)
14	5.26	28.47 (0.54)	88.88 (1.65)	24.62 (0.47)	6.38 (0.12)
21 (W)	6.40	32.32 (0.51)	74.75 (1.17)	30.45 (0.49)	8.20 (0.13)
22 (PW1)	5.62	29.07 (0.52)	74.25 (1.34)	28.68 (0.51)	7.07 (0.13)
23 (PW2)	6.27	34.70 (0.56)	81.80 (1.30)	33.03 (0.54)	9.20 (0.15)
24 (PW3)	5.77	31.42 (0.54)	67.32 (1.17)	35.25 (0.61)	7.92 (0.14)
26 (PW5)	6.34	33.78 (0.53)	72.18 (1.17)	42.70 (0.69)	14.20 (0.24)
28 (PW7)	6.69	35.83 (0.53)	74.80 (1.13)	54.90 (0.83)	14.20 (0.21)
35 (PW14)	9.55	47.48 (0.50)	106.47 (1.12)	78.30 (0.82)	25.42 (0.28)
49 (PW28)	18.55	87.03 (0.47)	164.88 (0.90)	145.65 (0.79)	52.82 (0.28)
63 (PW42)	28.12	130.07 (0.46)	242.47 (0.87)	197.48 (0.71)	69.27 (0.25)
SEM[17]	0.40/ 0.94	2.08/3.98 (0.04/0.02)	7.36/8.51 (0.17/0.06)	2.19/6,92 (0.05/0.03)	0.63/2.63 (0.01/0.02)

[1]Values in the parentheses represent the relative weight to body weight. PW, postweaning; Gest., gestation day; W, weaning; gestation day means are reported but not included in the statistical analysis, statistical analysis was assessed from birth to weaning (the suckling period) and from weaning to 42 d PW (the postweaning period); $n = 6$ per mean unless otherwise noted.
[2–7]Linear, quadratic, or cubic response ($P < 0.05$) for absolute weight and linear, quadratic, or cubic response ($P < 0.05$) for relative weight, respectively, to age in the suckling period.
[8–13]Linear, quadratic, or cubic response ($P < 0.05$) for absolute weight and linear, quadratic, or cubic response ($P < 0.05$) for relative weight, respectively, to age in the PW period.
[14,15]$n = 5$, $n = 4$, respectively.
[16]Stomach and cecum were cleaned with phosphate buffer saline prior to being weighed.
[17]SEM values are presented as absolute weights suckling period SEM/PW period SEM (relative weights suckling period SEM/PW period SEM).

In the postweaning period, the relative weight of the liver, pancreas ($P < 0.05$; linear and quadratic), stomach, and cecum ($P < 0.05$; linear, quadratic, and cubic) increased, whereas that of the spleen decreased linearly and quadratically ($P < 0.05$). In the postweaning period, the relative weight of the liver had a drop from 2.73% to 2.31% immediately following weaning, but then increased through the rest of the postweaning period until d 42 postweaning, where there was a decrease from 3.15% to 2.86%. The relative weight of the spleen increased from weaning to d 3 postweaning and then decreased afterward. The relative weight of the pancreas was relatively constant until d 3 postweaning and then increased afterward. Similar to the suckling period, the relative weight of the cecum increased from weaning to d 42 postweaning.

In the suckling period (Table 5), the relative volume of the stomach, cecum, and large intestine had a linear response ($P < 0.05$; linear, quadratic, and cubic for the stomach) to an increase in age, whereas the small intestine had a quadratic response ($P < 0.05$). The relative volume of the stomach increased from birth to d 3 postpartum, from 15.08% to 22.38%, from there it then decreased until weaning. The relative volume of the small intestine decreased from birth to d 7 postpartum, from 73.88% to 62.38%, and then increased until weaning. The relative volume of the cecum increased from birth to weaning (1.07%–4.91%). The relative volume of the large intestine increased linearly from birth to weaning.

