THE EFFECTS OF DIFFERENT NUTRIENT STRATEGIES ON REDUCING OSTEOCHONDROSIS DISSECANS LESIONS AND ENHANCING CARTILAGE PROPERTIES IN PIGS

N. Z. Frantz, J. L. Nelssen, G. Andrews[1], S. S. Dritz[2], M. D. Tokach, R. D. Goodband, and J. M. DeRouchey

Summary

A total of 80 gilts (PIC 327 × L1050; 86 lb initial BW) were used in an 84-d study to determine the effects of different nutrients on growth performance, carcass composition, the occurrence of osteochondrosis dissecans (OCD) lesions (a cartilage abnormality), and several cartilage criteria. Eight dietary treatments were formulated, consisting of control diet (standard corn-soy diet) or the control diet with fish oil (3.5%) replacing choice white grease; added proline and glycine (300% and 200% of lysine; added leucine, isoleucine, and valine (BCAA; 200%, 100%, and 100% of lysine, respectively); silicon (1000 ppm); copper and manganese (250 ppm and 100 ppm, respectively); added methionine and threonine (150% and 100% of lysine); and a combination of these strategies. The diets were formulated slightly in excess of the pig's requirement for lysine and to meet minimum true ileal digestibility (TID) ratios for the other essential amino acids. The diets were also formulated to be isocaloric by slightly adjusting the fat (choice white grease) content. Overall, d 0 to 84, pigs fed diets containing BCAA or silicon had greater ADG (P<0.05) than did those fed methionine/threonine or the combination diet; performance of pigs fed the remaining diets was intermediate. Pigs fed methionine/threonine had increased longissimus muscle area (P<0.05), compared with those fed the other dietary treatments, with longissimus muscle area of pigs fed fish oil intermediate. No other carcass responses were affected by dietary treatment (P>0.84). Pigs fed diets containing fish oil or silicon tended (P<0.07) to have an increased number of cartilage abnormalities and a higher score for severity of abnormalities (P<0.05), compared with those of pigs fed the other dietary treatments; scores of pigs fed proline/glycine or copper/manganese were intermediate. Pigs fed fish oil or silicon tended (P<0.07) to have a greater prevalence of potential lesions than did pigs fed the control diet, BCAA, methionine/threonine, or the combination diet; responses to the other dietary treatments were intermediate. Cartilage compression or shear force were unaffected by dietary treatment (P>0.31). In summary, feeding ingredients involved in cartilage and bone metabolism did not improve cartilage properties or reduce the incidence of OCD in gilts relative to the control diet in this study. Feeding diets containing fish oil or silicon caused an increase in the occurrence of potential lesions, the number of cartilage abnormalities, and the scores for severity of abnormalities.

(Key Words: Cartilage, Finishing Pig, OCD.)

[1]Department of Diagnostics/Pathobiology, College of Veterinary Medicine.
[2]Food Animal Health & Management Center, College of Veterinary Medicine.

Introduction

Osteochondrosis dissecans (OCD) remains a common problem among growing swine that occurs in approximately 85 to 90% of all pigs. Osteochondrosis dissecans is an irregularity in the underlying growth cartilage that has improperly calcified, leaving an area of cartilage protruding into the subchondral bone. It occurs primarily in the epiphyseal cartilage of the medial femoral condyle, humeral condyle, humeral head, and the growth plate of the distal ulna, costochondral junction, and the femur. It can cause reduced reproductive performance and increased culling rates in sows, and decrease performance and meat yield of finishing pigs. The direct cause of OCD is relatively unknown, but several studies have tried to determine how handling, moving, genetics, or nutrition may play a role in its development. It previously has been thought that rapid growth rate was a major cause of OCD in growing pigs. But current data indicate that OCD is caused by an abnormality in bone growth that causes cartilage canal vessels supplying blood to the end of growing long bones to improperly fill with bone matrix. The reduced blood supply provides an area of cartilage that is weakened and susceptible to trauma. When trauma occurs, this underlying weakness can allow damage to occur to the articular cartilage surface or can prevent the cartilage around it from properly maturing and growing at the appropriate rate. This damage to the articular cartilage surface results in pain and stiffness associated with the common lameness and decreased mobility seen in many pigs.

