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Effects of continual fluctuation in feed intake on growth performance response and carcass fat-to-lean ratio in grower-finisher pigs[1]

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ABSTRACT: An experiment was conducted to examine the effect of continual fluctuations in feed intake on grower-finisher pig growth performance and carcass fat-to-lean ratio (F:L). Sixty individually housed female pigs (Landrace × Large White) with initial BW of 29.8 ± 0.4 kg were randomly allocated to 1 of 4 feeding regimens (n = 15): 1) ad libitum throughout (AL); 2) 85% of the mean intake of the AL group during the previous week (R); 3) 70% of the mean intake on 1 d, and on the following day, 100% of the amount consumed by the AL group during the preceding week, with this pattern repeated every 2 d throughout (D); and 4) 70% of the mean intake for 3 consecutive days, and 100% of the amount consumed by the AL group for the next 3 d, with this pattern repeated throughout the experiment (3-D). Pigs receiving each treatment were fed the same diets during the weaner (10 to 20 kg), grower (20 to 50 kg), finisher 1 (50 to 70 kg), and finisher 2 (70 kg to slaughter at approximately 104 kg) growth phases. Pigs receiving fluctuated feed intake either by the D or 3-D feeding regimen showed a pattern of growth similar to that of pigs on the R feeding regimen. Pigs on the R and 3-D regimens were lighter at 28 d ($P < 0.05$) and pigs on the R, D, and 3-D regimens were lighter at 63 d ($P < 0.05$) than pigs on the AL regimen. Pigs on the R, D, or 3-D feeding regimens had a greater G:F between 15 to 42 d of the experiment than pigs fed AL throughout ($P < 0.05$). The R, D, and 3-D feeding regimens seemed to have some effect on carcass weight and dressing percentage, and pigs had a decreased P2 (located 65 mm from the midline of the carcass at the last thoracic rib) backfat depth ($P < 0.05$) compared with pigs fed AL. Pigs on the AL and 3-D feeding regimens had thicker subcutaneous fat at the last lumbar vertebrae on the dorsal edge of the loin than pigs on the R feeding regimen ($P < 0.05$). Carcass and visceral fat content and the F:L in the carcass and primal cuts, as measured by dual energy x-ray absorptiometry, were not different among treatments. However, pigs on the AL and 3-D feeding regimens had decreased estimated bone content in the carcass compared with pigs on the R and D feeding regimens ($P < 0.05$). The results indicated that continual fluctuation in feed intake either every other day or every 3 d had minimal effects on growth and carcass F:L compared with pigs fed the same restricted amount throughout the experiment.

Key words: carcass fat-to-lean ratio, intake fluctuation, performance, pig

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INTRODUCTION

Variation in growth performance and carcass quality is a common problem, and often it is a hidden cost to the pig industry (Payne et al., 1999; Trezona et al., 1999b). Trezona et al. (1999a, 2002) have demonstrated that at least some of this variation might be due to the pattern of feed intake over the long term. That is, if feed intake is restricted during the early stages of growth (before 50 kg of BW) for whatever the reason, pigs will be fatter than those fed optimally from weaning to slaughter at 100 kg of BW.

The other hypothesis, as suggested by Edwards (1999), is that some of the variation in carcass quality may be related to short-term fluctuations in feed intake, which commonly occur because of feed blockages or insufficient feeding spaces. Edwards (1999) conducted several simulations using the AUSPIG modeling program (Black et al., 1986) to predict the impact of fluctuations in feed intake on fat and protein deposition patterns. In one such scenario, daily fluctuations in feed intake increased fat deposition and decreased protein deposition, which would have increased the carcass fat-to-lean ratio (**F:L**) at the time of marketing.

Even if the differences in daily feed intake are not as dramatic as those used in that simulation, the mecha-

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nism by which the fluctuation influences fat and protein deposition should still hold if feed intake was insufficient or was in excess of that required for maximum protein deposition (de Greef, 1992). The hypothesis tested in this experiment was that the carcass F:L of pigs at slaughter would increase if the feed intake of pigs fluctuated during the growth period from 30 to 100 kg of BW. The subsequent objective was to determine the influence of fluctuations in feed intake on carcass composition, including carcass F:L.

MATERIALS AND METHODS

The experimental protocol used in this study was approved by the Department of Agriculture and Food Western Australia Animal Ethics committee. Animals were handled according to the Australian code of practice for the care and use of animals for scientific purposes (National Health and Medical Research Council, 2004).

