THE EFFECT OF DIETARY NUTRIENTS ON OSTEOCHONDROSIS LESIONS AND CARTILAGE PROPERTIES IN PIGS[1]

N. Z. Frantz, J. L. Nelssen, G. A. Andrews[2], M. D. Tokach,
R. D. Goodband, J. M. DeRouchey, and S. S. Dritz[3]

Summary

A total of 80 gilts (PIC 327 × 1050; 86 lb initial BW) were used in an 84-d study to determine the effect of different nutrients on the occurrence of osteochondrosis (OC) lesions, several cartilage criteria, growth performance, and carcass composition. Eight dietary treatments were formulated, consisting of 1) control (standard corn-soy diet, 3.5% choice white grease (CWG)) or the control diet plus 2) fish oil (3.5%) replaced CWG, 3) proline and glycine (Pro/Gly; 300 and 200% of lysine), 4) leucine, isoleucine, and valine (BCAA; 200, 100, and 100% of lysine, respectively), 5) silicon (1,000 ppm), 6) copper and manganese (Cu/Mn; 250 ppm and 100 ppm, respectively), 7) methionine and threonine (Met/Thr; 150 and 100% of lysine), and 8) combination of ingredients in diets 2 through 7. 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 (CWG) content, and were fed in three phases (1.07, 0.94, and 0.80% TID Lys). Upon completion of the feeding period, pigs were harvested, and the distal aspect of the left femur was evaluated by gross examination for OC lesions. The external surface was evaluated for abnormalities and given a severity score. Then each femur was sliced into 3-mm sections, and lesions were assigned a severity score for the underlying articular cartilage, and physeal growth plate. Overall (d 0 to 84), growth performance was unaffected by dietary treatment ($P>0.21$). Pigs fed diets containing fish oil or silicon tended ($P<0.07$) to have a higher severity score for external abnormalities (or defects in cartilage surface), compared with pigs fed the other dietary treatments, with pigs fed the control diet, Pro/Gly, or Cu/Mn intermediate. Pigs fed high Met/Thr, Cu/Mn, or silicon tended ($P<0.08$) to have lower articular cartilage severity scores than scores of pigs fed the control diet or BCAA, with the other dietary treatments intermediate. The occurrence of OC lesions at the growth plate, total faces with lesions, and total number of abnormalities were not affected by dietary treatment ($P>0.23$); there was a trend ($P<0.14$) for pigs fed diets containing high Met/Thr or fed the combination diet to have lower total severity scores than scores of pigs fed the control diet or fish oil, with the other treatments intermediate. Pigs fed additional Cu/Mn, Met/Thr, or the diet containing all additional ingredients had lower overall severity scores ($P<0.03$) than did pigs fed the control diet or fish oil. Cartilage compression or shear force were un-

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affected by dietary treatment (P>0.19), but pigs fed fish oil had a higher ratio for compression:shear energy (P<0.03), compared with the ratio for those fed the control diet, Cu/Mn, or silicon; the other treatments were intermediate. In summary, feeding pigs a diet containing additional silicon, Cu/Mn, Met/Thr, or a combination of these ingredients may offer the potential to reduce the incidence of osteochondrosis in gilts; more research will be required to verify these results.

(Key Words: Cartilage, Finishing Pigs, Osteochondrosis.)

Introduction

Osteochondrosis (OC) remains a common problem among growing swine; it occurs in approximately 85 to 90% of all pigs. Osteochondrosis 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, the growth plate of the distal ulna, and the costochondral junction. It can cause reduced reproductive performance and increased culling rates in sows due to lameness, and can decrease performance and meat yield of finishing pigs. The direct cause of OC is relatively unknown, but several studies have tried to determine how handling, genetics, or nutrition may play a role in its development. It previously has been thought that rapid growth rate or 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 were the major causes of OC in growing pigs. The reduced blood supply results in 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 prevent the cartilage around it from properly maturing and growing at the appropriate rate. This damage to the articular carti-

lage surface results in pain and stiffness associated with the common lameness and decreased mobility seen in many pigs.