Different nutrients recently have been evaluated for their ability to prevent arthritis and osteoarthritis in humans and animal models of the disease. Several amino acids and minerals play important roles in cartilage metabolism, and may present ways to intervene and prevent cartilage degradation or disease progression. The non-essential amino acids proline and glycine make up the building blocks of the collagen type II molecules that provide the framework of cartilage. In addition, the essential amino acid lysine plays a similar role in the makeup of collagen, whereas methionine provides a source of sulfur to form disulfide bonds and connect other molecules within the collagen molecule, and may influence cartilage metabolism. The branched-chain amino acids are involved in enzyme production and protein synthesis, as well as several of the protein components of the extracellular matrix, such as biglycan, fibromodulin, and decorin, leucine-rich proteins. Copper is involved in an enzyme, lysyl oxidase, that catalyzes the conversion of hydroxylysine residues in forming cross-links that stabilize the extracellular matrix. Manganese is involved in bone metabolism and cartilage formation through manganese-dependent glycosyltransferases, which are involved in the synthesis of proteoglycans. Manganese also has antioxidant activity on its own and in the mitochondria as manganese superoxide dismutase. Silicon is a mineral found in the earth's crust that has not been found to be essential in pigs; it may be involved in bone metabolism, however, and is found in collagen to link chondroitin sulfate molecules together. Fish oil contains high concentrations of the omega-3 fatty acids DHA and EPA that can potentially block the production of inflammatory intermediates by blocking the production of cytokines. This strategy may reduce the effects of specific cytokines that activate matrix metalloproteinases (MMP), which control the rate of extracellular matrix degradation and reduce expression of the type II collagen gene.

Therefore, the objective of this experiment was to screen dietary ingredients involved in cartilage and synovial fluid synthesis for their influence on growth performance, carcass characteristics, OCD lesions, and several cartilage criteria in growing-finishing pigs.

Procedures

General. Procedures used in these experiments were approved by the Kansas State University Animal Care and Use Committee. A total of 80 gilts (PIC line 327 × L1050; 86 lb initial BW) were blocked by weight in an 84-d growth assay. They were randomly allotted to one of eight dietary treatments. Dietary treatments consisted of control (standard corn-soy diet) or the control diet with fish oil (3.5%) replacing choice white grease; added proline and glycine (300% and 200% of lysine, respectively); added leucine, isoleucine, and valine (BCAA; 200%, 100%, and 100% of lysine, respectively); silicon (1000 ppm); copper and manganese (250 ppm and 100 ppm, respectively); added methionine and threonine (150% and 100% of lysine, respectively); and a combination of these strategies. Experimental diets were fed in meal form for 84 d. Pigs were phase-fed over the 84 d period, consisting of three 28-d phases. The values used in diet formulation and TID digestibilities were based on those published in the NRC (1998). Diet samples were analyzed for amino acid content.

The experiment was conducted at the Kansas State University Swine Research and Teaching Center. Each pen contained one pig, for a total of ten replicates (pigs) per treatment. The barn contains 80 totally slatted concrete pens (5 × 4 ft), providing approximately 20 sq ft per pig. Each pen was equipped with a one-hole dry self-feeder (Farmweld, Tuetopolis, IL) and nipple waterer to allow *ad libitum* access to feed and water.

Growth Performance and Carcass Composition. Pigs and feeders were weighed on d 0, 14, 28, 42, 56, 70, and 84 to determine ADG, ADFI, and F/G. At the start of the trial, all gilts were ultrasound scanned to determine initial backfat depth and longissimus muscle area. At the end of the trial, pigs were weighed before transport to the Kansas State University Meats Laboratory, where the left hind leg was collected for determination of OCD lesions as well as carcass data. Before transport, each pig was marked with a distinctive tattoo to allow the carcass data to be recorded for each pig. Carcass data were collected on each pig to evaluate 10th rib backfat depth, longissimus area, percentage lean, fat-free lean gain, and hot carcass weight. Fat depth was measured with a ruler at the 10th rib, 0.4 inch off the midline of the hot carcass, whereas longissimus area was traced on translucent paper and calculated using a grid. Percentage lean was calculated by using a standard equation, and fat-free lean index was calculated according to NPPC (1994) procedures.

