Pantothenic Acid Needs for Specific Biological Processes in Pigs

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Summary and Implications

Two lean growth strains of pigs and three dietary concentrations of bioavailable pantothenic acid [32, 132, 262% of the estimated NRC (5) requirements for 5 to 10 kg pigs] were utilized to determine the pantothenic acid needs for specific biological processes in the pig. Endogenous pantothenic acid production was estimated as 2.96 and 2.73 mg/BW kg$^{.75}$/d for the high and moderate lean strains. Based on dietary as well as endogenously synthesized pantothenic acid supplies, the gross efficiency of total pantothenic acid utilization was estimated as 10.5 % and was independent of dietary pantothenic acid concentration. Dietary pantothenic acid additions did not alter bodyweight gain or body energy retention. However, dietary pantothenic acid additions did alter body composition by redirecting energy from body fat accretion toward the more economically valuable process of protein accretion. Based on these data, pantothenic acid in amounts above that needed to support body energy accretion has a biological role in regulating body composition.

Introduction

Currently, vitamin requirements are largely based on the dietary concentration of a particular vitamin that results in maximum growth of the pigs being evaluated. However, much of the research that these vitamin requirements are based on was conducted in the 1950s and 1960s. Since that time, pigs have become more efficient meat-producing animals with an ability to grow more rapidly and to produce more proteinaceous tissue per kg of body weight gain.

Vitamin needs of pigs can be effectively estimated from empirical studies, but these estimates are only appropriate for pigs of a specific genetic strain, body weight, gender, herd health status, and climatic condition used in the study. Stahly et al. (14) has shown that higher dietary concentrations of one or more of a group of five B vitamins (niacin, pantothenic acid, riboflavin, B_{12}, and folic acid) are needed to optimize performance of a high lean growth strain of pigs compared with a moderate lean growth strain of pigs. These results indicate the dietary need for some vitamins may vary among pigs differing in their capacity for proteinaceous tissue growth.

A better approach to determine the vitamin requirements of pigs may be the factorial approach. Such an approach has been used to model both energy and amino acid needs of pigs from different strains, stages of growth, etc., by determining the amount of nutrients required for body maintenance and body protein and fat accretion (5).

Due to the important role pantothenic acid plays in carbohydrate, protein, and fat metabolism, determination of the amount of pantothenic acid required for specific biological processes (i.e. body maintenance and body protein and fat accretion) would be valuable information for estimating the pantothenic acid requirement of pigs.

Materials and Methods

Two lean growth strains of pigs with high and moderate genetic capacities for lean tissue accretion and three dietary pantothenic acid concentrations were used to estimate the pantothenic acid needs for specific biological processes in the pig. Pigs from the high and moderate lean strains used typically express carcass muscle contents of 55–57% and 51–53%, respectively, at market weights of 110 kg. The three dietary pantothenic acid concentrations consisted of a basal diet supplemented with d-calcium pantothenate to provide dietary additions of pantothenic acid equivalent to 0, 100, 200% of the estimated pantothenic acid requirement for 5 to 10 kg pigs (5). The basal diet (Table 1) contained an analyzed pantothenic acid content of 4.55 ppm and an estimated bioavailable pantothenic acid concentration of 3.25 ppm, which are equivalent, respectively, to 46 and 32% of the NRC (5) requirement (Table 2). The analyzed pantothenic acid content in the experimental diets and ingredients were determined by Woodson-Tenent Laboratory, Memphis, TN, via a microbiological technique according to AOAC (1) procedures. The bioavailable pantothenic acid content of the diet was calculated by multiplying the analyzed concentration in each ingredient by the estimated bioavailability of the pantothenic acid in the ingredient [corn, 20% (8); soybean meal, 100%, (13); all other ingredients, 100%]. All other vitamins were supplemented at dietary concentrations equivalent to 600% of the NRC (5) estimated requirements. Dietary amino acid concentrations met or exceeded the estimated needs for high lean strains of pigs. The concentration of each essential amino acid relative to lysine met or exceeded 100% of the ideal amino acid ratio (3).

To detect the amount of pantothenic acid needed to support body maintenance and body protein and fat accretion, all pigs must receive inadequate supplies of pantothenic acid from both exogenous (diet) and endogenous (body) sources so that linear responses to dietary additions of pantothenic acid can be achieved. The dietary pantothenic acid concentrations utilized in the study were estimated to represent deficient levels for pigs during the proposed stages of growth. All pigs were fed the basal diet from weaning through 10 kg BW to potentially minimize initial body stores of pantothenic acid and to minimize variation in body stores among pigs and lean strains.