In the postweaning period, the relative volume of the small intestine and large intestine had linear, quadratic, and cubic responses ($P < 0.05$), whereas the stomach had linear and cubic responses ($P < 0.05$) and the cecum had only a cubic response ($P < 0.05$). The relative volume of the stomach decreased immediately after weaning from 8.14% to 6.37%, then increased to 16.70% on d 3 postweaning and decreased again afterward until d 42 postweaning. The relative volume of the small intestine decreased from weaning to d 5 postweaning, from 67.25% to 44.87%, then increased to 54.51% on d 14 postweaning and decreased afterward to 50.28% on d 42 postweaning. The relative volume of the cecum increased from 4.91% at weaning to 6.28% on d 5 postweaning, then decreased to 4.34% on d 14 postweaning and increased to 8.65% on d 28 postweaning followed by a decrease to 5.05% on d 42 postweaning, respectively. The relative volume of the large intestine increased from weaning to d 5 postweaning, from 19.70% to 36.13%, then decreased to 31.50% on d 28 postweaning followed by an increase to 38.08% on d 42 postweaning.

In the suckling period of Experiment 1, the absolute length of the small intestine (Table 6) increased from 3.72 to 8.52 m, while the large intestine increased from 0.72 to 1.46 m (linear and quadratic, $P < 0.05$) with no difference in the relative length. In the postweaning period, linear and cubic responses ($P < 0.05$) were observed for the absolute length of the small and large intestine which increased from 8.52 to 16.20 m and from 1.46 to 3.50 m, respectively. The relative length of the small intestine decreased linearly and quadratically ($P < 0.05$) with a nadir at d 7 postweaning. Similarly, the large intestine increased linearly and quadratically ($P < 0.05$) with a peak at d 7 of the postweaning period.

Experiment 2

There was a sex effect for the pancreas and the cecum ($P = 0.042$ and $P = 0.006$, respectively) in which the barrows had heavier organs than the gilts. There were no observed sex effects ($P > 0.05$) for the liver, heart, spleen, kidneys, lungs, stomach, small intestine, or large intestine. However, there were no observed BW by sex interactions ($P > 0.05$) for the heart, spleen, kidneys, liver, lung, stomach, small intestine, or large intestine.

In Experiment 2, as BW increased the absolute weight of organs increased linearly ($P < 0.05$; Tables 7 and 8), but the relative weight decreased linearly ($P < 0.05$). The absolute weight of liver, spleen, kidneys, stomach, and large intestine had a quadratic increase ($P < 0.05$) as BW increased. The relative weight of heart and spleen had a quadratic decrease ($P < 0.05$) where the largest decrease occurred from 50 to 75 kg BW. The relative weight of liver, pancreas, kidney, stomach, and cecum decreased linearly ($P < 0.05$) as BW increased. The large intestine had a quadratic response ($P < 0.05$) for relative weight where it increased from 1.14% to 1.30% (30–75 kg BW) and then decreased to 1.08% at 150 kg BW.

The absolute volume of VO component segments increased with increasing BW (Table 9; linear and/or quadratic, $P < 0.05$). The relative volume of the small intestine decreased linearly ($P < 0.05$) from 36% to 25%, while the cecum initially increased in relative volume from 16% to 21% from 30 to 50 kg BW, but then decreased to 14% relative volume by 150 kg BW with linear and quadratic responses ($P < 0.05$). The large intestine relative volume increased (linear, $P < 0.05$) from 30 to 150 kg BW. The relative volume of the stomach to total VO volume did not change ($P > 0.05$) with increasing BW, remaining at approximately 16% of total volume.

Length of small and large intestine relative to the total length decreased and increased, respectively, as BW increased (Table 10; linear, $P < 0.05$). Overall, the relative length of the small and large intestine was at 80% and 20%, respectively.