Collection of Cartilage Data and OCD Lesions Scores. The left hind leg with an intact hip joint was collected and removed to visually determine the number of cartilage abnormalities and the occurrence of OCD lesions by visual examination. The joints were stored in 10% formalin until evaluation. Samples were evaluated for the number of abnormalities, given a severity of abnormality score (0 to 3), and given a "Yes" or "No" score for the presence or absence of a potential OCD lesion. In addition, a cartilage sample was cut from the proximal head of the femur. Cartilage samples were weighed, measured for thickness and length with a caliper, and then tested with an Instron machine to measure the ability to absorb compression or to resist shearing. Cartilage samples were placed between two flat surfaces of the Instron to perform the texture-profile analysis and were compressed half of the thickness to measure the ability of the cartilage to resist compression force. A second measure was conducted in which the cartilage was cut with a Warner-Bratzler shear blade to determine the ability of the cartilage to withstand shearing force. Compression values and shear values were adjusted to values per gram of cartilage weight to equalize for differences in the actual cartilage weight.

Statistical Analysis. Data were analyzed as a randomized complete-block design by using the PROC MIXED procedure of SAS, with pig as the experimental unit. The response criteria of growth performance, carcass composition, cartilage compression and shearing, number of abnormalities, severity of abnormalities score, and presence of potential OCD lesions were tested. Comparison of the presence of potential OCD lesions was done by chi-square analysis.

Results and Discussion

From d 0 to 28, pigs fed BCAA, silicon, or copper/manganese had greater ADG ($P<0.01$) than did pigs fed diets containing fish oil, proline/glycine, methionine/threonine, or the combination diet; ADG of pigs in the other treatments was intermediate. Pigs fed copper/manganese also tended to have improved F/G ($P<0.08$), compared with F/G of pigs fed fish oil, proline/glycine, methionine/threonine, or the combination diet; results of the other treatments were intermediate.

From d 0 to 56, pigs fed BCAA had greater ADG ($P<0.01$) than did pigs fed fish oil, proline/glycine, methionine/threonine, or the combination diet; ADG of pigs in the other treatments was intermediate. In addition, pigs fed copper/manganese had improved F/G ($P<0.05$), compared with F/G of pigs fed diets containing proline/glycine, methionine/threonine, or the control diet; results of the other dietary treatments were intermediate. Dietary copper addition has been shown to improve feed efficiency in the early growing-finishing phase in previous trials.

Overall, d 0 to 84, pigs fed diets containing BCAA or silicon had greater ADG ($P<0.05$) than did pigs fed methionine/threonine or the combination diet; ADG of pigs fed the remaining diets was intermediate.

Pigs fed methionine/threonine had increased longissimus muscle area ($P<0.05$), compared with that of pigs in the other dietary treatments; results of pigs fed fish oil were intermediate, but no other carcass differences were observed ($P>0.84$). This response is similar to previous trials in which excess methionine has increased longissimus muscle area.

Pigs fed diets containing fish oil or silicon tended ($P<0.07$) to have an increased number of cartilage abnormalities and had a higher score for severity of abnormalities ($P<0.05$), compared with scores of pigs in the other dietary treatments; scores of pigs fed proline/glycine or copper/manganese were intermediate. Pigs fed fish oil or silicon tended ($P<0.07$) to have a greater incidence of potential lesions than did pigs fed the control diet, BCAA, methionine/threonine, or the combination diet; incidence of potential lesions in pigs fed the other dietary treatments was intermediate. Cartilage compression and shear values were unaffected by dietary treatment ($P>0.31$).

