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OSTEOCHONDROSIS AND ARTHROSIS IN PIGS

VI. RELATIONSHIP TO FEED LEVEL AND CALCIUM, PHOSPHORUS AND PROTEIN LEVELS IN THE RATION

By

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GRØNDALEN, TRYGVE: *Osteochondrosis and arthrosis in pigs. VI. Relationship to feed level and calcium, phosphorus and protein levels in the ration.* Acta vet. scand. 1974, *15*, 147—169. — Eight feeding experiments, each comprising 48 boars or gilts, were carried out. The factors feed level, Ca, P and protein levels were varied within practical physiological limits. The animals were slaughtered at close to 100 kg live weight. Lesions in joints and bones were of a non-infectious, non-rachitic nature and of the osteochondrosis and arthrosis type. Ten to 12 g Ca and approx. 10 g P/kg ration gave histomorphologically seemingly more optimum structure of the spongious bone tissue and a higher ash percentage in bones than 7 g Ca and 6 g P, or unbalanced mineral levels in the ration. However, there was no significant difference in degree or incidence of joint and bone lesions between mineral groups. Neither were there such differences present between feed level groups or protein level groups. This may for the feed level groups be partly due to the low feed level pigs having a longer period of time during which they were highly susceptible to the development of lesions. The low feed level animals had longer long bones at 100 kg live weight than the high feed level animals. The length of the vertebral column was, however, approximately similar in the 2 feed level groups. The angles of the condyles and head of the femur according to the length axis were influenced by feed level or growth rate, most probably by an effect on the endochondral ossification.

osteochondrosis; arthrosis; nutrition; pig.

Somewhat differing views are held as to the effect of supplying minerals at a level higher than the given norms on the occurrence of joint and bone lesions in pigs without rickets. *Krook* (1965) and *Brown et al.* (1966) demonstrated joint lesions in pigs fed relatively low levels of calcium or high levels of phosphorus and considered that the animals were in a state of nutritional hyperparathyroidism with generalized osteodystrophia as the result. *Walker et al.* (1966) described experiments in which no variation in the extent of joint and bone lesions were found when the levels of Ca, P, Mn or Cu were varied within wide limits. Moreover, vitamin C and vitamin A status seemed to be normal in affected pigs. According to *Reiland et al.* (1972) no differences in the occurrence of joint lesions were demonstrated with variations in the amount of Ca, and Ca:P ratio in the feed. *Kurzweg & Winkler* (1972) assert, after describing experiments, that locomotory disturbances in pigs occur independent of the feeding levels of Ca, P, Mg, Cu, Zn and Mn and of the degree of mineralization of the skeleton. *Nielsen et al.* (1971) demonstrated that the Ca and P content of the feed within wide limits did not have any essential influence on the occurrence of leg weakness and arthrosis. However, 1.2 % Ca and 1 % P in the feed gave histo-morphologically better bone tissue development and seemed to a certain extent to lower the degree of joint lesions and leg weakness. *Hanssen & Breirem* (1971) concluded as the result of literature studies that variations within the range 0.5—1.0 % Ca and 0.4—0.9 % P, assuming a Ca:P ratio of approx. 1.2:1 and an adequate supply of vitamin D, did not have any marked effect and were without significance for slaughter pigs.

According to *Thurley* (1965) rapid growth rate in pigs is most important in the aetiology of joint lesions. Preliminary results obtained by *Ljunggren & Reiland* (1970) indicated that there is a positive correlation between rapid growth and the incidence of joint lesions. *Grøndalen & Vangen* (1974) demonstrated a higher incidence and degree of joint lesions in animals with a genetically determined rapid growth as compared with genetically determined slow growing animals in the same environment.

As part of a broad cooperative project 8 feeding experiments involving pigs were carried out during the period 1969 to 1973, mainly in order to throw light on the influence of certain nutritional factors on skeleton quality and mobility. Several institutions took part. The project was led by the Department of Animal Nutrition, Agricultural University of Norway. The Department of Pathology, Veterinary College of Norway, was responsible for the clinical examinations as regards mobility, and the post-mortem examinations of joints and bones. The influence of the investigated nutritional factors on the occurrence of osteochondrosis and arthrosis in pigs, and their effect on the shape of the bones are described in this article.

MATERIALS AND METHODS

Of the 8 experiments carried out, 4 involved boars and 4 gilts. In each experiment there were 8 different litters with 6 pigs in each litter, giving a total of 48 animals. The pigs were divided into 2 main groups, each comprising 3 subgroups (2 × 3 factorial experiment) such that there were 6 groups of 8 pigs in each experiment. These groups were made up by placing 1 pig from each litter in each group. The factors investigated in the different experiments are shown in Table 1.

Modern type of Norwegian Landrace pigs, recruited from efficient breeding establishments, were used. They were put on trial at 20—25 kg live weight. With the exception of SV 75 and

T a b l e 1. Feeding factors which varied in the experiments.