Discussion

The absolute and relative weights of VO at the end of Experiment 1 were similar to those at the beginning of Experiment 2, indicating that the two studies combined provide data that is continuous. At 10 kg BW, the absolute weight (g) of the liver, heart, spleen, and kidneys were in agreement with those reported by Doornenbal and Tong (1981). Absolute weights (g) of the stomach, liver, heart, spleen, as well as small intestine length (m) were also comparable to those reported by Craig et al. (2019) for pigs at both birth and d 29 of age. The absolute and relative weights of the liver, heart, and kidneys at 100 kg BW were also comparable to those reported by Ruusunen et al. (2007). However, the absolute weights of the heart, liver, spleen, and kidney were generally somewhat less than the absolute weights of those organs of serially slaughtered pigs from 20 to 140 kg reported by Landgraf et al. (2007). Anugwa et al. (1989) examined visceral organ weights in finishing pigs from 65 to 108 kg BW and observed a decline in relative liver and kidney weights with increasing BW as was observed herein in Experiment 2; the relative organ weights reported were generally about 10% less than reported herein with the exception of the spleen which was similar. One of the reasons for this difference in growing-finishing pigs could be because in the last 30 years there has been more genetic selection made for leaner pigs. It has been reported that leaner pigs are known to have greater VO weight (heart, lungs, spleen, liver, and kidney; Cliplef and McKay, 1993). Another potential explanation for the marginal differences across studies can be explained by the particular breeds of pigs used as McKay et al. (1984) noted differences for selected VO weight among three breeds of swine and their crosses.

The majority of the VO (liver, kidney, heart, spleen, and lung) in both the suckling and postweaning period of Experiment 1 had relative weights that decreased with the age of the pig after increases within the first 3–7 days after birth. Interestingly,

Table 5. Absolute and relative volume of selected visceral organs from birth to 42 d PW (Experiment 1)[1]

		Organ volume, absolute in mL and as (% total volume)				
Age, days	BW, kg[2,8,9]	Total volume[2,3,4,8,9]	Stomach[2,3,5,6,7,8,11,13]	Small intestine[2,4,6,8,9,10,11,12,13]	Cecum[2,5,8,10,13]	Large intestine[2,4,5,8,9,11,12,13]
Gest.108	1.15	30.18	6.09 (22.73)	17.82 (57.02)	0.27 (0.97)[12]	5.78 (19.28)
Gest.109	1.42	42.65	10.05 (23.85)	24.58 (57.34)	0.49 (1.12)	7.53 (17.69)
Gest.110	1.50	40.36	5.75 (14.59)	25.26 (62.01)	0.49 (1.20)	8.87 (22.20)
Gest.111	1.51	50.45	12.63 (26.25)	29.76 (57.86)	0.69 (1.32)	7.37 (14.58)
Gest.112	1.24	42.48	9.77 (23.01)	25.75 (60.54)	0.61 (1.49)	6.35 (14.96)
Gest.113	1.36	47.21	10.58 (22.38)	28.10 (59.76)	0.39 (0.83)	8.14 (17.03)
0 (Birth)	1.55	74.32	11.28 (15.08)[14]	56.02 (73.88)	0.71 (1.07)	9.48 (9.97)
1	1.57	86.15	10.17 (12.41)	57.35 (66.13)	1.66 (2.00)	16.97 (19.45)
2	1.74	116.65	23.68 (20.50)	75.83 (65.01)	2.01 (1.87)	15.13 (12.62)
3	1.67	105.91	23.84 (22.38)	66.99 (63.44)	2.13 (1.90)	12.96 (12.28)
5	2.47	158.17	34.82 (21.99)	99.96 (63.36)	3.09 (2.00)	20.3 (12.66)
7	2.67	200.30	34.74 (17.61)	126.83 (62.38)	6.63 (3.47)	32.10 (16.55)
14	5.26	404.00	39.33 (9.83)	260.47 (65.00)	16.77 (4.17)	87.43 (21.00)
21 (W)	6.40	419.15	33.20 (8.14)	278.09 (67.25)	20.82 (4.91)	87.04 (19.70)
22 (PW1)	5.62	332.28	19.27 (6.37)	206.40 (65.28)	15.17 (4.66)	73.68 (23.69)
23 (PW2)	6.27	486.74	68.09 (14.05)	267.79 (55.00)	32.32 (6.52)[12]	118.54 (24.42)
24 (PW3)	5.77	450.52	74.55 (16.70)	204.79 (45.97)	23.71 (5.42)	147.46 (31.91)
26 (PW5)	6.34	649.34	82.35 (12.71)[14]	264.00 (44.87)	36.47 (6.28)	215.41 (36.13)
28 (PW7)	6.69	788.64	91.08 (12.56)	391.06 (47.27)	33.48 (4.63)	273.02 (35.54)
35 (PW14)	9.55	1,334.18	125.86 (9.07)	728.00 (54.51)	56.11 (4.34)	424.22 (32.09)
49 (PW28)	18.55	3,187.75	228.75 (7.08)	1,663.45 (52.77)	276.67 (8.65)	1,018.89 (31.50)
63 (PW42)	28.12	4,796.57	314.54 (6.58)	2,477.08 (50.28)	252.47 (5.05)	1,824.19 (38.08)[14]
SEM[15]	0.40/ 0.94	27.83/172.74	3.94/16.30 (2.67/1.31)	14.76/82.95 (3.38/2.53)	2.01/17.72 (0.66/1.07)	9.47/74.47 (2.53/2.09)