Within each lean strain, 10 sets of four littermate barrows were evaluated. Pigs were weaned at 12 to 16 days of age (to minimize immune system activation), transported to central Iowa, placed in a facility physically isolated from other pigs, and treated with Naxcel for 3 days. Pigs were penned individually on slotted floors in 2 x 4 ft pens in a thermoneutral climate. Postweaning, pigs were fed a 1.8% lysine, low pantothenic acid diet for 8 days and then placed on the 1.5% lysine, basal diet [32% of the NRC (5) estimated pantothenic acid requirement for 5 to 10 kg pigs] until the pigs reached a body weight of 10 ± 1.5 kg. Pigs were allowed to consume feed and water ad libitum. The diet was provided in a meal form.

At 10 ± 1.5 kg body weight, pigs were randomly allotted within litter to one of the three dietary regimens. Pig weights, feed consumption, and feed wastage was determined every 4 days until individual pigs reached a body weight of 27 ± 1.5 kg. At bodyweights of 10 and 27 kg, a deuterium oxide dilution technique was used to determine body water, fat, and protein content (9). Immune status of the pigs was monitored at 10, 18, and 27 kg by monitoring serological titers for six major pathogens and serum concentrations of the acute phase protein, alpha-1-acid glycoprotein.

All pigs were sacrificed at the termination of the study to determine the final pantothenic acid body stores. The pigs' bodies were frozen and ground through a whole body grinder and subsampled. Analysis of the pantothenic acid content in the frozen pigs' bodies was performed by Ralston Analytical Laboratories, St. Louis, MO via microbiological technique according to AOAC (1) procedures. Additionally, a fourth barrow in each litter was killed at the initiation of the study to determine initial body pantothenic acid stores. The assay used for analyzing the body pantothenic acid content had a lower limit of detection of 0.412 ppm with an intra-assay variation of 8.4% and an inter-assay variation of 9.4%

Data were analyzed as a split-plot design (15) by using the GLM procedure of SAS (10). Lean pig strain was considered the whole-plot and dietary pantothenic acid concentrations represented the subplot. The pig was considered the experimental unit. Least square means are reported. Multiple regression techniques were used to estimate pantothenic acid needs (dietary and endogenous supplies) for body maintenance, body protein and fat accretion.

Table 1. Diet composition of basal diet.

Ingredient	%
Corn	62.33
Choice white grease	5.00
Soybean meal, dehulled	18.34
Casein	7.00
Amino acids[a]	1.04
Dicalcium Phosphate	2.97
Calcium Carbonate	1.04
Salt, iodized	.45
Potassium Sulfate	.36
Sodium Bicarbonate	.23
Trace mineral mix[b]	.21
Choline chloride, 60%	.23
Vitamin mix[c]	.10
Pantothenic acid carrier	.20
Antimicrobial agent[d]	.50

[a] Provided per kg of diet: 3.1 g lysine; 2.6 g threonine; .7 g isoleucine; .5 g tryptophan; 2.2 g methionine.

[b] Provided per kg of diet: 280 mg Fe; 240 mg Zn; 96 mg Mn; 28 mg Cu; .32 mg I; .3 mg Se.

[c] Provided per kg of diet: 13,200 IU Vit. A; 1,320 IU Vit. D_3; 96 IU Vit. E; 3 mg Vit. K; 90 mg niacin; 0 mg pantothenic acid; 21 mg riboflavin; .105 mg Vit. B_{12}; 1.8 mg folacin; .3 mg biotin; 9 mg pyridoxine; 6 mg thiamine; 100 mg ascorbic acid.

[d] Provided per kg of diet: 110 mg chlortetracycline, 55 mg penicillin and 110 mg sulfathiolzole.

Table 2. Pantothenic acid content of experimental diets.

	Added Pantothenic Acid, mg/kg		
Criteria	0	10	20
Pantothenic acid, mg/kg diet			
Analyzed total	4.55	14.97	28.05
Bioavailable	3.23	13.65	26.73

Results

Health Status of Experimental Animals

Pigs from both genetic strains were reared via a SEW scheme and exhibited a high health status. Specifically, the pigs were free of acquired antibodies for six major pathogens and exhibited low levels of the acute phase protein, AGP (Table 3). The serum antibodies for SIV and TGE present at 10 kg BW represented passively derived, maternal antibodies. The slower loss of the maternal SIV antibodies in the high lean strain reflected the greater level of SIV vaccination that their dams received. Based on these data, pigs from both strains possessed a high health status, which would allow their genetic capacity for growth to be expressed in the study.