Experiment	Sex	Feeding factors varied and outer values according to the recept in the two main groups: factors varied	two main groups: outer values	three subgroups: factors varied	three subgroups: outer values
SV 64	♂	Ca content, Ca:P ratio	7—12 g Ca and 6 g P/kg ration ratio 1.2:1 or 2:1	digestible crude protein	10—17 %
SV 68	♀	»	» »	»	10—17 %
SV 75	♂	feed level	B-norm + 10 % — 20 %	»	13—17 %
SV 80	♀	»	» ± 10 %	»	10—17 %
SV 84	♂	»	» + 10 % — 20 %	Ca and P content, Ca:P ratio	7—12 g Ca and 6—10 g P/kg ration ratio 1.2:1 or 0.7:1
SV 95	♀	»	» ± 10 %	»	»
SV 111	♂	»	» + 10 % — 20 %	digestible crude protein	11—26.0 %
SV 104	♀	»	» ± 10 %	»	9—23.5 %

80, and SV 104 and 111, parallel experiments i.e. 2 similar experiments, 1 involving boars and the other gilts, were carried out. As regards the mentioned parallel experiments, there were slight differences, concerning the protein component of the ration. These are shown in Table 8. During the first 4 experiments, the pigs were housed in pens with solid concrete floors and dung channels, whereas during the last 4 experiments (after building alterations) the dung channels consisted of cement slats (90 mm wide with 20 mm space between). The pens were approx. 15 m^2 in area including trough and dung channel. The pigs were individually fed twice daily according to the Norwegian B-norm (*Breirem & Homb* 1972) + 10 % which almost corresponded to ad lib. feeding. In the experiments in which feed level was an experimental factor, the feed level in 1 group was reduced to B-norm — 10 or 20 % as shown in Table 5.

Calcium and phosphorus were calculated fed at the level of either 7 or 12 g Ca/kg feed and either 6 or 10 g P/kg feed, mutual variations being possible. In the experiments in which mineral content was an experimental factor, the contents of Ca and P were according to analysis results as shown in Table 4. Ca and P levels in the other experiments were on analysis 6—7.6 g Ca and 5—7.3 g P/kg feed. The major mineral source was dicalciumphosphate. The vitamin D content was approx. 500 i. u./kg feed.

Protein levels fed were in some experiments held constant and in others reduced with increasing age. This is shown in Table 8. As regards SV 104 and SV 111, the purpose was to investigate whether protein per se had any specific effect on mobility or the extent of joint and bone lesions or whether it had a general effect through its effect on growth rate. Efforts were therefore made to ensure that growth rate was kept the same in the protein groups in each feed level group. Group I fed at the level of B-norm — 10 % received only the minimum necessary levels of protein (*Homb* 1972), whereas group II and group III received 40 % and 80 % more protein respectively than group I. Because of their ability to use protein, boars received more of this than gilts. In order to maintain equal growth rates in the 3 groups, group I and II received correspondingly greater amounts of carbohydrate. The difference of protein supply between the feed level groups was proportional to the difference in feed level. Table 8 shows the percentage of crude protein in the feed in these experiments. The figures must be considered as approximations as the ratio carbohydrate feed:protein feed had to be corrected somewhat as the experiment proceeded in order to maintain equal growth rates in the groups. The estimated amounts of protein and the analytical results were essentially the same except with regard to SV 68. The estimated amount of digestible crude protein was 17 % in the highest group and 10 % in the lowest group, while analytical results were 20.2 % and 12.9 %, respectively. In SV 84, the content of digestible crude protein was, according to analytical results, 15.6 % over the whole of the experimental period, while the corresponding figure for SV 95 was 13.6 %.

Tocopherol acetate was added at the rate of 10 mg/kg feed in the first 4 experiments and 25 mg/kg feed in the last 4.

A more detailed description of feed composition, feed sources, analytical results, additives and of how the experiments were planned and carried out, is given in a thesis issued by the Department of Animal Nutrition, Agricultural University of Norway (*Hanssen* 1974). The values given for calcium, phosphorus and protein content are average figures based on analytical results supplied by *Hanssen* (1973).

The pigs were slaughtered in the usual manner after electrical stunning as near to 100 kg live weight as was possible with weekly slaughtering. They were divided along the midline of the vertebral column and the left side was deboned. The left foreleg, left hind leg and the left side of the pelvis and lumbar region of the vertebral column were examined with regard to joint and bone lesions. These investigations were carried out in all experiments, except in the first 3 experiments, in which the lumbar region of the vertebral column was not examined. Subjective appraisal of the lesions was made according to a scale ranging from 1 to 5 (1: normal, 2: mild degree lesion, 5: severe degree lesion). Judgment was based on the extent and depth of lesions, on the presence of deposits and on the degree of deformation. Samples for histological examination were taken from the costochondral junction of ribs and from the first sacral vertebra in the first 6 experiments. The samples were treated as described in a previous article (*Grøndalen* 1974 a). Examination for rickets and generalized osteodystrophia fibrosa was carried out. Furthermore, cancellous bone from pigs in experiments involving minerals was subjectively appraised with regard to thickness and pericytic osteolysis. Samples for histological examination were taken from the psoas muscle and from a foreleg extensor muscle in the case of SV 68, SV 75 and SV 80. These sections were stained with haematoxylin-eosin (HE).

In 2 experiments, SV 84 and SV 95, the percentage of ash in dry matter of the third metacarpal bone was investigated according to the method described in a previous article (*Grøndalen & Vangen* 1974).

In experiments SV 64 and SV 68, microbiological investigations of the joint capsules of the hock, femoro-tibial and elbow joints were carried out. Serological tests with regard to circulating antibodies against Erysipelothrix insidiosa were made in all 8 experiments (*Mohn* 1973).

At slaughter, blood samples were taken for examination of glutamate-pyruvate-transaminase (GPT) and glutamate-oxal-acetate-transaminase (GOT) values and of alkaline phosphatase levels (*Aas-Hansen* 1973). Sex organs, thyroid, parathyroid and the adrenal glands were removed for investigation (*Garm* 1973).

