



Original Contribution

CHANGES OF BONE PARAMETERS OF GROWING PIGS TO DIFFERENT PHOSPHORUS LEVELS IN THE DIET

Dian Kanakov*, Petko Petkov, Krasimir Stojanchev

Department of Internal Non-Infectious Diseases, Faculty of Veterinary Medicine, The Thracian University, Stara Zagora, Bulgaria

ABSTRACT

The objectives of this study were to examine the response of growing pigs to different levels of phosphorus and to determine the effect of reducing phosphorus level on bone characteristics in the later growing stages. After slaughter, third metacarpals were removed from the front right foot of the pigs. The bones were weighed, the overall length of each bone and the width of bone shaft at the narrow and wide dimension were measured. Wall thickness, shear force resistance and ash percentage were also measured. Dry weight of the bone was significantly affected by treatment ($p < 0.05$). There was a similar trend for both bone ash weight and ash percentage, with those fed phase phosphorus diet (low phosphorus level in the later growing stages) having significantly lower values than the other treatments ($p < 0.01$). There was a trend for increased stress as dietary phosphorus level increased. We can conclude that pig bone development was significantly affected by dietary phosphorus level. The low-phosphorus diet gave significantly poorer results than the adequate-phosphorus diet; while there were no beneficial effects of supplementing phosphorus at a level higher than 2.4 g/kg. Lowering the phosphorus level to 1.6 g/kg in the late finishing stage seemed to have a deleterious effect.

Key words: Pig, Bone Parameters, Phosphorus

INTRODUCTION

All animals require adequate amounts of phosphorus because it is an important element in body metabolism. It accounts for over 25% of total body mineral matter, second only to calcium. Eighty percent of phosphorus is found in the skeleton, where it is deposited in bones with calcium, as the mineral hydroxyapatite (1). Twenty percent is located in the soft tissues, where it is involved in almost all biochemical reactions. A deficiency of phosphorus results in a depression in growth of body tissues with bone becoming soft and fragile. Prior to this situation phosphorus from skeletal tissue is drawn upon first to maintain homeostasis and this eventually leads to the first symptoms of imbalances called aberrations of the skeleton (2).

Adequate dietary phosphorus can be defined in either of two ways depending on

whether maximum bone development or maximum growth rate and performance is required. Adequate levels of phosphorus for maximum pig performance are lower than for maximum bone development. Maximum bone development is important for longevity of the animal and this higher level of dietary phosphorus required for maximum bone development may have an effect on breeding pig performance. However, feeding higher dietary phosphorus levels would increase the amount excreted by the animal and excess phosphorus in pig manure is a potential environment problem. It has also been proposed that lowering the dietary phosphorus levels in the late pig finishing stages would be beneficial by reducing the amount of phosphorus excreted, without having any detrimental effect on performance or carcass traits.

Bone mass, mineralisation measurements, and mechanical characteristics are considered very accurate indicators of phosphorus status. These include bone strength (stress), bending moment, bone ash weight, and bone ash percentage. When compared to plasma APA, these measurements were considered most sensitive

*Correspondence to: Dian T. Kanakov MD, The Thracian University, Faculty of Veterinary Medicine, Department of Internal Non-Infection Diseases; 6000 Stara Zagora, Bulgaria, E-mail dian@gbg.bg, Phone: +35942 28102640, Fax: +35942 45101, Mobile: +359889 448081

(3). These indices place phosphorus in a very important position.

Therefore the aim of our study was to see how changing phosphorus levels in the animals' diets could affect the status of these parameters.

MATERIALS AND METHODS

Animals and housing

The study was done in a commercial pig farm. Six groups, comprising three pigs per group, were used. Three groups were females and the other three were males. The animals weighed between 30 and 35 kg and were randomly assigned to the groups that were only sex-limited. One pen of each sex was assigned, at random, to one of the following three treatments.

- *Diet 1*: High phosphorus diet (3.0 g/kg digestible phosphorus; 5.9 g/kg total phosphorus).
- *Diet 2*: Medium phosphorus diet (2.4 g/kg digestible phosphorus; 5.3 g/kg total phosphorus).
- Phase fed phosphorus diet (2.4 g/kg digestible phosphorus to 60 kg live-weight followed by 1.6 g/kg digestible phosphorus to slaughter; 5.3 g/kg total phosphorus followed by 4.3 g/kg total phosphorus). Diet 2 to 60 kg and 3 to slaughter.