Therefore, the objective of these experiments was to screen dietary ingredients involved in cartilage and bone metabolism for their influence on OC lesion occurrence and severity, other cartilage criteria, growth performance, and carcass characteristics in growing-finishing pigs.

Procedures

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 $\times$ 1050; 86 lb initial BW) were blocked by weight in an 84-d growth assay. The experiment was conducted at the Kansas State University Swine Research and Teaching Center. Each pen contained one pig, for a total of 10 replicates (pigs) per treatment. The barn contains 80 pens with totally slatted concrete flooring (5 $\times$ 5 ft), providing approximately 25 sq ft/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.

Gilts were randomly allotted to one of 8 dietary treatments. Dietary treatments consisted of 1) control (standard corn-soy diet 3.5% choice white grease (CWG)) or the control diet plus 2) fish oil (3.5% replaced CWG), 3) proline and glycine (Pro/Gly; 300 and 200% of lysine, respectively), 4) leucine, isoleucine, and valine (BCAA; 200, 100, and 100% of lysine, respectively), 5) silicon (1,000 ppm), 6) copper and manganese (Cu/Mn; 250 ppm and 100 ppm, respectively), 7) methionine and threonine (Met/Thr; 150 and 100% of lysine, respectively), and 8) combination of ingredients in diets 2 through 7 (Tables 1 and 2). The control diet contained amino acidsPro (100% of lysine), Gly (65% of lysine), leucine (145% of lysine), isoleucine (69% of lysine), valine (76% of lysine), Met

(30% of lysine), and Thr (67% of lysine), with added amounts of Cu (16.5 and 14 mg/kg in Phase 1 and Phase 2 or 3, respectively), Mn (40 and 33 mg/kg in Phase 1 and Phase 2 or 3, respectively), and Si (0 mg/kg). 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). Minimum true ileal digestible (TID) amino acid ratios, relative to lysine (Lys), were maintained in all diets, with minimum ratios set at 30% for methionine, 60% for methionine and cystine, 65% for threonine, and 16.5% for tryptophan. The Phase 1 diets were formulated to contain 1.07% TID Lys and 1,568 kcal of metabolizable energy (ME, Table 1), the Phase 2 diets contained 0.94% TID Lys and 1,573 kcal of ME, and Phase 3 diets contained 0.80% TID Lys and 1,570 kcal of ME. In each phase, all essential amino acids other than those used in dietary treatments were provided at approximately 10% above the requirement for pigs in these weight ranges, and added fat concentration differed slightly to maintain isocaloric diets. Other essential nutrients were supplied at, or above, NRC estimates. Diet samples were analyzed for amino acid concentration, and contained concentrations similar to formulated amounts.

Pigs and feeders were weighed every 14 d to determine ADG, ADFI, and F/G. At the start of the trial, all gilts were ultrasound scanned to determine initial backfat depth and to estimate fat-free lean. 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 OC 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, 2.3 in off of the midline,

whereas longissimus muscle area was traced on translucent paper and calculated by using a grid. Percentage lean and fat-free-lean index were calculated according to NPPC (1994) procedures.

The left femur was collected and removed to visually determine the number of cartilage abnormalities (indentations or creasing of cartilage surface) and the occurrence of OC lesions by gross examination of the femoral condyle. The joints were cleaned of excess tissue and then stored in 10% formalin until evaluation. After external evaluation, the distal end of the femur was sliced into 3-mm sections by cutting perpendicular to the long axis of the bone with a bandsaw. This resulted in 12 faces (cut surfaces) for evaluation of lesions. Each joint was evaluated for the number of external abnormalities, OC lesions at the articular cartilage, and growth plate cartilage, and lesions were given a severity score (0 to 4) for all three locations, where 0 = normal, 1 = mild, 2 = moderate, 3 = severe, and 4 = OC dissecans, based on the extent of tissue involvement. Each joint was also categorized as "Yes" or "No" for the presence or absence of osteochondrosis lesions.