Animals, Diets, and Feeding

An experiment with 60 individually housed female pigs (Landrace × Large White) and 4 feeding regimens (n = 15/feeding regimen) was conducted, using a randomized complete block design. Pigs were acquired at 35 d of age (weaned at 21 d) from a commercial herd with a high health status and housed in group pens, where they were fed commercial creep and weaner diets until reaching the desired start BW for the experiment. At approximately 30 kg of BW, pigs were moved and housed in individual pens (1.62 m^2). Pigs were sorted by BW, assigned to 15 blocks based on BW, and randomly allocated to 4 treatments within a block. The 4 feeding regimens used were 1) ad libitum feed intake throughout (**AL**); 2) 85% of the mean intake of the AL group during the previous week (**R**); 3) 70% of the mean intake on 1 d, and on the following day, 100% of the mean intake of the AL group during the preceding week, with this pattern repeated every 2 d throughout (**D**); and 4) 70% of the mean intake for 3 consecutive days and then fed at 100% of the AL group for the next 3 d, with this pattern repeated throughout the experiment (**3-D**). Average feed intake for pigs on the D, 3-D, and R treatments was the same, but the pattern of feed intake differed. The 85% restriction amount was chosen based on the commercial applicability of and ethical rationale for long-term feed restriction. Pigs were only allowed access to a maximum of 100% of ad libitum intake of control pigs after restriction to maintain feed intake patterns, because allowing pigs to eat ad libitum after restriction could produce variable intake and hence variable feeding patterns within the group. As the feeding amount for pigs in the R, D, and 3-D groups was determined, there was a delay in adjusting feeding amounts correctly in the initial phase (first 2 wk) of the experiment. Pigs on each treatment were fed the same diets during the weaner (10 to 20 kg), grower (20 to 50 kg), finisher 1 (50 to 70 kg), and finisher 2 (70 kg to slaughter) phases, with each diet being formulated to meet the requirements of the animal for AA and energy (NRC, 1998; Table 1). Pigs had ad libitum access to water, and pigs on the restricted-feeding amounts were given all their allowance as one feeding in the morning. Body weights and feed intake of pigs were recorded on a weekly basis. The building was naturally ventilated and depended on natural light (approximately 12 h at the initiation of the experiment and 14 h at the end). The minimum and maximum temperature during the entire experimental period was 9.7 to 25.2°C, respectively, with a mean temperature of 17.2°C.

Carcass Composition

At approximately 104 kg of BW, pigs were slaughtered at a commercial abattoir by CO_2 stunning and exsanguination. After slaughter, viscera and flare fat (a fat depot comprising the perinephric and retroperitoneal fats) were collected from each pig, and the heart, liver, lungs, kidneys, and gastrointestinal tract were separated. The gastrointestinal tract was emptied, washed, patted dry with paper towel, and weighed before being frozen at −20°C. The viscera collected from each pig were later minced separately while frozen and then thawed, homogenized, and subsampled for chemical analysis of DM, fat, protein, and ash as described by Suster et al. (2003). The hot carcasses (AUSMEAT Trim 13, AUS-MEAT Ltd., South Brisbane, Queensland, Australia; head off, flare fat off, foretrotters off, and hindtrotters on) were weighed, and the backfat depth at the **P2** site (located 65 mm from the midline of the carcass at the last thoracic rib) was determined on the hot carcass at 45 min after slaughter by using a Hennessy grading probe (Hennessy Grading Systems Ltd., Sorrento, Queensland, Australia). The carcasses were split longitudinally before being moved into a chiller. Approximately 24 h postslaughter, the right side of the carcass was separated into the commercial primal cuts of shoulder, loin, belly, and hindquarters. The shoulder primal was removed from the middle with a straight cut between the last and second last lumbar vertebrae. The middle was cut parallel to the dorsal edge at the point of the last rib, to give the loin and belly primal cuts. Fat thickness (mm) in the shoulder, loin, belly, and ham were measured (Vernier scale caliper, Mitutoyo, Kanagawa, Japan). Fat thicknesses in the dorsal and ventral edges of the loin were measured at the 2nd rib, last rib, last lumbar vertebrae, and 11th rib. The fat thickness in the belly was measured at the 2nd rib, last rib, and last lumbar vertebrae. The primal cuts were analyzed for carcass fat, lean, and bone content by dual energy x-ray absorptiometry (**DXA**; Hologic QDR 4500A, Hologic Inc., Waltham, MA). Compared with the method of complete dissection and chemical analysis, DXA is reported to estimate within

Table 1. Ingredients and calculated composition of the experimental diets, as-fed basis

Item	Weaner	Grower	Finisher 1	Finisher 2
Ingredient, g/kg				
Barley	—	330	785	769
Wheat	713	373	—	—
Lupins	50	200	100	150
Soybean meal	70	—	—	—
Blood meal	25	14	21	—
Meat and bone meal	66	73	73	73
Fish meal	60	—	—	—
Canola oil	10	5	18	5
L-Lys	2.00	1.74	0.96	1.09
DL-Met	0.52	0.74	0.33	0.22
L-Thr	0.84	0.23	—	—
Mineral-vitamin premix[1]	1.50	0.70	0.70	0.70
Choline chloride	0.40	0.40	0.40	0.40
Salt	1.00	1.00	1.00	1.00
Calculated composition				
DE, MJ/kg	14.5	13.5	13.2	12.8
Starch, g/kg	447	415	426	419
Protein, g/kg	228	189	172	168
Fat, g/kg	38.2	36.0	45.0	34.5
Crude fiber, g/kg	30.3	57.6	55.9	62.4
NDF, g/kg	111	159	175	183
Standardized ileal digestible lysine, g/MJ of DE	0.80	0.60	0.55	0.50