In summary, feeding pigs added copper/manganese during the early growing-finishing phase resulted in improved F/G, compared with feeding the control diet. Feeding pigs diets containing fish oil or silicon tended to increase the occurrence of lesions and cartilage abnormalities compared with feeding the control diet. This may be due to a reduction in cartilage turnover by decreasing the production of matrix metalloproteinases with fish oil or by altering cartilage metabolism and bone metabolism with silicon. Feeding ingredients involved in cartilage and bone metabolism did not improve cartilage properties or reduce the incidence of OCD, relative to the control diet, in this study. Feeding diets containing fish oil or silicon caused an increase in the occurrence of lesions, the number of abnormalities, and the scores for severity of abnormalities.

Table 1. Diet Composition for Phase 1 (As-fed Basis)[a]

Item	Control	Fish Oil	Proline/ Glycine	BCAA	Silicon	Copper/ Manganese	Methionine/ Threonine	All Ingredients
Ingredient								
Corn	62.65	62.81	58.47	61.47	61.21	62.46	61.62	54.59
Soybean meal (46.5% CP)	30.45	30.42	30.80	30.54	30.56	30.45	30.53	31.13
Choice white grease	3.50	-	3.00	3.30	4.00	3.50	3.00	-
Menhaden fish oil	-	3.30	-	-	-	-	-	3.00
Monocalcium P (21 % P)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Limestone	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DL-methionine	0.06	0.06	0.07	0.07	0.07	0.06	1.05	1.08
L-threonine	0.06	0.06	0.06	0.06	0.06	0.06	0.45	0.45
L-valine	-	-	-	0.27	-	-	-	0.29
L-isoleucine	-	-	-	0.35	-	-	-	0.35
L-leucine	-	-	-	0.60	-	-	-	0.65
L-proline	-	-	2.55	-	-	-	-	2.55
L-glycine	-	-	1.70	-	-	-	-	1.70
Silicon	-	-	-	-	0.75	-	-	0.75
Manganese sulfate	-	-	-	-	-	0.02	-	0.02
Copper sulfate	-	-	-	-	-	0.10	-	0.10

Table 1. (continued)

Calculated analysis								
Total lysine, %	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
True ileal digestible amino acids								
Lysine, %	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Isoleucine:lysine ratio, %	69	69	69	100	69	69	69	100
Leucine:lysine ratio, %	145	145	145	200	145	145	145	200
Methionine:lysine ratio, %	32	32	32	32	32	32	123	124
Met & Cys:lysine ratio, %	60	60	60	60	60	60	151	151
Threonine:lysine ratio, %	65	65	65	65	65	65	100	100
Tryptophan:lysine ratio, %	20	20	20	20	20	20	20	20
Valine:lysine ratio, %	76	76	76	100	76	76	76	100
ME, kcal/lb	1568	1568	1568	1568	1568	1568	1568	1568
CP, %	19.5	19.5	19.3	19.4	19.4	19.5	19.4	19.1
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
P, %	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Available P	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Copper ppm	11	11	11	11	11	250	11	250
Manganese ppm	26.4	26.4	26.4	26.4	26.4	100	26.4	100
Silicon ppm	-	-	-	-	1000	-	-	1000
N-3 fatty acids, %[b]	1.36	13.62	1.46	1.40	1.30	1.36	1.44	13.71
N-6 fatty acids, %[b]	33.38	28.32	34.52	33.88	31.71	33.36	34.96	28.96
N-6:N-3 ratio	24.55	2.08	23.59	24.28	24.37	24.52	24.25	2.11
Unsaturated:saturated ratio	58.4	49.3	59.4	58.6	59.6	58.5	58.1	52.0
Lysine:calorie ratio, g/mcal	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47

[a]Diets fed in meal form from d 0 to 28.
[b]Expressed as a percentage of the total fat in the diet.