Table 3. Characterization of the health status of experimental pigs.

		Pig Weight, kg		
Criteria	Lean Strain	10	18	27
Serological titers[a] (number of positives for each antigen)				
APP	High	0/5	0/5	0/5
	Mod	0/5	0/5	0/5
MP	High	0/5	0/5	0/5
	Mod	1/5[b]	0/5	0/5
PRRS	High	0/5	0/5	0/5
	Mod	0/5	0/5	0/5
PRV	High	0/5	0/5	0/5
	Mod	0/5	0/5	0/5
SIV	High	5/5[b]	3/5	3/5
	Mod	2/5[b]	0/5	0/5
TGE	High	2/5[b]	0/5	0/5
	Mod	1/5[b]	1/5	1/5
Serum alpha-1-acylglycoprotein (AGP), µg/ml				
AGP	High	760	553	435
	Mod	618	452	420

[a] Actinobacillus pleuronpneumoniae (APP), mycoplasma hyopneumonia (MP), porcine reproductive and respiratory syndrome (PRRS) virus, pseudorabies (PRV), swine influenza virus (SIV), and transmissible gastroenteritis (TGE).
[b] Titers are assumed to be maternally derived antibodies that are disappearing over time.

Effect of Lean Strain on Growth and Body Nutrient Accretion

As expected, the high lean strain of pigs consumed less daily feed (947 vs 993 g/d), thus less metabolizable energy and pantothenic acid (13.7 vs 14.3 mg/d) than the moderate lean strain (Table 4). The high lean strain also grew faster (706 vs 661 g/d) and gained more weight per unit of feed (.747 vs .668) than the moderate lean strain (Table 4). The high lean strain of pigs deposited daily more body protein (124 vs 114 g) and less body fat (69 vs 76 g) than the moderate lean strain (Table 5). Furthermore, the body weight gain of the high lean strain contained a greater proportion of body protein to body fat (1.83 vs 1.53) than that of the moderate lean strain (Table 5). Daily body energy retention did not differ among lean strains. The differences in body protein and fat accretion rates between the strains allowed the role of pantothenic acid in supporting energy accretion as body protein and fat to be evaluated more robustly.

Dietary Pantothenic Acid Content and Intake

Based on the analyzed pantothenic acid concentrations in the experimental diets, the basal diet contained a deficient level of pantothenic acid relative to NRC (5) and the planned additions of pantothenic acid were met or slightly exceeded. Specifically, the basal diet was analyzed to contain 4.55 ppm of total pantothenic acid or an estimated bioavailable content of 3.23 ppm (Table 2). These values represent 46 and 32% of the current NRC (5) estimate of the pantothenic acid requirement for 5 to 10 kg pigs and 51 and 36% of the estimated requirement for 10 to 20 kg pigs. The planned additions of 10 and 20 ppm pantothenic acid equivalent to 100 and 200% of estimated requirements were analyzed to be 10.4 and 23.5 ppm, respectively. These values represent additions equivalent to 105 and 230% of the NRC (5) estimated requirements for 5 to 10 kg pigs.

Effect of Pantothenic Acid Additions on Growth and Body Nutrient Accretion

Daily intakes of bioavailable pantothenic acid increased linearly as dietary pantothenic acid concentration increased (Table 4). The magnitude of the increase was greater in the moderate lean strain.

As dietary pantothenic acid concentration increased, the amount of feed consumed per unit of body weight gain tended to decrease (P=.12) linearly (Table 4). The composition of the pigs' body weight gain also was altered as dietary pantothenic acid concentration increased. Specifically, the amount of body protein accrued per unit of body fat accretion in pigs (pooled across strain) was increased from 1.58 to 1.71 and 1.73 for animals fed diets containing 0, 10 and 20 ppm added pantothenic acid, respectively (Table 5). Furthermore, the protein content of body weight gain or body energy gain increased (P<.05) whereas the body fat content decreased (P<.05) linearly as dietary pantothenic acid concentration increased (Table 5). The magnitude of these changes in body composition was greater (P<.07) in the moderate lean strain. These changes occurred even though daily feed and energy intake, body weight gain, and body energy accretion were not altered by dietary pantothenic acid concentration.

Table 4. Effect of dietary bioavailable pantothenic acid (PA) concentration on pig growth, and efficiency of feed utilization in high and moderate lean strains fed from 10 to 27 kg body weight.