[1]Provided the following per kilogram of weaner (grower-finisher) diets: vitamin A, 10,500 (4,900) IU; vitamin D_3, 2,100 (980) IU; vitamin E, 30 (14) mg; vitamin K, 1.5 (0.7) mg; vitamin B_1, 1.5 (0.7) mg; vitamin B_2, 4.5 (2.1) mg; vitamin B_6, 2.25 (1.05) mg; vitamin B_{12}, 22.5 (12.5) μg; niacin, 18 (8.4) mg; pantothenic acid, 15 (7) mg; folic acid, 0.29 (0.13) mg; biotin, 45 (21) μg; calcium pantothenate, 16 (7.5) mg; Co, 0.3 (0.14) mg as sulfate; Cu, 15 (7) mg as sulfate; Fe, 90 (42) as ferrous sulfate; I, 0.75 (0.35) mg as potassium iodine; Mn, 60 (28) mg as oxide; Se, 0.45 (0.21) mg as sodium selenite; Zn, 150 (70) mg as zinc oxide; and antioxidant, 30 (14) mg as Endox (Kemin Industries Inc., Singapore).

a 5% difference for lean, protein, water, and ash and within a 10% difference for lipid (Suster et al., 2006). Carcass fat, lean, and bone contents were analyzed by using a fan beam x-ray bone densitometer (Hologic QDR 4500A, Hologic Inc.) as described by Suster et al. (2004). The half carcass was placed on the DXA table with the cut surface down and scanned, and fat, lean, and bone contents were estimated by using QDR 4500A regional analysis software (v8.26a:3, Hologic Inc.) and the calibration model developed by Suster et al. (2003). Measured fat and lean contents were then logarithmically transformed into base 10, and lipid and lean protein contents were predicted by using preestablished regression equations (Suster et al., 2003).

Statistical Analyses

Data were analyzed as a randomized complete block design by the ANOVA procedure of Genstat (version 8, VSN International Ltd., Hemel Hempstead, UK), with the pig as the experimental unit. Pigs were blocked based on initial BW. Data were tested for normal distribution within treatment and logarithmically transformed into base 10 where appropriate before being subjected to the ANOVA procedure. Fisher's protected LSD was used to assess the treatment effect. Because the treatment effect was not evident for the fat composition measured by DXA in the half carcass and primal cuts, data were pooled across treatments and linear regression analyses were conducted to examine the relationships between total carcass fat and carcass F:L.

RESULTS

Growth of Pigs

Average daily feed intakes of the 3 groups of pigs, in which feed intake was restricted for at least part of the time, were similar and were approximately 85% of those of the AL group, indicating that the target differences in ADFI were achieved. The differences in ADFI among the AL group and their counterparts were greater during the first 14 d (approximately 23%) than for the entire experimental period (15%) because of the delay in adjusting the feed amount in the initial phase of the experiment. There was never any feed remaining in the feeders for pigs in the D or 3-D group during the restrictive or refeeding (100% of ADFI in the AL treatment) period, and no abnormal behavior was observed.

There was no difference in starting BW, but by 4 wk into the experiment, pigs fed AL were heavier ($P < 0.05$) than pigs fed R and 3-D ($P < 0.05$). In addition, pigs in the AL group were heavier than their counterparts from wk 7 to 9 ($P < 0.05$; Figure 1). Pigs were slaughtered at the same BW; therefore, there was no difference in BW among treatments at the end of the experiment. Examination of the weekly growth pattern indicated that the depression of growth in pigs on the R, D, and 3-D feeding regimens occurred during the early stage of the experiment. Pigs on the R, D, and 3-D feeding regimens weighed approximately 3 kg less than pigs on the AL regimen after 1 wk of the experimental period ($P = 0.059$), and weighed approximately 4 kg less by wk 2 ($P < 0.05$). This was maintained until wk 8 of the experiment, after which the growth depression increased and there was a 7.5-kg difference ($P < 0.05$). The growth pattern of pigs on the D feeding regimen was identical to that of pigs on the R feeding regimen, whereas pigs on the 3-D feeding regimen showed a greater numerical growth depression after 7 wk.

Performance indices of the pigs are presented in Table 2. Pigs on the R and D feeding regimens had decreased ADG compared with those fed AL from 0 to 14 d ($P < 0.05$) and from 43 to 63 d ($P < 0.05$). Pigs on the 3-D feeding regimen even had decreased ADG compared with pigs on the D regimen from 0 to 14 d and from 43 to 63 d. Overall, pigs on the R, D, and 3-D feeding regimens had decreased ADG compared with pigs fed AL ($P < 0.05$). From d 0 to 14, pigs on the R and 3-D feeding regimens had decreased G:F compared with pigs fed AL and D ($P < 0.05$). However, compared with pigs fed AL, pigs on the R, D, and 3-D feeding regimens had consistently greater G:F from 15 to 42 d ($P < 0.05$). For the final finishing period (d 43 to 63), no differences were observed among treatments. As a consequence of the greater ADG, the AL group reached the target slaughter BW approximately 11 d earlier than pigs receiving the restricted-feeding treatments ($P < 0.05$).

Carcass and Viscera

There was no difference in carcass weight or dressing percentage (Table 3). The amount of flare fat was also not different among treatments. Pigs receiving the AL treatment had greater P2 depth compared with pigs receiving the other treatments ($P < 0.05$). Compared with the R group (85% AL), the difference was 3.0 mm. Although not statistically significant, the P2 depth for the 2 groups in which feed intake fluctuated daily (D) or in a 3-daily cycle (3-D) was approximately 1 mm thicker than for the R group.