In addition, a cartilage sample was cut from the patella for cartilage property analysis. Cartilage samples were weighed, measured for thickness and length with a caliper, and then tested for the ability to absorb compression or to resist shearing by using an Instron machine (Model 4201 was used to determine cartilage properties). Each cartilage sample was placed between two flat surfaces of the Instron to perform texture profile analysis and compressed half of its thickness to measure the ability of the cartilage to resist compression force. A second measure was conducted in which the cartilage was cut by using a Warner-Bratzler shear blade, to determine the ability of the cartilage to withstand shearing force. Compression values and shear values were adjusted to cartilage weight/g to

equalize for differences in the actual cartilage weight.

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, and number of abnormalities were tested. Although scored categorically, severity of abnormalities scores for the external surface, articular cartilage, and growth plate cartilage were done via PROC MIXED because the small number of observations at some of the severity scores prevented categorical analysis. An overall score using the number of abnormalities at each location, multiplied by the severity at each location and then summed, was created to provide an overall severity score or indication of joint status. A 'Yes' or 'No' rating of the presence of OC lesions was compared by using the Cochran-Mantzel-Haenszel test statistic for row mean scores in PROC FREQ. To evaluate the effect of amino acids or added minerals, relative to the other dietary treatments, single-degree-of-freedom contrasts were constructed.

Results and Discussion

Overall (d 0 to 84), growth performance was unaffected by dietary treatment (P>0.21, Table 3), but pigs fed high Met/Thr tended (P<0.10) to have increased longissimus muscle area, compared with pigs in the other dietary treatments, whereas pigs fed fish oil were intermediate; no other carcass differences were observed (P>0.84). This response is similar to previous trials in which excess methionine has increased lean muscle deposition.

For the joint evaluation data, the number of animals with OC was not affected by dietary treatment (P>0.52). Pigs fed diets containing fish oil or silicon tended (P<0.07, Table 5) to have a higher severity score for external abnormalities, compared with pigs in the other dietary treatments; scores of pigs fed the control diet, Pro/Gly, or Cu/Mn were intermediate, but the prevalence of external abnormalities and severity scores were not different from controls. Pigs fed high Met/Thr, Cu/Mn, or silicon tended (P<0.08) to have lower articular cartilage lesion severity scores than those of pigs fed the control diet or BCAA, with the other dietary treatments intermediate. The distribution of severity scores are shown for the three treatments that tended to reduce articular cartilage lesion severity, compared with the control (Chart 1). The occurrence of OC lesions at the growth plate, total faces with lesions, or total number of abnormalities were not affected by dietary treatment (P>0.23); there was a numerical trend (P<0.14) for pigs fed diets containing high Met/Thr or the combination diet containing all ingredients to have lower total severity scores than those of pigs fed the control diet or fish oil, with the other treatments intermediate. Finally, pigs fed additional Cu/Mn, Met/Thr, or the diet containing all additional ingredients, had lower overall severity scores (P<0.03), compared with scores of pigs fed the control diet or fish oil. An intermediate response to additional Pro/Gly and silicon was also observed, compared with the control diet or fish oil. Pigs fed the diets containing additional amino acids had lower external and total severity scores (P<0.05) than did pigs fed the other dietary treatments, but pigs fed diets containing minerals (silicon or copper and manganese) tended (P<0.08) to have lower articular cartilage severity scores and had lower overall severity scores (P<0.02).

Cartilage compression or shear force were unaffected by dietary treatment (P>0.19, Table 6), but pigs fed fish oil had a higher ratio for compression:shear energy (P<0.03), compared with those fed the control diet, Cu/Mn, or silicon; the other treatments were intermediate. This suggests that fish oil stiffened the cartilage or has less ability to absorb impact force and less ability to resist shear forces. This may have been due to the ability of n-3

fatty acids to inhibit matrix metalloproteinases that degrade collagen. In doing so, the normal turnover of cartilage may have been inhibited, resulting in collagen with decreased ability to function in absorbing energy or resist breaking apart.