It was the intention that each experiment should involve 48 pigs. However, 8 pigs were lost from SV 95 because of an error made in the deboning establishment, while other pigs were lost from various experiments, either due to random deaths, or disease which made the affected pigs unsuitable as experimental animals.

The shape of joints and bones were measured. Although the results obtained, as well as the measuring methods employed, will be described in a subsequent article (*Grøndalen* 1974 d), the differences in shape which were influenced by nutritional factors will be described in the present article.

The group identity of the pigs was not known at the time of post-mortem examination.

The results of the various investigations with regard to each judged characteristic and each animal were transferred to punch cards. According to standard programs, variation analyses based on the recorded characteristics were carried out for main groups, subgroups and litters. Regression analyses to demonstrate possible relationships between characteristics were carried out. Possible relationships between factors in the main groups and subgroups were also investigated*.

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* The statistical calculations were carried out at the Computing Centre, Agricultural University of Norway.

RESULTS

Gross examinations

General

Lesions in joints and bones consisted mainly of osteochondrosis and arthrosis. These diagnoses have been defined in previous articles (*Grøndalen* 1974a, b). The incidence and degree of lesions in the elbow joint, distal epiphyseal plate of the ulna, the lumbar intervertebral joints and in the medial condyle of the femur, together with the total percentage of affected pigs in each experiment are shown in Table 2. Mild degree osteochondrosis occurred commonly also in the other joints and epiphyseal plates. There was a tendency towards a lower incidence and milder degree of lesions in the elbow joint and medial condyle of the femur in gilts than in boars. Moreover, there seemed to be a decrease in incidence of "open" lesions (arthrosis) in the medial condyle of the femur from the first (SV 64) to the last (SV 111) experiment.

The relationship between lesions in different parts of the skeleton is shown in Table 3. This table shows that in general there was little connection between lesions in the various parts of the skeleton. Only 5 of the 39 correlation coefficients were statistically significant.

Table 2. Incidence of gross joint and bone lesions and mean lesion score in the experiments.

Experiment	Sex	Number of pigs investigated	Incidence of gross lesions and mean lesion score in the									
			elbow joint		distal epiphyseal plate of the ulna		lumbar intervertebral joints		medial condyle of the femur		sites mentioned, combined	
			incidence in %	mean lesion score	incidence in %	mean lesion score	incidence in %	mean lesion score	incidence in %	mean lesion score	incidence in %	mean lesion score
SV 64	♂	48	66.7	1.7	79.2	2.8	—	—	91.7 (10.4) *	2.8	100.0	2.4
SV 68	♀	47	51.1	1.8	74.5	2.5	—	—	78.7 (10.6)	2.6	95.7	2.3
SV 75	♂	46	69.6	2.4	80.4	2.7	—	—	87.0 (8.7)	2.8	97.8	2.6
SV 80	♀	47	40.4	1.6	80.9	2.5	34.0	1.4	83.0 (6.4)	2.8	95.7	2.1
SV 84	♂	46	58.7	2.4	73.9	2.4	45.7	1.8	93.4 (4.3)	2.7	100.0	2.3
SV 95	♀	38	28.9	1.6	76.3	2.2	52.6	1.7	73.7 (5.3)	2.4	97.4	2.0
SV 111	♂	46	50.0	2.0	73.9	2.5	56.5	1.9	95.7 (4.3)	2.9	100.0	2.3
SV 104	♀	47	42.6	1.9	74.5	2.4	42.6	1.7	68.0 (0.0)	2.1	95.7	2.0

* The figures in parantheses concern the incidence of "open" lesions (arthrosis).

Ca and P groups

The results of investigations regarding joint and bone lesions in experiments involving Ca and P are shown in Table 4. This table also shows the results of investigations concerning the ash content of the third metacarpal bone which were carried out in experiments SV 84 and 95. There was no statistically significant difference in degree of lesions between groups within experiments ($P > 0.05$).

The high level mineral group (group II) in SV 84 showed a tendency towards a lower incidence and milder degree of lesion than in the other 2 groups. However, in the case of SV 95 it was the low level mineral group (group I) which had the least marked lesions.

In SV 95 there was a statistically significant difference ($P < 0.05$) between groups as regards the percentage of ash in fat free dry matter in the third metacarpal bone. The group fed

Table 3. Relation between lesions in different parts of the skeleton.

Lesions in parts of the skeleton related	Correlation coefficient calculated on lesion score — experiment and sex							
	SV 64 ♂	SV 68 ♀	SV 75 ♂	SV 80 ♀	SV 84 ♂	SV 95 ♀	SV 111 ♂	SV 104 ♀
elbow joint — distal epiphyseal plate of the ulna	0.05	— 0.03	— 0.13	— 0.17	— 0.23	— 0.05	0.08	— 0.28
elbow joint — medial condyle of the femur	0.32*	0.19	0.13	0.22	0.26	0.45*	0.15	0.17
elbow joint — lumbar intervertebral joints	—	—	—	0.18	— 0.04	— 0.03	0.02	— 0.02
distal epiphyseal plate of the ulna — medial condyle of the femur	0.12	0.10	0.05	— 0.02	0.03	0.02	— 0.01	0.01
distal epiphyseal plate of the ulna — lumbar intervertebral joints	—	—	—	— 0.25	— 0.08	— 0.04	— 0.39*	0.21
medial condyle of the femur — lumbar intervertebral joints	—	—	—	— 0.09	— 0.32*	0.12	0.26	0.30*

* statistically significant ($P < 0.05$).