For the measures of carcass fatness, the AL group had a greater fat depth at the last lumbar vertebrae of the dorsal ($P < 0.05$) and ventral regions ($P < 0.05$) of the loin compared with pigs receiving the other treatments, except those receiving the 3-D for the dorsal region. Pig on the 3-D treatment also had a greater fat depth at the last lumbar vertebrae of the dorsal edge of the loin compared with those in the R group ($P < 0.05$). However, there were no other differences among treatments in subcutaneous fat thickness at other locations. There were no differences in the weight of any visceral organs, nor were there any differences in the chemical fat, protein, or ash contents of the viscera (Table 4).

Carcass F:L

The compositions of the half carcass and primal cuts, as measured by DXA, are presented as a proportion of carcass weight in Table 5. There were no differences in the fat or lean content of the half carcass or any of the primal cuts. There was also no treatment effect on the F:L in the half carcass or the primal cuts. The only differences were in the estimated bone content of the half carcass ($P < 0.05$) and the loin ($P < 0.001$) primal cut. Pigs on the AL and 3-D feeding regimens had decreased estimated bone content in the half carcass ($P < 0.05$) and loin ($P < 0.05$) compared with pigs in the R and D feeding regimens. Estimated lipid and protein contents

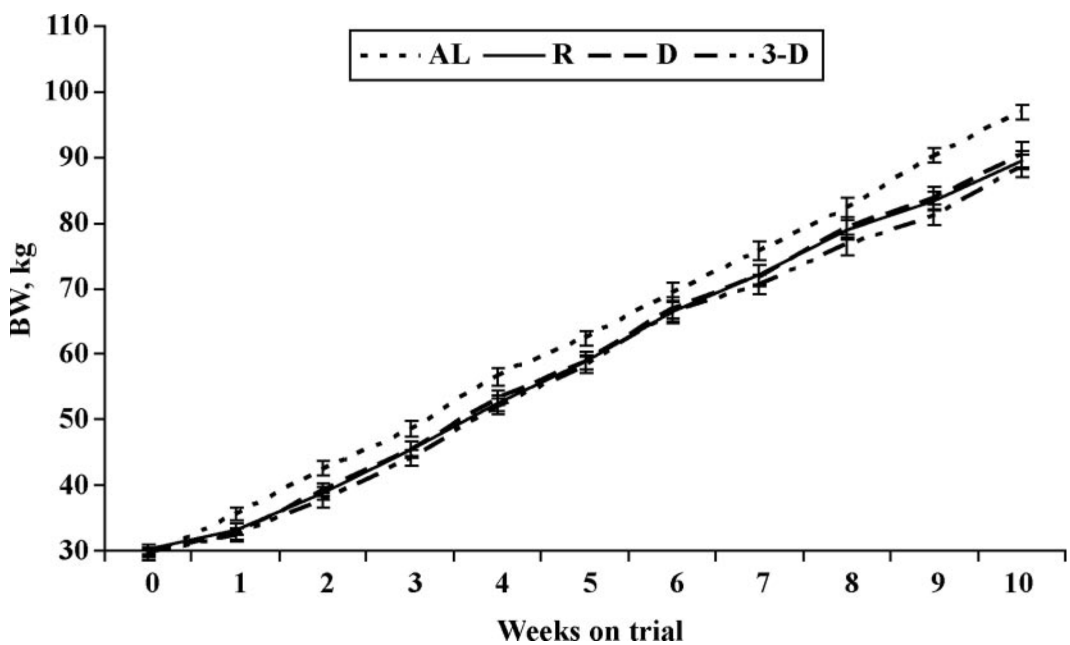

Figure 1. Impact of fluctuations in feed intake on growth of female pigs between 30 to 100 kg. Treatments: AL = feeding ad libitum; R = feeding 85% of ad libitum; D = feeding 70% ad libitum 1 d, then 100% of ad libitum the next day; and 3-D = feeding 70% ad libitum for 3 d, then 100% ad libitum for the next 3 d. R and 3-D vs. AL at wk 4, $P < 0.05$, and R, D, and 3-D vs. AL during wk 7 to 9, $P < 0.05$.

Table 2. Impact of fluctuations in feed intake on the growth performance of female pigs