In summary, feeding pigs high Met/Thr not only increased loin eye area, but tended to reduce the total severity score, compared with the control diet. In addition, feeding pigs diets containing high Met/Thr, silicon, or Cu/Mn may reduce the severity of OC lesions at the articular cartilage (Chart 1). Although there is no requirement established for silicon in pigs, it may be essential for proper bone and cartilage strength due to its role in chondroitin sulfate metabolism and collagen formation. Copper also is required for the enzyme lysyl oxidase that helps form crosslinks in cartilage between collagen molecules, and may help stabilize the cartilage matrix from degradation or provide vascular stability to blood vessel walls. Finally, Met/Thr have indirect effects on cartilage metabolism. Methionine is thought to drive cartilage synthesis and also donate sulfur for the process of proteoglycan formation. Threonine can be converted to glycine, which is part of the collagen, and is also incorporated into collagen in small quantities itself. Feeding ingredients such as Met/Thr, Cu/Mn, silicon, or a combination of these ingredients that are involved in cartilage and bone metabolism may help reduce the incidence of OC by either positively influencing cartilage/bone metabolism or by preventing excess cartilage degradation, but this evidence only provides initial information and more research will be required to verify the results found in this study.

Table 1. Diet Composition (As-fed Basis)[ab]

Item	Phase 1	Phase 2	Phase 3
Ingredient			
Corn	62.65	68.60	74.05
Soybean meal (46.5% CP)	30.45	24.95	19.50
Choice white grease[c]	3.50	3.50	3.50
Monocalcium phosphate (21 % P)	1.50	1.25	1.25
Limestone	1.05	1.00	1.00
Salt	0.35	0.35	0.35
Vitamin premix	0.15	0.13	0.13
Trace mineral premix	0.15	0.13	0.13
L-lysine HCl	0.15	0.15	0.15
DL-methionine	0.06	0.03	-
L-threonine	0.06	0.05	0.05
Total	100.00	100.00	100.00
Calculated Analysis			
Total lysine, %	1.20	1.05	0.90
True ileal digestible amino acids			
Lysine, %	1.07	0.94	0.80
Isoleucine:lysine ratio, %	69	69	70
Leucine:lysine ratio, %	145	154	164
Methionine:lysine ratio, %	32	31	29
Met & Cys:lysine ratio, %	60	60	60
Threonine:lysine ratio, %	65	66	68
Tryptophan:lysine ratio, %	20	19	19
Valine:lysine ratio, %	76	78	80
ME, kcal/lb	1568	1573	1570
CP, %	19.5	17.4	15.4
Ca, %	0.80	0.72	0.72
P, %	0.70	0.62	0.62
Lysine:calorie ratio, g/mcal	3.47	3.03	2.60

[a]Diets fed in meal form in three 28-d phases.
[b]Dietary treatments were created by substituting ingredients for corn, except that fish oil replaced CWG.
[c]Amount of CWG varied slightly in the diet so that diets were isocaloric in each phase.

Table 2. Dietary Treatments[a]

Treatment	
Control[b]	Standard corn-soybean meal diet with 3.5% choice white grease.
Fish oil	3.5% fish oil replaced choice white grease, resulting in a n-6 to n-3 ratio of 2:1.
Pro/Gly	L-proline at 2.55% and L-glycine at 1.70% were added to create a ratio of proline:lysine of 300% and a glycine:lysine ratio of 200%.
BCAA	L-leucine was added at 0.60%, L-isoleucine at 0.35%, and L-valine at 0.29% to create a leucine:lysine ratio of 200%, isoleucine:lysine ratio of 100%, and valine:lysine ratio of 100%.
Silicon	Silicon was added at 0.80% (Zeolite A) to create the silicon diet (1,000 ppm).
Cu/Mn	Copper was added at 0.1% (250 ppm) and manganese was added at 0.02% (100 ppm).
Met/Thr	DL-methionine was added at 1.05% to create a methionine:lysine ratio of 150% and L-threonine was added at 0.45% to create a threonine:lysine ratio of 100%.
All ingredients	Contained all additional dietary ingredients at the expense of corn and choice white grease.