[1]Values in the parentheses represent the relative volume to total volume; total volume, sum of all individual segment volumes (stomach, small intestine, cecum, and large intestine); PW, postweaning; Gest., gestation day; W, weaning; gestation day means are reported but not included in the statistical analysis, statistical analysis was assessed from birth to weaning (the suckling period) and from weaning to 42 d PW (the postweaning period); $n = 6$ per mean unless otherwise noted.

[2–7]Linear, quadratic, or cubic response ($P < 0.05$) for absolute volume and linear, quadratic, or cubic response ($P < 0.05$) for relative volume, respectively, to age in the suckling period.

[8–13]Linear, quadratic, or cubic response ($P < 0.05$) for absolute volume and linear, quadratic, or cubic response ($P < 0.05$) for relative volume, respectively, to age in the PW period.

[14]$n = 5$.

[15]SEM values are presented as absolute weights suckling period SEM/PW period SEM (relative weights suckling period SEM/PW period SEM).

Table 6. Absolute and relative length of selected visceral organs from birth to 42 d PW (Experiment 1)[1]

		Organ length, absolute in m and as (% total length)		
Age, days	BW, kg[2,4,5]	Total length[2,3,4]	Small intestine[2,3,4,5,6,7]	Large intestine[2,3,4,5,6,7]
Gest.108	1.15	3.30	2.64 (79.93)	0.66 (20.07)
Gest.109	1.42	4.00	3.24 (80.88)	0.76 (19.12)
Gest.110	1.50	4.14	3.35 (80.77)	0.79 (19.23)
Gest.111	1.51	4.24	3.48 (81.93)	0.76 (18.07)
Gest.112	1.24	4.12	3.41 (82.71)	0.71 (17.29)
Gest.113	1.36	4.21	3.49 (82.66)	0.73 (17.34)
0 (Birth)	1.55	4.44	3.72 (84.19)	0.72 (15.81)
1	1.57	5.31	4.44 (83.35)	0.88 (16.65)
2	1.74	5.45	4.52 (83.03)	0.93 (16.97)
3	1.67	5.41	4.57 (84.42)	0.84 (15.58)
5	2.47	6.43	5.40 (83.92)	1.03 (16.08)
7	2.67	7.09	5.94 (83.61)	1.15 (16.39)
14	5.26	9.70	8.26 (85.23)	1.43 (14.77)
21 (W)	6.40	9.98	8.52 (85.46)	1.46 (14.54)
22 (PW1)	5.62	9.47	8.02 (84.70)	1.45 (15.30)
23 (PW2)	6.27	9.66	8.18 (84.58)	1.49 (15.42)
24 (PW3)	5.77	10.07	8.41 (83.49)	1.66 (16.51)
26 (PW5)	6.34	10.45	8.75 (83.64)	1.70 (16.36)
28 (PW7)	6.69	10.72	8.72 (81.30)	2.00 (18.70)
35 (PW14)	9.55	12.80	10.51 (82.08)	2.29 (17.92)
49 (PW28)	18.55	16.86	13.98 (82.88)	2.89 (17.12)
63 (PW42)	28.12	19.70	16.20 (82.26)	3.50 (17.74)
SEM	0.40/ 0.94	0.36/ 0.47	0.30/0.41 (1.14/82.26)	0.08/0.11 (1.14/0.63)

[1]Values in the parentheses represent the relative length to total length; total length, sum of small and large intestine length; PW, postweaning; Gest., gestation day; W, weaning; gestation day means are reported but not included in the statistical analysis, statistical analysis was assessed from birth to weaning (the suckling period) and from weaning to 42 d PW (the postweaning period); n = 6 per mean unless otherwise noted.
[2,3]Linear or quadratic response ($P < 0.05$), respectively, to age for absolute length in the suckling period.
[4–7]Linear or cubic response ($P < 0.05$) respectively, for absolute length and linear or quadratic response ($P < 0.05$) for relative length to age in the PW period.
[8]SEM values are presented as absolute weights suckling period SEM/PW period SEM (relative weights suckling period SEM/PW period SEM).