Table 2. Diet Composition for Phase 2 (As-fed Basis)[a]

Item	Control	Fish Oil	Proline/ Glycine	BCAA	Silicon	Copper/ Manganese	Methionine/ Threonine	All Ingredients
Ingredient								
Corn	68.61	68.72	65.04	67.61	67.12	68.37	67.66	61.59
Soybean meal (46.5% CP)	24.96	24.95	25.26	25.04	25.09	24.98	25.04	25.56
Choice white grease	3.35	-	3.00	3.30	3.95	3.45	3.00	-
Menhaden fish oil	-	3.25	-	-	-	-	-	3.05
Monocalcium P (21 % P)	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Limestone	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Trace mineral premix	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
L-lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DL-methionine	0.03	0.03	0.04	0.03	0.04	0.03	0.90	0.90
L-threonine	0.05	0.05	0.06	0.05	0.06	0.05	0.40	0.40
L-valine	-	-	-	0.22	-	-	-	0.23
L-isoleucine	-	-	-	0.30	-	-	-	0.30
L-leucine	-	-	-	0.45	-	-	-	0.50
L-proline	-	-	2.15	-	-	-	-	2.15
L-glycine	-	-	1.45	-	-	-	-	1.45
Silicon	-	-	-	-	0.75	-	-	0.75
Manganese sulfate	-	-	-	-	-	0.02	-	0.02
Copper sulfate	-	-	-	-	-	0.10	-	0.10

Table 2. (continued)

Calculated analysis								
Total lysine, %	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
True ileal digestible amino acids								
Lysine, %	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Isoleucine:lysine ratio, %	69	69	69	100	69	69	69	100
Leucine:lysine ratio, %	154	154	154	200	154	154	154	200
Methionine:lysine ratio, %	31	31	31	31	31	31	123	124
Met & Cys:lysine ratio, %	60	60	60	60	60	60	151	151
Threonine:lysine ratio, %	66	66	66	66	66	66	100	100
Tryptophan:lysine ratio, %	19	19	19	19	19	19	19	19
Valine:lysine ratio, %	78	78	78	100	78	78	78	100
ME, kcal/lb	1573	1573	1573	1573	1573	1573	1573	1573
CP, %	17.4	17.4	17.3	17.4	17.4	17.4	17.4	17.1
Ca, %	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
P, %	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Available P	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Copper ppm	11	11	11	11	11	250	11	250
Manganese ppm	26.4	26.4	26.4	26.4	26.4	100	26.4	100
Silicon ppm	-	-	-	-	1000	-	-	1000
N-3 fatty acids, %[b]	1.23	13.26	1.29	1.24	1.17	1.22	1.28	13.42
N-6 fatty acids, %[b]	34.28	28.92	35.04	34.32	32.24	33.92	35.39	29.43
N-6:N-3 ratio	27.96	2.18	27.13	27.74	27.67	27.91	27.73	2.19
Unsaturated:saturated ratio	53.4	45.0	53.9	53.6	55.0	53.7	53.0	46.9
Lysine:calorie ratio, g/mcal	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03

[a]Diets fed in meal form from d 28 to 56.
[b]Expressed as a percentage of the total fat in the diet.

Table 3. Diet Composition for Phase 3 (As-fed Basis)[a]

Item	Control	Fish Oil	Proline/ Glycine	BCAA	Silicon	Copper/ Manganese	Methionine/ Threonine	All Ingredients
Ingredient								
Corn	74.03	74.19	71.07	73.30	72.60	73.79	73.23	68.01
Soybean meal (46.5% CP)	19.52	19.51	19.78	19.59	19.65	19.55	19.59	20.04
Choice white grease	3.30	-	3.00	3.25	3.85	3.40	3.00	-
Menhaden fish oil	-	3.15	-	-	-	-	-	3.10
Monocalcium P (21 % P)	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Limestone	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Trace mineral premix	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
L-lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DL-methionine	-	-	0.01	-	-	-	0.75	0.75
L-threonine	0.05	0.05	0.05	0.05	0.05	0.05	0.33	0.33
L-valine	-	-	-	0.17	-	-	-	0.18
L-isoleucine	-	-	-	0.25	-	-	-	0.25
L-leucine	-	-	-	0.30	-	-	-	0.35
L-proline	-	-	1.75	-	-	-	-	1.78
L-glycine	-	-	1.25	-	-	-	-	1.25
Silicon	-	-	-	-	0.75	-	-	0.75
Manganese sulfate	-	-	-	-	-	0.02	-	0.02
Copper sulfate	-	-	-	-	-	0.10	-	0.10