T a b l e 4. Incidence of gross joint and bone lesions, mean lesion score and bone ash content in the experimental groups concerning calcium and phosphorus.

Experiment	Group	Sex	Number of pigs investigated	Food content* (g/kg) of		Incidence of gross lesions and mean lesion score in the										Ash content in % of fatless dry matter in the third metacarpal bone
						elbow joint		distal epiphyseal plate of the ulna		lumbar intervertebral joints		medial condyle of the femur		sites mentioned, combined		
				Ca	P	incidence in %	mean lesion score	incidence in %	mean lesion score	incidence in %	mean lesion score	incidence in %	mean lesion score	incidence in %	mean lesion score	
SV 64	I	♂	24	7.4	6.0	62.5	1.7	79.2	2.7	—	—	87.5	2.9	100.0	2.4	—
„	II	♂	24	12.1	6.7	70.8	1.8	79.2	2.9	—	—	95.8	2.8	100.0	2.5	—
SV 68	I	♀	23	6.4	6.1	47.8	1.7	69.6	2.5	—	—	73.9	2.5	95.7	2.2	—
„	II	♀	24	10.9	6.0	54.2	1.8	79.2	2.5	—	—	83.3	2.8	95.8	2.4	—
SV 84	I	♂	16	6.0	6.0	68.8	2.8	75.0	2.6	37.5	1.7	93.8	2.7	100.0	2.5	64.6
„	II	♂	16	10.0	10.0	43.8	2.2	50.0	2.0	56.3	2.1	87.5	2.5	100.0	2.2	65.4
„	III	♂	14	6.0	10.0	64.3	2.6	100.0	2.6	42.9	1.7	100.0	2.9	100.0	2.5	64.0
SV 95	I	♀	12	6.4	6.0	25.0	1.3	75.0	2.1	41.7	1.5	66.7	2.1	100.0	1.8	62.1
„	II	♀	12	11.8	10.4	33.3	2.1	75.0	2.1	41.7	1.6	83.3	2.5	100.0	2.1	63.1
„	III	♀	14	6.4	10.6	33.3	1.4	78.6	2.5	71.4	1.9	71.4	2.4	92.9	2.1	61.2

* The figures are the mean values of the analysis results from each group's foodstuff.

Table 5. Incidence of gross joint and bone lesions and mean lesion score in the experimental groups concerning feed level.

Experiment	Group	Sex	Number of pigs investigated	Feed level	Average age in days at 100 kg live weight	Incidence of gross lesions and mean lesion score in the: elbow joint		distal epiphyseal plate of the ulna		lumbar intervertebral joints		medial condyle of the femur		sites mentioned, combined	
						incidence in %	mean lesion score	incidence in %	mean lesion score	incidence in %	mean lesion score	incidence in %	mean lesion score	incidence in %	mean lesion score
SV 75	I	♂	24	B-norm + 10 %	171	79.2	2.6	83.3	2.7	—	—	91.7	2.9	95.8	2.7
„	II	♂	22	„ — 20 %	198	59.1	2.2	77.3	2.8	—	—	81.8	2.7	100.0	2.6
SV 80	I	♀	23	„ + 10 %	171	34.8	1.5	78.3	2.3	39.1	1.5	95.7	2.9	100.0	2.1
„	II	♀	24	„ — 10 %	201	45.8	1.8	83.3	2.7	29.2	1.3	70.8	2.6	91.7	2.1
SV 84	I	♂	24	„ + 10 %	169	66.7	2.3	75.0	2.3	50.0	1.9	91.7	2.6	100.0	2.3
„	II	♂	22	„ — 20 %	202	50.0	2.5	72.7	2.5	40.9	1.7	95.5	2.8	100.0	2.4
SV 95	I	♀	23	„ + 10 %	174	30.4	1.6	78.3	2.3	52.2	1.7	91.3	2.6	100.0	2.1
„	II	♀	15	„ — 10 %	202	26.7	1.5	73.3	2.1	53.3	1.7	46.7	2.0	93.3	1.8
SV 111	I	♂	23	„ + 10 %	176	56.5	2.1	78.3	2.7	52.2	1.7	100.0	3.1	100.0	2.4
„	II	♂	23	„ — 20 %	199	43.5	1.8	69.6	2.4	60.9	2.1	91.3	2.7	100.0	2.3
SV 104	I	♀	23	„ + 10 %	190	39.1	1.7	82.6	2.5	43.5	1.8	73.9	2.1	100.0	2.0
„	II	♀	24	„ — 10 %	209	45.8	2.2	66.7	2.3	41.7	1.6	62.5	2.0	91.7	2.0

high levels of Ca and P showed the highest ash percentage. The ashing results as regards SV 84 are, due to labelling errors, based on only 17 bones altogether (6 from group I, 7 from group II and 4 from group III). These results were not treated statistically.

Feed level groups

The results of investigations regarding joint and bone lesions in experiments involving feed level are shown in Table 5. There were no statistically significant differences in degree of lesion between groups within experiments ($P > 0.05$). There was, however, an insignificant tendency towards a lower lesion incidence in the low feed level groups in some experiments.