Item	Lean Strain	Added PA, mg/kg 0	10	20
No. of pens	High	10	10	10
	Mod	10	10	10
Days on test	High	24.7	23.7	25.9
	Mod	28.9	27.6	27.2
Pig weight, kg				
Initial	High	10.1	10.0	9.9
	Mod	9.9	9.8	9.8
Final	High	28.0	27.7	27.9
	Mod	27.7	27.6	28.0
Growth and feed utilization				
Feed, g/d[a]	High	956	949	937
	Mod	996	1010	973
Body gain, g/d[b]	High	710	704	704
	Mod	648	672	664
Feed/gain[b,c]	High	1.35	1.35	1.33
	Mod	1.54	1.51	1.47
Pantothenic acid intake				
Bioavail., mg/d[d]	High	3.09	12.95	25.04
	Mod	3.22	13.78	26.01

[a] Strain effect, P=.06.
[b] Strain effect, P<.02.
[c] Linear effect of PA, P=.12.
[d] Linear effect of PA, P=.01.

Table 5. Effect of dietary bioavailable pantothenic acid (PA) concentration on body nutrient and energy accretion rates in high and moderate lean strains of pigs fed from BW of 10 to 27 kg.

Item	Lean Strain	Added PA, mg/kg 0	10	20
Body nutrient accretion				
Protein, g/d[a]	High	125	124	124
	Mod	110	116	116
Fat, g/d[a]	High	71	66	70
	Mod	80	77	71
Energy, Mcal/d	High	1.38	1.32	1.37
	Mod	1.38	1.38	1.33
Protein:fat[a,b]	High	1.77	1.90	1.81
	Mod	1.39	1.54	1.66
% BW gain as protein[a,b,c]				
	High	17.55	17.65	17.56
	Mod	17.12	17.28	17.41
% BW gain as fat[a,b,c]				
	High	9.98	9.36	9.96
	Mod	12.37	11.39	10.72
% energy gain as protein[a,b,c]				
	High	51.36	53.13	51.70
	Mod	45.42	47.77	49.55
% energy gain as protein[a,b,c]				
	High	48.64	46.87	48.30
	Mod	54.58	52.23	50.45

[a] Strain effect, P<.05.
[b] Linear effect of PA, P<.05.
[c] Linear effect of PA x Strain effect, P<.07.

Pantothenic Acid Utilization

As desired for the experimental protocol, the pigs in both genetic strains initially contained similar body stores of pantothenic acid. Initially, body pantothenic acid concentrations were 4.41 and 4.50 ppm in the high and moderate lean strains, respectively (Table 6). These values are equivalent to total body stores of 44.7 and 44.4 mg. Over the duration of the study, the body concentrations of pantothenic acid in the pigs fed the basal diet declined slightly from 4.41 to 4.24 ppm in the high lean strain and 4.50 to 4.15 ppm in the moderate lean strain. However, as dietary pantothenic acid concentration increased, the final body concentrations (mg/kg BW) of pantothenic acid as well as total body stores (mg/pig) increased linearly. The gross efficiency of utilization of dietary pantothenic acid was calculated as the amount of pantothenic acid accrued in the body per unit of dietary bioavailable pantothenic acid consumed. As dietary intakes of pantothenic acid increased, the gross efficiency of pantothenic acid utilization declined from 80 to 94% in pigs fed the basal diet to 30 to 37% and 18 to 23% for pigs fed diets containing 10 and 20 ppm added pantothenic acid, respectively (Table 6).

To estimate the gross efficiency of utilization of total pantothenic acid, both exogenous (diet) as well as endogenous supplies of pantothenic acid must be accounted for. Through the use of regression analyses, endogenous pantothenic acid production was estimated as 2.96 ± 0.79 and 2.73 ± 1.13 mg/ BW kg$^{.75}$/d for the high and moderate lean strains. Thus, daily endogenous production would be equivalent to 26 and 24 mg/pig/d, respectively. Based on dietary as well as endogenously synthesized pantothenic acid supplies, the gross efficiency of total pantothenic acid utilization was estimated as 10.5 % and was independent of dietary pantothenic acid concentration (Table 6).

Table 6. Effect of dietary bioavailable pantothenic acid (PA) concentration on body pantothenic acid content and utilization in two lean strains of pigs.