Table 3. (continued)

Calculated analysis								
Total lysine, %	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
True ileal digestible amino acids								
Lysine, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Isoleucine:lysine ratio, %	70	70	70	100	70	70	70	100
Leucine:lysine ratio, %	164	164	164	200	164	164	164	200
Methionine:lysine ratio, %	29	29	29	29	29	29	123	124
Met & Cys:lysine ratio, %	60	60	60	60	60	60	151	151
Threonine:lysine ratio, %	67	67	67	67	67	67	100	100
Tryptophan:lysine ratio, %	19	19	19	19	19	19	19	19
Valine:lysine ratio, %	80	80	80	100	80	80	80	100
ME, kcal/lb	1571	1571	1571	1571	1571	1571	1571	1571
CP, %	15.4	15.4	15.2	15.3	15.3	15.4	15.3	15.1
Ca, %	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
P, %	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Available P	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Copper ppm	11	11	11	11	11	250	11	250
Manganese ppm	26.4	26.4	26.4	26.4	26.4	100	26.4	100
Silicon ppm	-	-	-	-	1000	-	-	1000
N-3 fatty acids, %[b]	1.08	12.83	1.13	1.09	1.04	1.07	1.12	13.18
N-6 fatty acids, %[b]	34.79	29.66	35.48	34.87	32.86	34.42	35.76	29.77
N-6:N-3 ratio	32.17	2.31	31.47	31.99	31.73	32.09	32.02	2.26
Unsaturated:saturated ratio	49.0	41.1	49.1	49.1	50.8	49.3	48.4	42.5
Lysine:calorie ratio, g/mcal	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60

[a]Diets fed in meal form from d 56 to 84.
[b]Expressed as a percentage of the total fat in the diet.

Table 4. Effect of Different Nutrients on Growth Performance[ab]

	Control	Fish Oil	Proline/ Glycine	BCAA	Silicon	Cu/Mn	Meth/Thr	All Ingredients	SE	Probability, P <
d 0 to 28										
ADG, lb	2.41^{def}	2.29^{cde}	2.25^{cde}	2.48^{f}	2.42^{ef}	2.50^{f}	2.23^{cd}	2.21^{c}	0.089	0.01
ADFI, lb	5.00	4.96	4.87	5.05	4.93	4.94	4.87	4.72	0.215	0.89
F/G	2.08^{cd}	2.17^{c}	2.17^{c}	2.04^{cd}	2.04^{cd}	1.98^{d}	2.18^{c}	2.15^{c}	0.077	0.08
d 0 to 56										
ADG, lb	2.38^{de}	2.27^{cd}	2.26^{cd}	2.47^{e}	2.39^{de}	2.39^{de}	2.17^{c}	2.19^{c}	0.080	0.01
ADFI, lb	5.57^{d}	5.23^{cd}	5.32^{cd}	5.64^{d}	5.54^{d}	5.21^{c}	5.16^{c}	5.02^{c}	0.212	0.05
F/G	2.34^{c}	2.31^{cd}	2.36^{c}	2.28^{cd}	2.32^{cd}	2.19^{d}	2.38^{c}	2.30^{cd}	0.075	0.31
d 0 to 84										
ADG, lb	2.40^{cd}	2.34^{cd}	2.37^{cd}	2.48^{d}	2.44^{cd}	2.48^{d}	2.28^{c}	2.28^{c}	0.104	0.21
ADFI, lb	6.13^{d}	5.85^{cd}	5.97^{cd}	6.17^{d}	6.16^{d}	6.04^{cd}	5.82^{cd}	5.68^{c}	0.248	0.26
F/G	2.56	2.50	2.52	2.50	2.53	2.45	2.55	2.50	0.087	0.91

[a]Treatments with different superscripts [c,d,e,f] differ by P<0.05.