[a]All dietary treatments were fed in meal form and maintained throughout the three 28-d feeding phases.
[b]The control diet contained amino acid levels of Pro (100% of lysine), Gly (65% of lysine), leucine (145% of lysine), isoleucine (69% of lysine), valine (76% of lysine), Met (30% of lysine), and Thr (67% of lysine), with mineral levels of Cu (16.5 and 14 mg/kg in Phase 1 and Phase 2 or 3, respectively), Mn (40 and 33 mg/kg in Phase 1 and Phase 2 or 3, respectively), and Si (0 mg/kg).

Table 3. Effect of Different Nutrients on Growth Performance and Carcass Composition[a]

Item	Control	Fish Oil	Pro/Gly	BCAA	Silicon	Cu/Mn	Met/Thr	All Ingredients[b]	SED	Probability, P < Treatment
Growth, d 0 to 84[c]										
ADG, lb	2.40	2.34	2.37	2.48	2.44	2.48	2.28	2.28	0.104	0.21
ADFI, lb	6.13	5.85	5.97	6.17	6.16	6.04	5.82	5.68	0.248	0.26
Feed/Gain	2.56	2.50	2.52	2.50	2.53	2.45	2.55	2.50	0.087	0.91
Carcass data										
Initial backfat, in	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.02	0.83
HCW, lb[d]	209.6	205.8	205.0	209.1	212.7	206.8	201.3	197.1	-	0.43
Final backfat, in	0.63	0.62	0.59	0.56	0.56	0.61	0.63	0.63	0.06	0.84
Final LEA, in	7.55[f]	7.92[fg]	7.46[f]	7.52[f]	7.49[f]	7.58[f]	8.27[g]	7.28[f]	0.327	0.10
Fat-free lean index	55.4	55.7	55.3	55.7	55.8	55.5	56.1	54.5	1.09	0.90
Fat-free lean gain, lbs/day[e]	0.936	0.953	0.949	0.955	0.957	0.948	0.960	0.926	0.025	0.88

[a]Each value is the mean of 9 or 10 replications, with pigs initially 86 lbs, and average final weight of 290 lbs.
[b]Diet contained all treatment ingredients combined into one diet.
[c]Pigs were fed diets in meal form in three 28-d phases.
[d]Hot carcass weight was used as a covariate in analysis, except for fat-free-lean gain.
[e]Calculated as the final fat-free lean minus initial fat-free lean, divided by days on feed.
[f,g]Treatments with different superscripts differ P<0.05.

Table 4. Effect of Different Nutrients on Cartilage Parameters[a]

	Treatment									Probability, P <
	Control	Fish Oil	Pro/Gly	BCAA	Silicon	Cu/Mn	Met/Thr	All[b]	SED	Treatment
Cartilage measures										
Cartilage weight, g[c]	1.07	1.26	1.08	1.22	1.24	1.10	1.16	1.26	0.138	0.65
Cartilage thickness, cm[d]	0.38	0.37	0.36	0.38	0.36	0.33	0.36	0.39	0.042	0.96
Cartilage length, cm[e]	3.19	3.37	3.22	3.25	3.28	3.21	3.30	3.32	0.109	0.71
Instron measures										
Compression energy, n/g[f]	85.4	126.9	144.7	102.5	86.0	59.8	116.4	110.7	39.22	0.59
Shear energy, n/g[g]	516.9	378.7	437.9	505.2	523.1	565.8	505.4	561.6	74.03	0.19
Total energy, n/g[2h]	1271.4	1226.8	976.5	1303.3	1342.3	1401.9	1326.9	1539.6	291.54	0.73
Ratio of CE/SE[i]	0.15[k]	0.41[j]	0.31[jk]	0.25[jk]	0.17[k]	0.15[k]	0.25[jk]	0.21	0.081	0.03