Mean values of the length of the femur, tibia and vertebral column in different feed level groups are shown in Table 6. The length of the femur and tibia seemed throughout to be greater in boars than in sows at 100 kg live weight. Moreover, in most of the experiments, the femur and the tibia were statistically significantly longer ($P < 0.05$ or 0.01) in the low feed level groups, which also were older at 100 kg live weight (Table 5), than in the high feed level groups. The length of the vertebral column measured post mortem from the medial anterior border of the pubis (pecten ossis pubis) to the cranial region of the atlas showed, however, no differences between sex or feed level groups.

Table 6. Mean values of the length of the femur, the tibia and the vertebral column in various feed level groups, and significance (P) for group differences.

Experiment	Sex	The length of the tibia in cm			The length of the femur in cm			The length of the vertebral column in cm		
		feed level B-norm		significance for group differences (P)	feed level B-norm		significance for group differences (P)	feed level B-norm		significance for group differences (P)
		+10 %	—10 or —20 %		+10 %	—10 or —20 %		+10 %	—10 or —20 %	
SV 64	♂	18.2	—	—	19.0	—	—	103	—	—
SV 68	♀	17.9	—	—	19.2	—	—	103	—	—
SV 75	♂	18.2	19.2	< 0.01	19.3	20.3	< 0.05	103	103	> 0.05
SV 80	♀	18.0	18.7	< 0.01	19.0	20.1	< 0.01	102	103	> 0.05
SV 84	♂	18.3	19.1	< 0.01	19.5	20.5	< 0.01	102	102	> 0.05
SV 95	♀	18.1	18.5	< 0.05	19.1	20.0	< 0.01	103	103	> 0.05
SV 111	♂	18.5	19.0	> 0.05	19.6	20.4	< 0.01	104	105	> 0.05
SV 104	♀	18.5	18.7	> 0.05	19.7	20.0	< 0.05	103	103	> 0.05

Mean values of the shape of the femur are given in Table 7. The condyle:length axis angle (measured medially between the length axis of the femur and a line touching the condyles distally) was throughout less in boars than gilts, and in most of the experiments statistically significantly less in the high feed level groups than in the low feed level groups. In SV 111 the evenness of the medioplantar region of the distal epiphyseal plate of the femur was subjectively appraised according to a scale ranging from 1 to 5, where 1 was even and 5 very uneven. The correlation coefficient between this and the condyle:length axis angle was —0.80 ($P < 0.01$). There was no statistically significant difference ($P > 0.05$) between feed level groups as regards the degree of unevenness of the epiphyseal plate.

Although the twisting of the medial condyle of the femur (measured as the angle between the length axis of the femur and the condyle) was not statistically significantly different between feed level groups, there was a strong tendency for the medial condyle to be more twisted in the high feed level groups. The angle between the epiphyseal plate of the head of the femur and the length axis also seemed to be different between feed level groups. This was investigated in only 4 experiments, but was

Table 7. Mean values of the shape of the femur in various feed level groups, and significance (P) for group differences.

Experiment	Sex	The twisting of the medial condyle of the femur according to the length axis in°			The condyle:length axis angle in°			The angle between the epiphyseal plate of the head of the femur and the length axis of the femur in°		
		feed level B-norm		significance for group differences (P)	feed level B-norm		significance for group differences (P)	feed level B-norm		significance for group differences (P)
		+10 %	—10 or —20 %		+10 %	—10 or —20 %		+10 %	—10 or —20 %	
SV 64	♂	13	—	—	87	—	—	—	—	—
SV 68	♀	12	—	—	90	—	—	—	—	—
SV 75	♂	16	12	> 0.05	87	90	< 0.05	—	—	—
SV 80	♀	13	12	> 0.05	91	92	< 0.01	—	—	—
SV 84	♂	13	12	> 0.05	88	91	< 0.05	64	67	< 0.01
SV 95	♀	14	10	> 0.05	90	92	< 0.05	65	68	< 0.01
SV 111	♂	15	13	< 0.05	88	90	> 0.05	67	71	> 0.05
SV 104	♀	13	13	> 0.05	90	91	> 0.05	70	72	> 0.05

statistically significantly less in the high feed level groups in 2 experiments, and showed the same tendency in the other 2. It was not possible to demonstrate tendencies towards differences between feed level groups as regards shape of bones other than the femur.

Protein groups

Results of investigations concerning joint and bone lesions in experiments involving the protein content of the feed are shown in Table 8. There was no statistically significant difference in degree of lesion between groups within experiments ($P > 0.05$). There was a tendency towards more marked lesions in the high protein groups in SV 104 and SV 111. However, in SV 68, in which relatively high levels of protein were also fed, there was a tendency in the other direction.

Histological examinations

No evidence of rickets or generalized osteodystrophia fibrosa was demonstrated on histological examination. In general, pericytic osteolysis and osteoclastic activity did not seem to be increased to a pathological degree. On subjective appraisal of the morphology of the cancellous bone in the experiments involving minerals as an experimental factor there was a tendency towards thicker bone trabeculae and a lesser degree of pericytic osteolysis in the high balanced mineral groups. These groups also had the highest percentage of ash in the third metacarpal bone in SV 84 and SV 95. Hyaline muscle degeneration was not demonstrated on histological examination of the skeletal musculature from animals in SV 68, SV 75 and SV 80. According to *Garm* (1973) no histomorphological differences of the parathyroids were demonstrated between mineral groups in SV 64, SV 68, SV 84 or SV 95.

Other examinations

The results of ashing the third metacarpal bone in experiments SV 84 and 95 are given in Table 4. High Ca and high P levels in the feed gave the highest ash percentage. High P and normal Ca levels gave a lower ash percentage than normal P and normal Ca levels.