Table 7. Absolute and relative weights of selected visceral organs from 30 to 150 kg BW (Experiment 2)[1]

		Organ weight, absolute in g and as (% BW)				
BW, kg category	Age, d	Liver[2,3,4]	Heart[2,4,5]	Pancreas[2,4]	Spleen[2,3,4,5]	Kidneys[2,3,4]
30	66.5	624 (2.07)	151 (0.50)	53 (0.18)	67 (0.22)	155 (0.51)
50	87.9	1,025 (1.95)	226 (0.43)	91 (0.17)	96 (0.18)	266 (0.51)
75	115.8	1,455 (1.90)	292 (0.38)	101 (0.13)	103 (0.13)	329 (0.43)
100	123.6	1,633 (1.64)	351 (0.35)	124 (0.13)	110 (0.11)	341 (0.34)
125	146.5	1,776 (1.41)	421 (0.34)	152 (0.12)	151 (0.12)	389 (0.31)
150	175.6	2,018 (1.37)	483 (0.33)	157 (0.11)	184 (0.13)	423 (0.29)
SEM		42 (0.04)	10 (0.01)	6 (0.01)	6 (0.01)	11 (0.02)

[1]Values in the parentheses represent the relative weight to body weight (BW), n = 8. Actual slaughter weights for the six BW categories were 30.4, 50.0, 75.5, 99.2, 125.3, and 147.0, respectively.
[2,3]Linear or quadratic response to slaughter weight ($P < 0.05$) for absolute weight, respectively.
[4,5]Linear or quadratic response to slaughter weight ($P < 0.05$) for relative weight, respectively.

the relative weight of the pancreas had an increase in the postweaning period, but then decreased through Experiment 2. This increase in the relative weight of the pancreas may be attributed to weaning and postweaning development as pigs are adapted to the solid feed. Lindemann et al. (1986) also observed heavier relative pancreatic weight in the immediate postweaning period compared to preweaning. Additionally, the relative weight of the cecum increased in Experiment 1 (suckling and post-weaning periods) and then decreased until 75 kg BW in Experiment 2 where it became a relatively constant relative weight of about 0.15%. In Experiment 1, the relative weight of the spleen increased until d 7 in the suckling period, and then decreased until 75 kg BW in Experiment 2 where it stabilized at a relative weight of about 0.13%. The constant relative weight of the spleen at 0.13% was also reported by Anugwa et al. (1989) for the control pigs at similar BW (75 kg). Even though there were decreases observed in the relative weight of the majority of VO in Experiment 2, the relative weight of heart, pancreas, spleen,

Table 8. Absolute and relative weights of selected visceral organs from 30 to 150 kg BW (Experiment 2)[1]

		Organ weight, absolute in g and as (% BW)			
BW category, kg	Age, d	Stomach[2,3,4]	Cecum[2,4]	Large intestine[2,3,4,5]	Small intestine[2,4,5]
30	66.5	186(0.61)	66(0.22)	346(1.14)	915(3.03)
50	87.9	318(0.61)	116(0.22)	650(1.23)	1,229(2.33)
75	115.8	383(0.50)	114 (0.15)	993(1.30)	1,319(1.72)
100	123.6	429(0.43)	164 (0.17)	1,171(1.18)	1,247(1.25)
125	146.5	534(0.42)	206(0.16)	1,386(1.09)	1,490(1.19)
150	175.6	582(0.40)	202 (0.14)	1,589(1.08)	1,555(1.06)
SEM		13(0.02)	8(0.01)	36 (0.04)	49 (0.07)

[1]Values in the parentheses represent the relative weight to body weight (BW), $n = 8$. Actual slaughter weights for the six BW categories were 30.4, 50.0, 75.5, 99.2, 125.3, and 147.0, respectively.
[2,3]Linear or quadratic response to slaughter weight ($P < 0.05$) for absolute weight, respectively.
[4,5]Linear or quadratic response to slaughter weight ($P < 0.05$) for relative weight, respectively.