	Lean	Added PA, mg/kg		
Item	Strain	0	10	20
Body PA Content				
Concentration, mg/kg BW				
Initial	High	4.41	4.41	4.41
	Mod	4.50	4.50	4.50
Final[a]	High	4.24	5.93	6.74
	Mod	4.15	5.60	6.19
Dietary PA intake and retention				
Body PA retained, mg/pig[a]	High	74	120	144
	Mod	71	111	129
Dietary bioavailable PA intake, mg/pig[a,b]	High	78	326	639
	Mod	89	366	717
Gross efficiency of dietary PA retention, %[a,b]	High	94	37	23
	Mod	80	30	18
Gross efficiency of dietary and endogenous PA retention, %	High	10	12	11
	Mod	10	11	10

[a] Linear effect of PA, P=.01.
[b] Strain effect, P<.05.

Discussion

As desired, the pigs' initial body stores of pantothenic acid were low. Initial concentrations of pantothenic acid in the whole body (including organs) averaged 4.46 ppm. These values are significantly lower than reported values (8.6 ppm) for pork muscles (6), even though concentrations of pantothenic acid typically are greater in liver, heart, spleen, and kidneys than muscle (7). Furthermore, the objective of establishing a pantothenic acid deficiency seemed to be achieved. This statement is based on the linear increase in body pantothenic acid stores that occurred as dietary pantothenic acid concentrations increased. These data indicate that tissue saturation had not occurred at the highest dietary concentration of pantothenic acid evaluated.

The original experimental hypothesis was that pigs experiencing insufficient supplies of pantothenic acid would respond to each incremental addition of dietary pantothenic acid with incremental increases in body energy accretion. The increases in body energy accretion were hypothesized to consist of increases in both body protein and fat accretion. These responses were previously reported in pair-fed chicks (2). It was projected that once these changes in energy and nutrient accretion were quantified, the pantothenic acid needed to support the energy needs for the various biological processes could be defined.

Unexpectedly, daily body energy accretion as well as body weight gain and feed intake were not altered by dietary pantothenic acid concentration. But, body composition and thus the form that the energy was retained in the body was altered. Specifically, body protein accretion was increased and body fat accretion decreased as dietary pantothenic acid concentrations increased. The experimental model utilized in this study did not allow the partitioning of pantothenic acid needs for specific biological functions when total body energy accretion was not increased and one use of dietary energy (body fat accretion) was actually reduced by pantothenic acid additions. Based on these data, d-calcium pantothenate has an additional biological role beyond its facilitation of body energy accretion per se. Dietary pantothenic acid seems to function to reduce body fat deposition and potentially allow the energy spared from fat deposition to be redirected toward body protein accretion. These results are supported by earlier work with pair-fed chicks where dietary pantothenic acid additions to a deficient diet reduced the incorporation of ^{14}C labeled acetate into long-chain fatty acids (4). In pair-fed rats, dietary pantothenic acid additions to a deficient diet also have been reported to reduce serum triglycerides and free fatty acid concentration (16).

The high energy intake relative to maintenance needs achieved in high health, lean pigs as well as their high muscle contents may contribute to the observed responses to pantothenic acid. Force-feeding glucose significantly lowers incorporation of pantothenic acid into hepatic and cardiac CoA even though tissue concentration of pantothenate are not altered (11). These data indicate that dietary energy intake and/or glucose does not alter pantothenic acid uptake per se, but regulates the biosynthesis and/or degradative pathway between pantothenate and CoA. In addition, muscle tissue may be more sensitive than hepatic tissue to a pantothenic acid deficiency. Feeding deficient pantothenic acid diets have been shown to result in up to a 90% reduction in liver pantothenate stores without lowering hepatic CoA concentration (12). However, muscle CoA stores decline in close correlation with dietary pantothenic acid intake (12).

The current NRC (5) estimates of the dietary pantothenic acid requirement of pigs is 10 ppm for 5 to 10 kg pigs and then declines linearly to 7 ppm for pigs weighing 120 kg. Even though the pigs in the current study had superior rates of body weight gains and efficiency of feed utilization compared with that of pigs in the studies use to establish the NRC pantothenic acid requirements, our data would indicate that these dietary pantothenic acid intakes may be adequate to support maximal rates of body weight gain and energy accretion in high health, high lean pigs at least in the pigs' early stages of development. However, when basing pantothenic acid needs on maximizing proteinaceous tissue and minimizing fatty tissue in the pigs' bodies, a greater level of dietary intake is needed. Based on these data, pantothenic acid serves to redirect energy away from body fat accretion and towards the more favorable biological process of protein accretion when fed at concentrations above that required to support maximal body energy retention.

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