Table 8. Incidence of gross joint and bone lesions and mean lesion score in the experimental groups concerning protein.

Experiment	Group	Sex	Number of pigs investigated	Food content* (%) of digestible crude protein, live weight period 20-40 kg	40-65 kg	65-100 kg	Average age in days at 100 kg live weight	Incidence of gross lesions and mean lesion score in the elbow joint: incidence in %	elbow joint: mean lesion score	distal epiphyseal plate of the ulna: incidence in %	distal epiphyseal plate of the ulna: mean lesion score	lumbar intervertebral joints: incidence in %	lumbar intervertebral joints: mean lesion score	medial condyle of the femur: incidence in %	medial condyle of the femur: mean lesion score	sites mentioned, combined: incidence in %	sites mentioned, combined: mean lesion score
SV 64	I	♂	16	13.5	11.7	10.3	176	68.8	1.9	68.8	2.5	—	—	81.3	2.6	100.0	2.3
„	II	♂	16	16.9	14.8	13.5	166	62.5	1.6	81.3	3.0	—	—	93.8	3.0	100.0	2.5
„	III	♂	16	13.5	13.5	13.5	168	68.8	1.7	87.5	2.9	—	—	100.0	2.9	100.0	2.5
SV 68	I	♀	15	16.0	14.4	12.9	189	46.7	1.6	80.0	2.7	—	—	80.0	2.7	93.3	2.3
„	II	♀	16	20.0	18.0	16.0	189	56.2	1.8	62.5	2.1	—	—	75.0	2.3	93.8	2.1
„	III	♀	16	16.0	16.0	16.0	186	50.0	1.9	81.3	2.6	—	—	81.3	2.9	100.0	2.5
SV 75	I	♂	16	18.3	18.3	18.3	181	56.2	1.9	75.0	2.6	—	—	87.5	2.8	100.0	2.4
„	II	♂	15	15.5	15.5	15.5	183	80.0	3.0	86.7	2.9	—	—	86.7	2.9	100.0	2.9
„	III	♂	15	13.8	13.8	13.8	188	73.3	2.3	80.0	2.7	—	—	86.7	2.7	100.0	2.6
SV 80	I	♀	15	18.1	15.7	13.9	180	46.7	1.6	80.0	2.8	40.0	1.5	93.3	2.9	93.3	2.2
„	II	♀	16	13.9	13.9	13.9	184	31.2	1.4	81.3	2.6	18.8	1.3	75.0	2.8	93.8	2.0
„	III	♀	16	13.9	12.5	10.7	195	43.8	1.8	81.3	2.2	43.8	1.5	81.3	2.6	100.0	2.0
SV 111	I	♂	16	14.5	12.5	11.0	188	43.8	1.8	87.5	2.8	50.0	1.8	87.5	2.7	100.0	2.3
„	II	♂	15	20.5	17.5	15.0	187	46.7	1.8	66.7	2.6	53.3	2.1	100.0	2.9	100.0	2.4
„	III	♂	15	26.0	22.5	20.0	186	60.0	2.4	66.7	2.1	66.7	1.9	100.0	3.1	100.0	2.4
SV 104	I	♀	16	13.0	11.0	9.0	200	37.5	1.8	81.3	2.5	25.0	1.4	62.5	2.0	100.0	1.9
„	II	♀	16	18.5	15.5	12.5	200	31.2	1.8	68.8	2.3	37.5	1.6	62.5	2.1	87.5	2.0
„	III	♀	15	23.5	20.0	16.5	199	60.0	2.2	73.3	2.3	66.7	2.0	80.0	2.1	100.0	2.2

* The figures are mean values of the analysis results from each group's foodstuff.

Microbiological examination of the joint capsules in experiments SV 64 and SV 68 with regard to bacteria and mycoplasma was negative. Nor was the presence of circulating antibodies against Erysipelothrix insidiosa demonstrated in any of the samples (*Mohn* 1973). No statistically significant differences in alkaline phosphatase values between mineral- or other groups were found (*Aas-Hansen* 1973).

Serum transaminase values (GPT and GOT) which indicate the status of the musculature were raised (*Aas-Hansen*). These values will be discussed in a later article concerning leg weakness (*Grøndalen*. In press).

No evidence of an interplay between nutritional factors that should influence the degree of joint and bone lesions was demonstrated.

Differences between litters as regards the shape of bones and joints and joint lesions, and a relationship between these characteristics were demonstrated. This will be described in a later article (*Grøndalen* 1974 d).

DISCUSSION AND CONCLUSIONS

The purpose of the experiments was primarily to find out if the energy content of the ration and the feeding levels of minerals and protein within practical physiological limits had any influence on the occurrence of leg weakness or the extent of skeletal lesions. Therefore feeding levels were neither extremely low nor extremely high. The incidence of leg weakness will be returned to in a later article (*Grøndalen*. In press).

Lesion localization and type did not deviate from the previously demonstrated pattern (*Grøndalen* 1974 a, b). Microbiological investigations (*Mohn* 1973) showed in agreement with most authors that the common lesions are of a non-infectious nature. The incidence of lesions in the experimental animals was high, perhaps somewhat higher than previously demonstrated (*Grøndalen* 1974 a). There was a tendency towards a lower incidence and degree of lesions in gilts than in boars. Although the difference was not great, it did seem to be fairly constant. There was also a tendency that boars had longer bones at 100 kg live weight than gilts.

It was demonstrated that there is little connection between the degree of lesions in the various joints and skeletal regions.