Table 9. Absolute and relative volume of selected visceral organs from 30 to 150 kg BW (Experiment 2)[1]

		Organ volume, absolute in mL and as (% total volume)				
BW, kg category	Age, d	Total[2]	Stomach[2]	Small intestine[2, 3, 4]	Cecum[2, 3, 4, 5]	Large intestine[2, 4]
30	66.5	3,893	612 (15)	1,385 (36)	606 (16)	1,290 (33)
50	87.9	6,644	831 (13)	2,203 (33)	1,427 (21)	2,184 (33)
75	115.8	10,973	1,864 (17)	3,339 (30)	1,842 (17)	3,927 (36)
100	123.6	13,329	1,949 (14)	3,877 (29)	2,069 (16)	5,434 (41)
125	146.5	15,053	2,854 (19)	3,892 (26)	2,583 (17)	5,723 (38)
150	175.6	18,092	2,921 (16)	4,615 (25)	2,520 (14)	8,037 (45)
SEM		504	213 (2)	223 (1)	132 (1)	275 (2)

[1]Values in the parentheses represent the relative volume to total volume, $n = 8$. Actual slaughter weights for the six BW categories were 30.4, 50.0, 75.5, 99.2, 125.3, and 147.0, respectively.
[2,3]Linear or quadratic response to slaughter weight ($P < 0.05$) for absolute volume, respectively.
[4,5]Linear or quadratic response to slaughter weight ($P < 0.05$) for relative volume, respectively.

kidney, stomach, and cecum remained constant after 75 or 100 kg BW. These VO having constant relative weights indicate that the organs are growing at a constant rate to the pig's body. The protein deposition curve peaks in pigs around 70 kg and pigs are no longer in an accelerating growth phase (Schinckel and de Lange, 1996) which may be related to this plateauing of relative organ growth.

In Experiment 1, relative volume decreased for the stomach and small intestine, decreasing from approximately 20% to 7% and from 70% to 50%, respectively. In contrast, the relative volume of the cecum and large intestine increased with age from approximately 2% to 6% and 10% to 38%, respectively. At the end of Experiment 1 (25 kg BW), the reported relative volumes were 7% stomach, 50% small intestine, 5% cecum, and 38% large intestine. Interestingly, there were always increases in the relative volume of VO (stomach, cecum, and large intestine except for small intestine) from birth to the first 1 or 2 days after birth. This rapid increase in VO size in the first few days after birth may be associated with the initiation of colostrum ingestion immediately after birth (Xu et al., 1992) to prepare the GIT to digest nutrients. In Experiment 2, the volume of the stomach was consistently around 15% of the total GIT volume, the relative volume of the small intestine decreased from 36% to 25% from 30 to 150 kg BW, the cecum had an increase in volume from 16% to 21% from 30 to 50 kg BW, but then decreased to 14% by 150 kg BW, and the relative volume of the large intestine increased from 33% to 45% from 30 to 150 kg BW during Experiment 2. The relative volume of the small intestine and cecum contrasts with Argenzio (1993), who adapted data from Colin (1871) from necropsied pigs and reported the relative volume of the GIT in percentages is the following, 29% stomach, 33% small intestine, 6% cecum, and 32% large intestine.

Unlike the relative weights of the VO, the relative volumes across Experiments 1 and 2 do not seem like a continuation of data. One explanation for the difference in relative volumes across these experiments, and potentially other studies, is the way volume was measured. For example, in Experiment 1, the stomach and cecum were filled until they were subjectively determined as "full," not filled to a maximum capacity as it was in Experiment 2 where tissue stretching could occur. Secondly, the diets differed in one major component, namely fiber. Experiment 2 diets contained 20% DDGS to more closely approximate current feeding practices and fiber content of diets is known to affect volume capacity of the GIT (Jørgensen et al., 1996).