[a]Each value is the mean of 9 or 10 replications, with pigs initially 86 lb, and a final weight of 290 lbs.
[b]Diet contained all dietary ingredients added into one diet
[c]Weight of the cartilage sample taken from the patella.
[d]The thickness of the cartilage sample.
[e]The length of the cartilage sample.
[f]Amount of energy in newtons per gram of cartilage to compress the cartilage half its thickness.
[g]Amount of initial energy in newtons per gram of cartilage to shear the cartilage into two pieces.
[h]The total amount of energy required to shear the cartilage into two pieces.
[i]The ratio of compression force or energy to shear force or energy, in which smaller values would indicate more desirable characteristics.
[j,k]Treatments with different superscripts differ by P<0.05.

Table 5. Effect of Different Nutrients on the Occurrence of Osteochondrosis[a]

| | | | | Treatment | | | | | | | Probability, P < | | |
| | | | | | | | | | | | | Contrasts | |
Item	Control	Fish Oil	Pro/Gly	BCAA	Silicon	Cu/Mn	Meth/Thr	All[b]	SED	Treatment	Minerals vs AAs	Minerals vs others	AAs vs others
Total animals/trt[c]	10	10	10	10	10	9	10	10	-	-	-	-	-
Animals with lesions[d]	9	9	9	9	6	7	7	7	1.5	0.52	-	-	-
External													
Abnormalities[e]	1.9^{op}	2.6^{o}	2.0^{op}	1.4^{p}	2.5^{o}	1.8^{op}	1.3^{p}	1.4^{p}	0.56	0.13	0.31	0.86	0.02
Severity score[f]	2.1^{op}	2.5^{o}	1.9^{op}	1.4^{p}	2.4^{o}	1.8^{op}	1.3^{p}	1.4^{p}	0.48	0.07	0.24	0.94	0.01
Articular cartilage													
Number of faces[g]	5.0^{o}	4.5^{op}	2.4^{op}	5.0^{o}	2.2^{q}	2.3^{op}	2.6^{op}	4.1^{op}	1.44	0.16	0.57	0.19	0.87
Severity score[h]	2.0^{o}	1.3^{opq}	1.2^{opq}	1.6^{op}	0.7^{q}	0.8^{pq}	0.7^{q}	1.3^{opq}	0.48	0.08	0.38	0.08	0.98
Growth plate													
Number of faces[i]	0.9	1.7	1.2	0.6	1.2	1.6	1.8	0.2	0.68	0.23	0.58	0.47	0.25
Severity score[j]	0.6	1.1	0.9	0.6	0.8	0.8	1.0	0.1	0.43	0.38	0.27	0.21	0.43
Overall													
Total faces[k]	5.9	6.2	3.6	5.6	3.4	3.9	4.4	4.3	1.81	0.63	0.52	0.17	0.68
Total abnormalities[l]	8.7	8.8	5.6	7.0	5.9	5.7	5.7	5.7	1.89	0.54	0.75	0.21	0.27
Total severity[m]	4.7^{o}	4.9^{o}	4.0^{op}	3.6^{op}	3.9^{op}	3.3^{op}	3.0^{p}	2.8^{p}	0.85	0.14	0.70	0.12	0.05
Overall score[n]	17.1^{o}	15.0^{op}	8.8^{pq}	12.4^{opq}	8.4^{pq}	6.4^{q}	6.6^{q}	7.0^{q}	3.76	0.03	0.36	0.02	0.11
Final weight	294.6	282.3	291.4	293.4	298.8	287.3	284.2	285.4	10.23	0.70	0.89	0.81	0.68