Different phosphorus levels were achieved by varying the level of dicalcium phosphate in the diet. Digestible phosphorus levels were calculated by the BESTMIX 5.021 feed formulation programmer.

Pigs were housed in fully slatted pens (concrete slats, 75 mm solid with 20 mm slots), 1.2 x 1.4 m with steel rail partitions. Pigs were fed from a Hyundai FIRE computerized feeder with dry pelleted feed *ad libitum*. Water was available *ad libitum* from one BALP2 drinking bowl per group. Temperature control was by ceiling mounted exhaust fan, which was controlled by a Stienen3 AFC 5 temperature controller with temperature regulated at 20-22°C. Air entry was from a service passage, via three manually adjusted inlets on the wall, at the side of the room, opposite the fan.

Pigs were observed closely at least twice daily. Any pigs showing signs of ill health were treated as appropriate. Feeders and drinkers were checked daily and cleaned or adjusted as required.

Feeding and management

Pigs were fed *ad libitum* with care taken to avoid feed wastage. Feeders were allowed to empty at least once weekly to avoid a built up of stale feed. Feed for the group was recorded at the time of feeding into standard record sheets.

Feeder accuracy was checked each week on Monday by removing approximately 1.0 kg feed from the trough. Feed removed was weighed and checked against the weight recorded on the computer. The calibration was adjusted if required.

Slaughter

Pigs were slaughtered when the average live weight exceeded 103 kg (on a Monday). In uneven groups the pigs were slaughtered over two days. Pigs were transported to the slaughterhouse and killed by bleeding after stunning.

Feed manufacture

Feed was manufactured in 1-ton batches, conditioned by steam heating to 50°C before pelleting into 5 mm pellets. Cereals were ground through a 3-mm screen before mixing. The vitamin-trace mineral mix was premixed through 5 kg cereal before addition to the mixer. Feed was then stored in pre-weighed 40 kg sacks, which were stamped with ID number and date of manufacture and closed by sewing. Batches of feed were fed in the order of manufacture.

Composition and calculated nutrient content of the diets are shown in **Table 1** and **Table 2**.

Table 1: Composition of experimental feeds, kg/ton

	Diet 1	Diet 2	Diet 3
Barley	350	350	350
Wheat	409.25	410.75	415.75
Soya Hi-Pro	215.0	215.0	215.0
Lysine Synthetic	2.5	2.5	2.5
Methionine Synthetic	0.75	0.75	0.75
Threonine	1.0	1.0	1.0
Di Cal Phos	8.5	5.5	0
Limestone Flour	8.5	10	13.5
Salt	3.0	3.0	3.0
Vit-Mins	1.5	1.5	1.5
Total	1000	1000	1000

Bone parameters

Immediately after slaughter, third metacarpals were removed from the front right foot of all experimental pigs and frozen at -20°C in

airtight containers. Bones were later thawed and extraneous tissue was removed. The bones were then weighted and the overall length of each bone and the width of bone shaft at the narrow and wide dimension were measured (**Figure 1**).

Bones were cut in half at the midpoint, using a fine saw (junior hacksaw). Wall thickness at the midpoint of the narrow, wide and perpendicular dimensions was measured using a dial calliper⁴ and averaged to determine a value for wall thickness at the midpoint of the overall bone length (**Figure 1**).

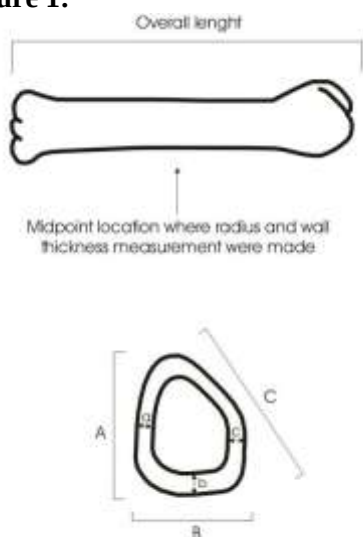
After bone measurements were taken, the marrow was removed and the bone was again weighed. The bone was dried in a crucible for 16 hours in an oven at 103°C. Bones were re-weighed on removal from the oven after cooling and ashed at 600°C until a consistent white ash was obtained (c. 48 hours). The crucible and its contents were weighed after cooling.