	Treatment[1]					
Item	AL	R	D	3-D	SEM[2]	*P*-value
BW, kg						
Start	29.4	30.3	29.8	29.8	0.8	0.874
End	103.7	104.6	104.1	104.2	0.5	0.708
ADG, g						
0 to 14 d	936[a]	606[bc]	676[b]	566[c]	30	0.001
15 to 28 d	1,055	979	1,055	1,022	32	0.816
29 to 42 d	922	1,000	979	1,026	35	0.212
43 to 63 d	929[a]	806[b]	794[b]	708[c]	30	0.001
Overall	958[a]	843[b]	856[b]	817[b]	20	0.001
ADFI, kg						
0 to 14 d	2.11[a]	1.53[b]	1.54[b]	1.48[b]	0.05	0.001
15 to 28 d	2.65[a]	2.26[b]	2.28[b]	2.21[b]	0.06	0.001
29 to 42 d	3.00[a]	2.74[b]	2.68[b]	2.74[b]	0.08	0.024
43 to 63 d	3.20[a]	2.75[b]	2.68[b]	2.64[b]	0.07	0.001
Overall	2.84[a]	2.37[b]	2.34[b]	2.31[b]	0.05	0.001
G:F, kg/kg						
0 to 14 d	0.45[a]	0.39[b]	0.44[a]	0.38[b]	0.01	0.001
15 to 28 d	0.38[a]	0.43[b]	0.44[bc]	0.46[c]	0.01	0.001
29 to 42 d	0.31[a]	0.37[b]	0.36[b]	0.37[b]	0.01	0.001
43 to 63 d	0.29	0.29	0.30	0.27	0.01	0.104
Overall	0.34[a]	0.36[b]	0.37[b]	0.35[ab]	0.01	0.024
Days to market weight	79.5[a]	90.5[b]	89.6[b]	91.0[b]	2.4	0.004

[a–c]Within a row, means without a common superscript letter differ ($P < 0.05$).

[1]Treatments: AL = feeding ad libitum; R = feeding 85% of ad libitum; D = feeding 70% ad libitum 1 d, then 100% ad libitum the next day; and 3-D = feeding 70% ad libitum for 3 d, then 100% ad libitum for the next 3 d.

[2]Pooled SEM.

Table 3. Carcass measurements and subcutaneous fat thickness (mm) of female pigs with variations in feed intake patterns

	Treatment[1]					
Item	AL	R	D	3-D	SEM[2]	*P*-value
Carcass weight, kg	70.7	72.2	72.7	73.0	0.6	0.075
Dressing percentage, %	69.2	69.1	70.0	70.1	0.3	0.065
Flare fat,[3] g	901	799	808	761	75	0.596
Subcutaneous fat thickness, mm						
P2[4]	14.9[a]	11.9[b]	12.7[b]	12.9[b]	0.7	0.021
Shoulder	35.8	35.4	34.6	32.4	1.3	0.237
Loin (dorsal)						
2nd rib	30.4	29.0	30.7	28.3	1.4	0.626
Last rib	18.3	18.6	17.4	17.7	1.0	0.804
Last lumbar vertebrae	21.2[a]	15.1[c]	16.9[bc]	19.3[ab]	1.3	0.006
Loin (ventral)						
2nd rib	21.8	19.4	17.8	20.1	1.3	0.218
Last rib	13.5	13.0	11.9	13.1	0.9	0.624
In line with last lumbar vertebrae	21.4[a]	16.1[b]	16.8[b]	17.1[b]	1.4	0.039
11th rib	20.6	19.8	17.8	19.9	1.5	0.599
Belly						
2nd rib	8.9	7.4	9.4	9.7	0.8	0.229
Last rib	19.9	18.3	19.0	20.3	1.0	0.472
In line with last lumbar vertebrae	21.1	20.0	18.1	22.0	1.4	0.243
Ham	24.1	21.2	21.8	21.0	1.4	0.415

[a–c]Within a row, means without a common superscript letter differ ($P < 0.05$).

[1]Treatments: AL = feeding ad libitum; R = feeding 85% of ad libitum; D = feeding 70% ad libitum 1 d, then 100% ad libitum the next day; and 3-D = feeding 70% ad libitum for 3 d, then 100% ad libitum for the next 3 d.

[2]Pooled SEM.

[3]A fat depot that comprises perinephric and retroperitoneal fats.

[4]Located 65 mm from the midline of the carcass at the last thoracic rib.

Table 4. Relative viscera weight (g/kg of BW) and composition of female pigs with variations in feed intake patterns

Item	Treatment[1]				SEM[2]	*P*-value
	AL	R	D	3-D		
Viscera weight, g/kg of BW						
Heart	3.61	3.83	3.80	3.68	0.17	0.469
Lungs	8.09	7.29	7.95	7.98	0.48	0.324
Kidneys	3.37	2.85	3.16	3.11	0.21	0.099
Liver	14.4	14.4	13.9	13.7	0.5	0.361
Gastrointestinal tract (empty)	36.9	37.6	38.3	36.8	0.1	0.609
Total	66.4	61.5	67.1	65.3	3.9	0.421
Viscera chemical composition, % of DM						
Fat	63.0	60.8	59.6	62.7	1.3	0.243
Protein	34.9	37.0	38.2	35.3	1.2	0.220
Ash	2.2	2.2	2.2	2.1	0.1	0.819
Fat:protein	1.85	1.68	1.61	1.83	0.10	0.339

[1]Treatments: AL = feeding ad libitum; R = feeding 85% of ad libitum; D = feeding 70% ad libitum 1 d, then 100% ad libitum the next day; and 3-D = feeding 70% ad libitum for 3 d, then 100% ad libitum for the next 3 d.

[2]Pooled SEM.

in the half carcass were not different among treatments. Regression analysis showed that the DXA estimate of carcass fat (%) was closely related to the F:L for total carcass and all the primal cuts (Figure 2).