This is in agreement with previous results (*Grøndalen & Vangen* 1974) and supports the supposition that local conditions in the joint may be significant in the aetiology of osteochondrosis and arthrosis (inter al. *Schilling* 1963, *Kurzweg & Winkler* 1972, *Grøndalen* 1974 c). This does not, however, rule out the possibility that a general weakness of cartilage or bone tissue also may occur (inter al. *Krook* 1965, *Brown et al.* 1966, *Grøndalen & Vangen*).

The values of the investigated serum transaminases were raised, most probably because of stress before slaughter (*Aas-Hansen* 1973). It is, however, difficult to comment on what part the muscles play in the development of joint and bone lesions. *Thurley* (1967) and *Kurzweg & Winkler* maintain that weak musculature is of significance in the aetiology of joint lesions. This has previously been partly supported by results obtained when investigating genetically different pigs (*Grøndalen & Vangen*).

The vitamin E supplement was increased after the 4th experiment from 10 mg of tocopherol acetate/kg to 25 mg/kg feed. This should have decreased the possibility of muscle degeneration. It did not have any obvious effect on the incidence and degree of skeletal lesions, although the incidence of "open" lesions in the medial condyle of the femur was less in the last 4 experiments as compared with the first 4, however, without the possibility to draw any conclusions from the result.

It was reasonable to suppose that an interaction between factors such as energy levels, protein and mineral levels of the ration could be possible. Calculations on the effect of such interaction on the degree of lesions did not give any statistically significant results. Thus interaction between the factors in the main groups and subgroups seems to have no essential significance for the development of joint and bone lesions.

There was no tendency towards differences of significance in gross lesions between the groups fed different mineral levels. It should be mentioned that the lowest mineral and vitamin D levels fed were not below recommended norms. The results are in agreement with those referred to by *Walker et al.* (1966), *Kurzweg & Winkler* and *Reiland et al.* (1972).

Krook and *Nielsen* (1973) suggested tendencies towards reduction in degree of lesions with a high, balanced mineral content in the ration. Modern type pigs produce more bone tissue in a shorter time than older type pigs (*Grøndalen & Vangen*), and perhaps also show a greater degree of mineralization (*Günther & Rosin* 1970). Nevertheless there seems little to be gained with regard to gross lesions in increasing Ca levels in the ration above approx. 7 g/kg and P levels above approx. 6 g/kg feed, if vitamin D levels are adequate and the minerals supplied can be resorbed from the gut.

On the other hand, the micro-structure of the bone tissue seemed to be influenced by the amount of minerals supplied. Histomorphologically, the cancellous bone trabeculae seemed to be thicker and pericytic osteolysis less marked in the groups fed high levels of both Ca and P. The bone tissue of these groups also showed the highest ash content. The ash content of the bone tissue in the high P and normal Ca groups was lower than in the groups fed normal balanced Ca:P levels, although no histomorphological differences between these groups could be demonstrated. Histomorphological findings and ashing results are in agreement with results obtained by *Baustad et al.* (1967) and *Nielsen et al.* (1971). Even though no histomorphological difference between the groups as regards the parathyroid glands was demonstrated (*Garm* 1973), it must be assumed that a slight nutritional hyperparathyroidism existed in the groups fed high P and normal Ca levels with consequent mobilization of calcium from the skeleton and low ash content in the bones. This view is shared by inter al. *Krook, Brown et al.* and *Krishnarao & Draper* (1972). The last mentioned authors carried out their mineral investigations on mice. Results from experiments involving other animals (several authors) also support this hypothesis.

Chapman et al. (1962), *Combs et al.* (1962), *Liptrap et al.* (1970), *Cromwell et al.* (1970, 1972) and *Spencer et al.* (1971) have carried out investigations regarding variations in the Ca and P levels in rations fed to pigs inter al. in relation to break or cutting strength, and to ash percentage of the bones. When looking at their results as a whole, it seems, in spite of the fact that the results deviate somewhat, that break strength and ash percentage increase with balanced increase in Ca and P supply, while increase of either Ca or P alone only exerts an influence in those cases in which the basal diet is low in Ca and P.

It seems to be clear that more minerals are deposited in the skeleton when high, balanced levels are fed and that the spongiosa assumes histomorphologically a more optimum structure. It could be thought, as *Nielsen* assumed, that better mineralization would among other things give stronger tendon and ligament insertions. However, after evaluation of the present gross and histological results and the cited literature, there do not seem to be any reasons for recommending an increase in the accepted mineral norms for growing pigs, as the skeletal improvements brought about cannot be seen to have any significant effect on mobility (*Grøndalen*. In press) or on the incidence and degree of skeletal lesions.

The difference in feed level led to an average age difference between groups of approx. 27 days at 100 kg live weight. No real tendency towards a difference in incidence and degree of joint and bone lesions between the groups was observed. It is reasonable to suppose that this lack of difference was partly due to the low feed level pigs, because of their longer life span, being more exposed to the predisposing factors causing lesions. Thus slaughter at the same age (e.g. 6 months) rather than at the same weight might have given another picture. Most investigations involving feed level have otherwise been evaluated with regard to clinical mobility. *Thurley* (1965) and *Ljunggren & Reiland* (1970) assume, however, that rapid growth is one of the aetiological factors involved in the development of lesions. *Reiland* (1974) has moreover found that the development of osteochondrosis can be prevented by restrictive feeding. A connection joint lesions-growth rate has been shown after investigating pigs with genetically determined differences in growth rate, raised under the same environmental conditions (*Grøndalen & Vangen*).