It was previously reported that the absolute length of the small intestine increased 24% in the first week of life for pigs (Xu et al., 1992). In contrast, the findings from the present study (Experiment 1, Table 6) show that the small intestine increased from 3.72 to 5.94 m, which is roughly 62%, within the first week of life. The large intestine also increased roughly 62% as well as the absolute length increased from 0.72 to 1.15 m. The relative length of the small intestine was between 83.03% and 85.46% until weaning and then slightly decreased to 82% after weaning. The relative length of the large intestine was between 14.54% and 16.97% until weaning but, as expected, slightly increased

Table 10. Absolute and relative length of selected visceral organs from 30 to 150 kg BW (Experiment 2)[1]

		Organ length, absolute in m and as (% total length)		
BW category, kg	Age, d	Total[2,3]	Small intestine[2,3,4]	Large intestine[2,3,4]
30	66.5	15.36	12.51 (81.42)	2.85 (18.58)
50	87.9	18.54	14.92 (80.41)	3.63 (19.59)
75	115.8	21.54	17.24 (79.99)	4.31 (20.01)
100	123.6	22.45	17.87 (79.59)	4.58 (20.41)
125	146.5	24.01	19.22 (80.03)	4.79 (19.97)
150	175.6	24.93	19.93 (79.87)	5.00 (20.13)
SEM		0.58	0.50 (0.48)	0.14 (0.48)

[1]Values in the parentheses represent the relative length to total length, $n = 8$. Actual slaughter weights for the six BW categories were 30.4, 50.0, 75.5, 99.2, 125.3, and 147.0, respectively.
[2,3]Linear or quadratic response to slaughter weight ($P < 0.05$) for absolute length.
[4]Linear or quadratic response to slaughter weight ($P < 0.05$) for relative length.

in the postweaning period. However, the relative lengths of the intestine were rather static in pigs of 30 kg BW and greater (Experiment 2, Table 10), with the small intestine staying at 80% of the total length and the large intestine constituting 20% of the total length. This result indicates that suckling and early postweaning periods are times of greater increases in intestinal size compared to that of older pigs. Whether this difference rate of intestinal size accretion also represents differences in functional capacity remains to be determined. Overall, the relative lengths of the pig intestines of the present study are in agreement with data over a century old as reported by Colin (1871) of 78% and 21%, respectively, for the small and large intestine of a normal market weight French pig.

Conclusions and Implications

The absolute weights of the VO increased with BW and age over time. Overall, this leads to the obvious, and unsurprising, conclusion that the VO weight of the growing pig is dependent on the BW of the pig, with the assumption that the pig is in good health and receiving an adequate diet. The fact that the majority of the VO's relative weight decreased from birth to 150 kg BW demonstrates that the VO are a larger portion of the pig's BW from birth through the nursery period (25 kg) than the growing-finishing period (30–150 kg BW). After the nursery period, other components of the body, such as skeletal muscle and adipose tissue, account for more of the pig's BW change. The increasing size of the VO as determined through continuous increasing volume, length, and weight from the time of birth through 25 kg BW, showed that the VO of these young pigs accreted in size more rapidly than did the older, heavier pigs providing potential insight to the functional capacity of VO in younger pigs. In contrast, the relative length of the small and large intestine were relatively constant in the 30–150 kg pigs (growing-finishing period), remaining at ~80% of the total length as the small intestine and the large intestine as ~20% of the total length of the intestines. Overall, these data beg the obvious question for future studies of whether the functional capacity (the ability to digest, absorb, and metabolize) nutrients parallels VO size or not. Regardless, the data of the present study provide baseline data for further assessment of the effects of a variety of factors including diet, genetics, sex, maturity, and environment on VO size and functional capacity in growing pigs from birth through market weight.

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Conflict of interest statement

The authors declare no conflict of interest.

Literature Cited

Anugwa, F. O., V. H. Varel, J. S. Dickson, W. G. Pond, and L. P. Krook. 1989. Effects of dietary fiber and protein concentration on growth, feed efficiency, visceral organ weights and large intestine microbial populations of swine. *J. Nutr*. **119**:879–886. doi:10.1093/jn/119.6.879

Argenzio, R. A. 1993. General functions of the gastrointestinal tract and their control and integration. In: Swenson, M. J. and W. O. Reece, coeditors, *Dukes' physiology of domestic animals*. 11th ed. Ithaca and London: Comstock Publishing Association; p. 325–335.