DISCUSSION

A short-term pig study, which simulated random out-of-feed events up to 3 times (20-h duration) during a 5-wk experimental period, showed that growth depression was evident only during the week in which out-of-feed events occurred, but overall growth was not affected in either weaner or grower pigs (Linneen et al., 2007). Using a more frequent out-of-feed event model, Brumm and Colgan (2005) demonstrated that fluctuation in feed intake once a week for 109 d depressed the growth of pigs by 35 g/d because of decreased feed intake. In the present study, decreased ADFI for pigs with restricted feed intake, fluctuations in feed intake every other day, or fluctuations in feed intake every 3 d depressed ADG by 115, 104, and 118 g/d, respectively. Pigs on the D and 3-D feeding regimens consumed 15% less feed and grew 12% less than pigs on the AL regimen, indicating feed intake was the main contributor to growth retardation.

Edwards (1999) suggested, based on simulations conducted using the computer growth model (AUSPIG), that when pigs were fed the same amount as pigs with a consistent ADFI, but daily intake fluctuated by 30%, they would have a decreased G:F and ADG. A proposed mechanism was that pigs would use more energy and protein for maintenance or fat deposition when ADFI was less or greater than steady ad libitum intake. However, no such effects, in terms of ADG and G:F, were observed in the current study when the intake of pigs was fluctuated on either a daily (D) or a 3-d (3-D) cycle compared with pigs consuming 85% of the intake of the AL group every day (R). This lack of difference in performance between the R and D or 3-D regimens might indicate that, other than a limited nutrient supply for optimal growth, no other stressors such as gastric ulcers, ileitis, and hemorrhagic bowel syndrome (Brumm et al., 2005) were involved when pigs were exposed to fluctuations in feed intake, which was confirmed at slaughter.

Brumm et al. (2006) suggested, based on the observation that the growth of pigs was reduced in the early stage of growth (53 d from 23 kg of BW), but not in the later stage (54 to 109 d), when pigs were exposed to weekly out-of-feed events, that pigs can adapt to repeated out-of-feed events by changing their feed intake pattern. Examination of the performance indices in the current study showed that reductions in ADG and G:F in pigs on the R, D, and 3-D feeding regimens, compared with pigs on the AL regimen, occurred in the initial 14 d of the experiment, but that ADG was comparable with ADG of pigs on the AL regimen during the next 4 wk, perhaps because of improved feed efficiency. The greater G:F in restricted-fed pigs can be explained by compensatory growth after adaptation to the variable nutrient availability (Heyer and Lebret, 2007). These observations infer that, to some extent, pigs can adapt to altered feed intake patterns and can use fluctuating available nutrients efficiently, allowing BW gain and growth efficiency to be maintained.

Based on findings by Edwards (1999) and Trezona (2001), the hypothesis tested was that fluctuations in feed intake every other day or every 3 d would influence the carcass F:L at slaughter. In the present study, carcass F:L results obtained by DXA indicated that continuous feed restriction and fluctuations in feed intake decreased backfat depth by 3 and 2 mm, respectively, compared with AL feeding. Total carcass fat content and the carcass F:L were not influenced by the R or the D and 3-D feeding regimens, indicating that the variation in feed intake used in this experiment did not affect the rate of fat or protein deposition. This is contrary to our expectation that fluctuations in feed intake would

Table 5. Percentage (%) of fat, lean, and bone tissues and fat-to-lean ratio (F:L) in the half-carcass and primal cuts of female pigs with variations in food intake patterns measured by using dual energy x-ray absorptiometry (DXA)

	Treatment[1]					
Item	AL	R	D	3-D	SEM[2]	*P*-value
Carcass weight, kg	70.7	72.2	72.7	73.0	0.6	0.075
Half carcass						
Fat, %	24.6	22.8	22.6	22.7	1.3	0.661
Lean, %	64.2	65.0	65.3	66.1	1.2	0.741
Bone, %	11.2^{a}	12.2^{b}	12.1^{b}	11.2^{a}	0.3	0.020
F:L	0.39	0.36	0.35	0.35	0.03	0.622
Shoulder						
Fat, %	19.2	18.3	18.1	19.3	0.8	0.676
Lean, %	61.4	61.9	62.3	61.6	0.8	0.882
Bone, %	19.4	19.8	19.6	19.1	0.5	0.751
F:L	0.32	0.30	0.29	0.32	0.02	0.645
Loin						
Fat, %	18.7	17.2	17.9	16.2	1.4	0.617
Lean, %	79.5	80.7	79.9	82.1	1.4	0.590
Bone, %	1.8^{a}	2.1^{b}	2.2^{b}	1.7^{a}	0.1	0.001
F:L	0.24	0.22	0.23	0.20	0.02	0.611
Belly						
Fat, %	23.7	22.0	22.3	20.8	2.1	0.800
Lean, %	76.1	77.7	77.3	79.0	2.1	0.800
Bone, %	0.2	0.3	0.4	0.2	0.1	0.185
F:L	0.33	0.30	0.30	0.27	0.03	0.715
Ham						
Fat, %	16.6	15.7	14.5	15.1	1.0	0.520
Lean, %	70.2	70.2	71.9	71.9	1.0	0.475
Bone, %	13.2	14.1	13.6	13.0	0.3	0.115
F:L	0.24	0.23	0.20	0.21	0.02	0.458
DXA predicted content,[3] kg						
Half-carcass lipid	8.95	8.39	8.43	8.31	0.51	0.804
Half-carcass protein	4.47	4.57	4.65	4.66	0.08	0.318

[a,b]Within a row, means without a common superscript letter differ ($P < 0.05$).