[b]Each value is the mean of 9 or 10 replications with pigs initially 86 lb and an average final weight of 290 lb.

Table 5. Effect of Different Nutrients on Carcass Composition[ab]

	Control	Fish Oil	Proline/ Glycine	BCAA	Silicon	Cu/Mn	Meth/ Thr	All Ingredients	SE	Probability, P <
Initial backfat, in	0.22	0.21	0.20	0.22	0.20	0.20	0.21	0.20	0.016	0.83
Initial LEA, in	1.42	1.52	1.53	1.41	1.47	1.46	1.43	1.45	0.092	0.86
Hot carcass weight[c]	209.6	205.8	205.0	209.1	212.7	206.8	201.3	197.1		
Final backfat, in	0.631	0.615	0.593	0.563	0.555	0.609	0.632	0.627	0.061	0.84
Final LEA, in	7.55[de]	7.92[ef]	7.46[de]	7.52[de]	7.49[de]	7.58[de]	8.27[f]	7.28[d]	0.327	0.05
Lean, %	55.47	55.69	55.29	55.74	55.75	55.48	56.14	54.51	1.088	0.90
Fat-free lean gain/ day, lb	0.936	0.953	0.949	0.955	0.957	0.948	0.960	0.926	0.025	0.88

[a]Treatments with different superscripts [d,e, f] differ by $P < 0.05$.

[b]Each value is the mean of 9 or 10 replications with pigs initially 86 lb and an average final weight of 290 lb.

[c]Hot carcass weight was used as a covariate in analysis.

Table 6. Effect of Different Nutrients on Cartilage Parameters[ab]

	Control	Fish Oil	Proline/ Glycine	BCAA	Silicon	Cu/Mn	Meth/Thr	All Ingredients	SE	Probability, P <
Cartilage weight, g[c]	1.07	1.26	1.08	1.22	1.24	1.10	1.16	1.26	0.138	0.72
Cartilage thickness, cm[d]	0.38	0.37	0.36	0.38	0.36	0.33	0.36	0.39	0.042	0.90
Cartilage length, cm[e]	3.19	3.37	3.22	3.25	3.28	3.21	3.30	3.32	0.109	0.71
Compression force, n/g[f]	-326.4	-520.5	-548.6	-500.5	-389.3	-390.0	-512.5	-424.8	148.5	0.87
Shear force, n/g[g]	-418.9	-370.4	-375.9	-488.3	-427.5	-476.4	-401.3	-411.0	59.8	0.31
No. of pigs with lesions[h]	5[k]	9[l]	8[kl]	5[k]	9[l]	5[k]	6[kl]	5[k]		0.14
No.of abnormalities/pig[i]	1.4[k]	2.4[l]	2.0[kl]	1.3[k]	2.4[l]	1.7[kl]	1.3[k]	1.4[k]	0.54	0.17
Average severity score[j]	1.7[mn]	2.5[n]	1.9[mn]	1.5[m]	2.5[n]	1.8[mn]	1.4[m]	1.4[m]	0.48	0.10

[a]Treatments with different superscripts [k,l] differ by P < 0.07 and [m,n] differ by P < 0.05.

[b]Each value is the mean of 9 or 10 replications with pigs initially 86 lb.

[c]Weight of the cartilage sample taken from the chondyle on the end of the femur.

[d]The thickness of the cartilage sample measured as it would sit perpendicular to the joint surface.

[e]The length of the cartilage sample measured as it would sit parallel with the joint surface.

[f]Amount of energy, in newtons per gram of cartilage, to compress the cartilage half its thickness.

[g]Amount of energy, in newtons per gram of cartilage, to shear the cartilage into two pieces.

[h]Number of pigs per treatment with potential lesions, by visual inspection of cartilage surface.

[i]The average number of abnormalities per pig, by visual inspection of the cartilage surface.

[j]Assigned a score of 0 to 3, where 0 = no damage and 3 = abnormalities that are severe.