Bone strength was determined using a Hounsfield tensiometer⁵ based on the method by (4). Force was applied at a rate of 10 mm/min. The maximum force required to cause shear failure was recorded.

Table 2: Calculated analysis of feeds, g/kg

	Diet 1	Diet 2	Diet 3
Crude Protein	188	189	189
Lysine	11.1	11.1	11.1
Methionine	3.5	3.5	3.5
Meth+Cyst	6.9	6.9	6.9
Threonine	7.6	7.6	7.6
Tryptophan	2.3	2.3	2.3
Isoleucine	8.4	8.4	8.4
Leucine	13.7	13.7	13.7
Phenil+Tyros	14.8	14.8	14.8
Valine	9.2	9.2	9.2
Lysine digestible	9.8	9.8	9.8
Methionine dig.	3.2	3.2	3.2
Meth+Cyst dig.	6.1	6.1	6.1
Threonine dig.	6.5	6.5	6.5
Tryptophan dig.	1.9	1.9	1.9
Dry Matter	866	866	866
Energy DE MJ/kg	13.4	13.4	13.4
Energy NE MJ/kg	9.5	9.6	9.6
Fat	18.0	18.5	18.6
Linoleic	8	8	8
Crude fibre	35	35	35
Ash	46	45	43
Calcium	6.0	6.0	6.1
Total phosphorus	5.9	5.3	4.3
Digestible phosphorus	3.0	2.4	1.6
Potassium	7.4	7.4	7.5
Sodium	1.5	1.5	1.5
Starch+Sugar	458	459	461

Figure 1:



A=Wide
B=Narrow dimension
C=perpendicular dimension
Dimensions a, b, c = locations of wall

Thickness Measurements:
Radius= $A+B/2=r$
Wall thickness= $a+b+c/3$

Measurements and Analysis

Representative samples of the diets were taken in the feed mill at manufacture. All samples were ground using a Christy Laboratory Mill⁶ with a 2 mm screen and stored in plastic containers at -20°C pending analysis. Feed samples were analysed for dry matter, crude fibre, crude protein, ash, oil, pellet durability, total Ca and total P.

Dry matter was determined by drying in an oven at 103°C for 4 hours and ash by incineration in a muffle furnace⁷ at 550°C for 16 hours. Crude protein was determined as N*6.25 using a LEGO FP 20008. Crude fibre was measured by a Tecator⁹ semi-automatic instrument and oil by extraction with perchlorethylene in a Foss Let 1530010. Pellet

durability was determined using a Holmen11 Pellet Tester.

Statistical Analysis

Statistical analysis was by methods of SAS Inc, Gary, N. Carolina for a randomized complete block design.

RESULTS

Chemical composition of the diets

Chemical composition of the diets fed in this experiment is shown in **Table 3**. The ash content of diets 2 and 3 was lower than expected. Crude protein was also lower. All other components were similar to expected values.

Table 3: Analyzed chemical composition of experimental diets, g/kg

Diet No.	1	2	3
Dry matter	860	856	856
Ash	43	39	39
Oil	18	18	19
Crude Fibre	35	37	33
Crude Protein	172	166	178
Total P	6.3	5.35	4.45
Pellet Durability	972	970	970

Pig Health

In general, the health of the pigs in this experiment was good. **Table 4** shows the number of pigs that were removed from the trial and the reasons.

Table 4: Reasons for removal of pigs from experiment

Diet	sex	N ₂	day	reason
Diet 1 (High phosphorus)	Female	1	63	Pneumonia

Bone parameters

Treatment had no effect on any bone dimensions measured (**Table 5**) ($p>0.10$). Fresh bone weight was also unaffected. However, the weight of the empty bone tended to be lower on diet 1 changed to 3 at 60 kg live weight compared to the other diets ($p=0.08$). Dry weight of the bone was significantly affected by treatment ($p<0.05$), with the group fed diet 1 changed to 3 having the lightest bone dry weights. There was a similar trend for both bone ash weight and ash percentage, with those fed 1 and then changed to 3 at 60 kg having significantly lower values than the other treatments ($p<0.01$). There were no differences between treatment 1 and 2 for bone characteristics. Bone stress was not significantly affected by treatment ($p=0.47$).