[1]Treatments: AL = feeding ad libitum; R = feeding 85% of ad libitum; D = feeding 70% ad libitum 1 d, then 100% ad libitum the next day; and 3-D = feeding 70% ad libitum for 3 d, then 100% ad libitum for the next 3 d.

[2]Pooled SEM.

[3]For prediction of lipid and protein content, DXA (Hologic Inc., Waltham, MA) measurements of fat and lean tissue weight were logarithmically transformed to base 10 and calculated by using preestablished equations (Suster et al., 2003).

increase the carcass F:L. This discrepancy between the modeling simulation and the present study was most probably due to insufficient feed intake to accommodate the maximum protein deposition capacity after short-term feed restriction. If pigs had been allowed ad libitum access to feed after short-term restriction, as in the modeling simulation, pigs may have eaten more than the ad libitum intake of the control pigs, and the amount of feed intake could have exceeded the maximum protein deposition capacity. In this situation, excess energy and protein would have been used for fat tissue deposition (de Greef, 1992). However, the numerically decreased carcass F:L of pigs in the R, D, and 3-D regimens compared with pigs in the AL regimen might be a reflection of the small number of animals used in this experiment, and the accuracy of DXA estimation may also have contributed to the lack of statistically significant results. Nevertheless, the hypothesis that the carcass F:L in pigs at slaughter would increase if the feed intake of pigs fluctuated was rejected under the current experimental feeding regimens.

Increasing the energy intake (i.e., feeding amount) is known to increase the carcass F:L and decrease the proportion of body protein deposited in the carcass lean (Campbell and Taverner, 1988; Bikker et al., 1995). Albeit with no statistically significant differences, increased carcass lean and numerically decreased carcass fat with the D and 3-D feeding regimens agreed with findings by Bikker et al. (1996a). Overall, the tendency for increased carcass weight in pigs on the R, D, and 3-D regimens could be a reflection of numerically decreased fat content and numerically increased lean and bone content in the half carcass. Because pigs were weighed and slaughtered in the same time frame (weighed at 0900 h, fasted for 12 h, and slaughtered at 0900 h on the next morning), the interval between weighing and slaughter and the amount of the gut content were maintained consistently to minimize carcass weight and dressing percentage variations, respectively.

It was evident that twice as many pigs on the D and 3-D treatments had a P2 depth of 14 mm or greater compared with those pigs consuming the same amount