The results as regards the length of femur and tibia seem to confirm the findings of several authors that bone growth cannot be speeded up by increasing the energy content of the ration, but that it increases with age rather than weight. In all but 2 experiments, the length of the tibia and femur in the low feed level animals was statistically significantly greater than in the high feed level animals. In the 2 experiments deviating from this, the age difference at slaughter was only 19 and 23 days respectively. Furthermore there was a tendency towards larger bones in boars than in sows at 100 kg live weight. The average length of the vertebral column at 100 kg live weight was, however, very constant. This is difficult to explain. In previous investigations concerning back and bone length in pigs with genetically determined differences in growth rate (*Grøndalen & Vangen*) the ratio between the length of the vertebral column and the long bones was about the same. The results of the present study could suggest that the growth of vertebrae can be speeded up by high level feeding. It is also possible to assume that the rapid lengthwise growth slows down in the vertebral column before it does in the long bones and that the lengthwise growth in the long bones is somewhat reduced in the high feed level animals because of the extra load (*Grøndalen & Grøndalen* 1974). A combination of the last 2 suppositions seems to be the most likely.

The results show that the shape of the femur is influenced by rapid increase in weight. This was especially marked in the case of the condyle:length axis angle, for which the difference was statistically significant in 4 out of 6 experiments. The twisting of the medial condyle was affected at the same time. The marked relationship between small medial condyle of the femur and uneven epiphyseal plate at the same site (SV 111), suggests that endochondral ossification is affected and that this results in reduced lengthwise growth in the regions subjected to the greatest pressure, which are assumed to be medially in the joint. The slope of the epiphyseal plate of the head of the femur in relation to the length axis showed the same tendency. It seemed, however, that this was only true until the head of the femur obtained the typical low profile. The angle then became larger. It has previously been demonstrated (*Grøndalen* 1974 b) that this type of head of the femur usually showed a premature closure of the epiphyseal plate, starting in the area towards the trochanter. The total of such low heads of femur in pigs at 100 kg live weight was not so large that it is possible to be sure that the condition shows differences between feed level groups. In SV 111, 6 animals had an obviously low head of femur, a ridge innermost towards the trochanter, and premature closure of the epiphyseal plates. Of these, 4 animals were from the high feed level group. In the other experiments there were fewer animals with low head of femur.

Protein levels fed did not seem to have significant effect on the occurrence of osteochondrosis and arthrosis in pigs. However, there was a certain tendency towards higher degree and incidence of lesions at high protein levels in SV 104 and SV 111, although this was not statistically significant. In these experiments the growth promoting effect of protein was compensated by corresponding levels of carbohydrate such that the average slaughter age was constant for the protein groups. The experiments were inter al. planned with the intention of investigating whether very high protein levels would influence joint capsules (*Månsson et al.* 1971) which was expected to give lameness soon after starting the experiment. This will be returned to in a subsequent article (*Grøndalen.* In press).

General conclusions concerning joint and bone lesions after these investigations must be that there is little to gain by increasing feeding levels of Ca and P above accepted norms, even though this will affect mineralization of bones. Neither do feed levels or protein levels have any significant effect on the extent of lesions. However, certain reservations are taken with regard to feed level as the low feed level pigs had a longer period of time during which they were susceptible to the development of lesions than the high feed level pigs. Moreover, feed level undoubtedly affected the shape of the femur, most probably through an effect on endochondral ossification. The changes to which the femur was subjected, especially the head, are probably irreversible (*Grøndalen* 1974 b). This may be of essential significance with regard to mobility, and for the durability of, in the first instance, the hip joint. The effect of feed level on mobility (leg weakness) will be described in a subsequent article (*Grøndalen.* In press).

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SAMMENDRAG

Osteochondrose og arthrose hos gris. VI. Relasjon til fórstyrke, calcium, fosfor og proteinnivå i fóret.

I åtte foringsforsøk, hvert med 48 råner eller purker, ble faktorene fórstyrke, Ca, P og proteinnivå variert innenfor praktiske fysiologiske grenser. Dyra ble slaktet ved 100 kg levende vekt. Lesjonene i ledd og knokler var av ikke-infeksiøs, ikke-rakitisk natur, og av typen osteochondrose og arthrose. 10—12 g Ca og ca. 10 g P per kg fór ga histomorfologisk tilsynelatende en bedre struktur av spongiøst beinvev, og en høyere askeprosent i knoklene enn 7 g Ca og 6 g P, eller ubalanserte mineralnivåer i fóret. Det var imidlertid ingen signifikante forskjeller i grad eller frekvens av ledd- og knokkellesjoner mellom mineralgruppene. Det var heller ingen slike forskjeller tilstede mellom fórstyrkegrupper eller proteinnivågrupper. Dette kan for fórstyrkegruppenes vedkommende delvis skyldes at dyr på lav fórstyrke hadde en lengre leveperiode hvor de var lett mottagelige for leddlesjoner. Dyr på lav fórstyrke hadde lengre rørknokler ved 100 kg levende vekt enn dyr på høy fórstyrke. Lengden av hvirvelsøylen var imidlertid svært lik i de to fórstyrkegruppene. Vinkelen for vekstlinjen til caput og for condylene på femur, i forhold til lengdeaksen, var påvirket av fórstyrke eller veksthastighet, mest sannsynlig ved en virkning på den endochondrale forbeining.

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