[a]Each value is the mean of 9 or 10 replications, with one pig per pen, initially 86 lb. [b]Diet contained all dietary ingredients added into one diet. [c]Total animals evaluated per treatment. [d]The number of animals with OCD lesions (Cochran-Mantzel-Haenszel test). [e]Number of abnormalities noted upon visual evaluation of the intact joint. [f]Severity score (0-4 with 0 normal, 1 mild, 2 moderate, 3 severe, and 4 OC dissecans) of abnormalities by visual evaluation of the external joint. [g]The number of faces showing lesions from cutting the condyle into 3mm slices per animal. [h]Severity score (0-4 with 0 normal, 1 mild, 2 moderate, 3 severe, and 4 OC dissecans) for the articular cartilage faces. [i]The number of faces showing lesions in the growth plate per animal. [j]Severity score (0-4 with 0 normal, 1 mild, 2 moderate, 3 severe, and 4 OC dissecans) for the faces in the growth plate. [k]Total faces showing lesions at the articular cartilage and growth plate, evaluating 12 cut surfaces. [l]Sum of external abnormalities, articular faces, and growth plate faces. [m]Sum of severity scores for external abnormalities, articular cartilage, and growth plate faces. [n]Calculated as the number of abnormalities multiplied by the severity for each location, and then summed. [o,p,q]Treatments with different superscripts differ (P<0.05).
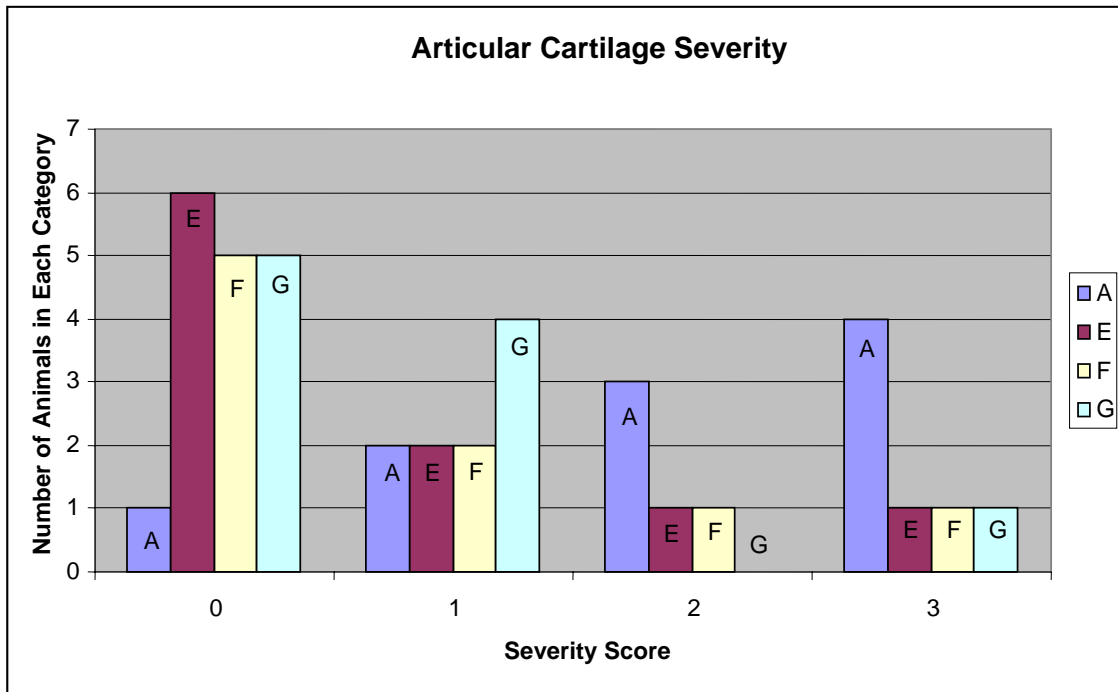
Chart 1. Distribution of Articular Cartilage Severity Scores for Treatments Silicon, Cu/Mn, and Methionine/threonine, Compared with Controls. A = control, E = silicon, F = Cu/Mn, and G = methionine/threonine (Only nine pigs fed Cu/Mn finished the experiment.)