Cliplef, R. L. M. and R. M. McKay. 1993. Visceral organ weights of swine selected for reduced backfat thickness and increases growth rate. *Can. J. Anim. Sci*. **73**:201–206. doi:10.4141/cjas93-020

Colin, G. 1871. *Traité de physiologie comparée des animaux domestiques*. Baillière, Paris: Dukes' Physiology of Domesticated Animals.

Craig, J. R., F. R. Dunshea, J. J. Cottrell, J. B. Furness, U. A. Wijesiriwardana, and J. R. Pluske. 2019. A comparison of the anatomical and gastrointestinal functional development between gilt and sow progeny around birth and weaning. *J. Anim. Sci*. **97**: 3809–3822. doi:10.1093/jas/skz217

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

Jørgensen, H., X. Q. Zhao, and B. O. Eggum. 1996. The influence of dietary fibre and environmental temperature on the development of the gastrointestinal tract, digestibility, degree of fermentation in the hind-gut and energy metabolism in pigs. *Br. J. Nutr*. **75**:365–378. doi:10.1079/bjn19960140

Landgraf, S., A. Susenbeth, P. W. Knap, H. Looft, G. S. Plastow, E. Kalm, and R. Roehe. 2007. Developments of carcass cuts, organs, body tissues and chemical body composition during growth of pigs. *Anim. Sci*. **82**:889–899. doi:10.1017/ASC2006097

Lindemann, M. D., S. G. Cornelius, S. M. el Kandelgy, R. L. Moser, and J. E. Pettigrew. 1986. Effect of age, weaning and diet on digestive enzyme levels in the piglet. *J. Anim. Sci*. **62**:1298–1307. doi:10.2527/jas1986.6251298x

McKay, R. M., W. E. Rempel, S. G. Cornelius, and C. E. Allen. 1984. Visceral characteristics of three breeds of swine and their crosses. *Can. J. Anim. Sci*. **64**:9–19.

NRC. 2012. *Nutrient requirements of swine*. 11th ed. Washington, DC: National Academy Press.

Nyachoti, C., C. De Lange, B. McBride, S. Leeson, and H. Schulze. 2000. Dietary influence on organ size and in vitro oxygen

consumption by visceral organs of growing pigs. *Livest. Prod. Sci.* **65**:229–237. doi:10.1016/s0301-6226(00)00157-3
Pond, W. G., H. G. Jung, and V. H. Varel. 1988. Effect of dietary fiber on young adult genetically lean, obese and contemporary pigs: body weight, carcass measurements, organ weights, and digesta content. *J. Anim. Sci.* **66**:699–706. doi:10.2527/jas1988.663699x
Ruusunen, M., K. Partanen, R. Pösö, and E. Puolanne. 2007. The effect of dietary protein supply on carcass composition, size of organs, muscle properties and meat quality of pigs. *Livest. Sci.* **107**:170–181.
Schinkel, A. P. and C. F. M. de Lange. 1996. Characterization of growth parameters needed as inputs for pig growth models. *J. Anim. Sci.* **74**:2021–2036. doi:10.2527/1996.7482021x
Shields, R. G., Jr, D. C. Mahan, and P. L. Graham. 1983. Changes in swine body composition from birth to 145 kg. *J. Anim. Sci.* **57**:43–54. doi:10.2527/jas1983.57143x
Tess, M. W., G. E. Dickerson, J. A. Nienaber, and C. L. Ferrell. 1986. Growth, development and body composition in three genetic stocks of swine. *J. Anim. Sci.* **62**:968–979. doi:10.2527/jas1986.624968x
Theil, P. K., M. O. Nielsen, M. T. Sørensen, and C. Lauridsen. 2012. *Lactation, milk and suckling*. Denmark: Danish Pig Research Centre Copenhagen; p. 1–47.
Xu, R. J., P. T. Sanglid, Y. Q. Zhang, P. Tungthanathanisch, M. J. Birtles, G. W. Reynolds, and H. V. Simpson. 1992. Growth and morphological changes in the small intestine in piglets during the first three days after birth. *J. Dev. Physiol.* **18**:161–172.