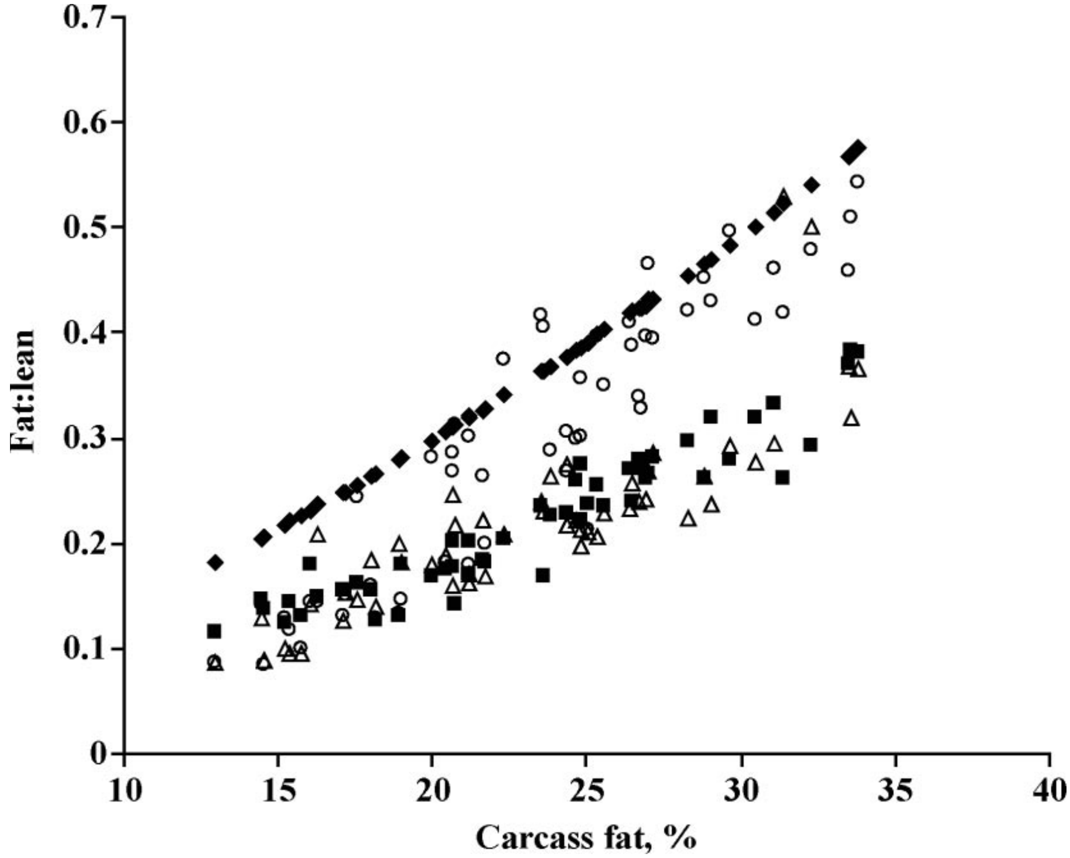

Figure 2. Linear relationships between hot carcass fat (%) and fat-to-lean ratio (F:L) in the hot carcass and primal cuts estimated by dual energy x-ray absorptiometry. Hot carcass [♦; F:L = −0.0753 + 0.0188 hot carcass fat %, R^2 = 0.997, residual SD (RSD) = 0.00567, and $P <$ 0.001], ham (■; F:L = −0.0552 + 0.0119 hot carcass fat %, R^2 = 0.888, RSD = 0.02329, and $P < 0.001$), belly (○; F:L = −0.206 + 0.0217 hot carcass fat %, R^2 = 0.852, RSD = 0.05000, and $P < 0.001$), and loin (△; F:L = −0.0889 + 0.0133 hot carcass fat %, R^2 = 0.715, RSD = 0.04591, and $P < 0.001$).

of feed per day (30 vs. 14% of pigs, respectively; data not shown). This result might indicate that variation in feed intake may have an impact on carcass quality, but to detect statistically significant differences, larger numbers of animals per treatment would be required to account for the large CV in the criteria measured.

Comparison between the D and 3-D feeding regimens indicated that fluctuation in feed intake every 3 d was possibly more deleterious, in terms of carcass quality and growth, than daily fluctuation in feed intake. For example, the 3-d fluctuation in feed intake increased subcutaneous fat depth in the loin, decreased carcass bone content, and reduced ADG from 0 to 14 d and from 43 to 63 d compared with pigs fed the same amount of feed continuously. In contrast, there were no differences between pigs with daily fluctuations in feed intake and pigs that were continuously on restricted feeding. Endocrine studies (summarized in Hornick et al., 2000) showed that restriction of feed increased the release of pituitary GH, whereas the number of GH receptors decreased. Subsequently, increased circulating GH decreased secretion of IGF-I, and stimulated the mobilization of body fat and anabolism of body protein. Therefore, moderate feed restriction is known to reduce fat deposition, whereas severe feed restriction promotes loss of body protein and fat. When refeeding, insulin secretion is markedly increased; hence, the efficiency of protein and fat deposition is increased by increasing the uptake and anabolism of nutrients (Hornick et al., 2000). Although concentrations of plasma insulin and GH were not measured, it is possible that daily fluctuations in feed intake and, in turn, daily fluctuations in pituitary GH concentrations may have permitted only a marginal time span for the alteration of nutrient partitioning, whereas longer term fluctuations in feed intake (3-D) increased the time span, allowing for modification of carcass composition because the changes in endocrine secretion induced by restrict feeding and refeeding persisted for several days or weeks (Hornick et al., 2000).

Decreased feeding has been reported to reduce visceral organ weight in growing pigs and hence to reduce fasting heat production (Koong et al., 1982; Bikker et al., 1996b). Heyer and Lebret (2007) showed that feed restriction decreased visceral organ weight, but during realimentation, visceral weight rapidly increased to greater than that of ad libitum-fed pigs. Bikker et al. (1996b) reported that compensatory growth occurs primarily in the visceral organs. In pigs, a greater gut weight as a consequence of compensatory growth has been explained by increased feed intake during realimentation (Heyer and Lebret, 2007). However, visceral organ weight was not influenced by any of the feeding regimens used in the present study, which is in agreement with Le Bellego et al. (2002). This might be due to the experimental design of the current study, in which pigs in the R, D, and 3-D feeding regimens did not have the opportunity for compensatory growth because they were restricted to 70% and then fed the same amount of feed consumed by AL pigs, rather than being allowed ad libitum access to feed during the refeeding period.

Increased bone mass in pigs on the R and D feeding regimens compared with pigs on the AL feeding regimen is in agreement with the results of Godfrey et al. (1991) but is difficult to explain. Steiner et al. (2006) suggested that increasing the feeding amount negatively affects the digestibility of P and Ca if dietary concentrations of P and Ca are sufficient, whereas the feeding amount positively affects the digestibility of P and Ca when dietary concentrations of these minerals are marginal. This notion may apply to the current finding because diets in the present study contained a sufficient amount of P (6.5 to 7.6 g/kg) and Ca (8.7 to 10.0 g/kg).

In summary, this study showed that restricted feeding depressed the growth of pigs and extended the time to reach the target slaughter BW by 11 d. Restriction or fluctuation of feed intake decreased the P2 backfat depth. However, continual fluctuations in feed intake had a minimal effect on the growth pattern of pigs and the carcass F:L compared with pigs fed the same restricted amount throughout the experiment. The pattern of F:L in all primal cuts was a reflection of total carcass fat content. The number of replicates (n = 15) used in this study may not have been sufficient to minimize the variation in carcass F:L among animals; hence, a large-scale investigation is warranted.

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