However there was a trend for increased stress as dietary phosphorus level increased.

DISCUSSION

In our experiment, treatment was found to have no significant effect on bone dimensions. These findings are in agreement with work done somewhere (5) that reported no effect of phosphorus level on bone measurements. On the other hand, however another study (6) found that increased P in the diet increased wall thickness.

Empty bone weight tended to be affected by treatment, but not significantly ($P=0.08$), while dry weight and ash weight were both significantly affected by the diet ($p<0.01$). There were very small differences in weights between diet 1 and diet 2, with no increases as the dietary phosphorus level increased. The low-phosphorus diet resulted in lower dry weights and ash weights. This is in agreement with another investigation (7). They reported no increase in weight when phosphorus was supplemented above requirements. However, there was a decrease in weights as the phosphorus level was decreased, which agreed with our results. Contrary to this, another investigation (8) reported an increase in bone dry weight with increasing dietary phosphorus up to an available phosphorus level of 4 g/kg.

Bone ash percentage was significantly affected by treatment also ($p<0.01$) showing, an increase as phosphorus level increased. Another investigation done somewhere (6) agrees with this. Another investigation (7) showed a reduction in bone ash percentage in low-phosphorus diets, while in high-phosphorus diets there was no difference found in ash percentage. In a similar study (8) there was a reported curvilinear response in bone ash concentration as phosphorus level increased. Similarly, other investigations (9) found that ash concentration increased as phosphorus level in the diet increased. However, as stated earlier (5), there were found no changes in total ash concentration of bones.

Bone stress (force measured in N) in this experiment was not significantly affected by treatment although there was an established trend for increased bone strength with increasing dietary phosphorus intake. Pigs on the low phosphorus diet (diet 1 to 3) had considerably lower stress values than the high phosphorus diet (diet 1). Reports in the literature, however, have shown that dietary phosphorus levels have a significant effect on

bone strength values (6), compared to a high level and a low level of dietary phosphorus (0.8 and 0.4%). It was found that bone-bending moment was greatest on the high phosphorus diet with bones from the low phosphorus diet unable to withstand as much stress as bones from the high phosphorus diet. Combs et al. (4) found similar results when they compared calcium/phosphorus levels at 70, 85, 100, 115, and 130% of estimated requirements. Bone shear stress increased at a

decreasing rate in response to increasing dietary calcium/phosphorus intake. These results agreed with Kempen (10) who compared four dietary phosphorus levels (0.4, 0.5, 0.6, and 0.7% total phosphorus). They found that bone strength increased significantly with increasing phosphorus level but at a decreasing rate. These results are confirmed by other researchers (9, 11, and 12).

Table 5: Effects of treatment on bone dimensions, weight and bone strength

Diet	LI	1.2	1.1 changed to 1.3 at 60 kg	s.e.	P-value'
g/kg digestible P	3.0	2.4	2.4/1.6		
Bone length (mm)	76.8	76.8	75.9	0.78	0.65
Wide dimension (A) in mm	16.2	16.3	16.2	0.20	0.83
Narrow dimension (B) in mm	13.8	13.6	14.0	0.29	0.61
Perpendicular dimension (C) in mm	18.5	18.6	18.2	0.25	0.36
Wall thickness (A) in mm	1.42	1.36	1.31	0.051	0.286
Wall thickness (B) in mm	2.47	2.41	2.27	0.090	0.299
Wall thickness (C) in mm	1.33	1.28	1.25	0.039	0.355
Fresh weight (g)	25.6	25.8	24.1	0.73	0.20
Empty bone weight (g)	22.7	23.0	21.2	0.60	0.08+
Dry weight (g)	15.8	16.0	14.4	0.38	0.05*
Ash weight (g)	7.34	7.35	6.34	0.170	<0.01**
Ash in bone (g/kg)	466	461	440	4.9	<0.01**
Bone stress (force in N)	3817	3757	3430	243.33	0.47

1 + PO.10; * $p < 0.05$; ** $p < 0.01$

In contrast to these some others (7) compared different dietary calcium/phosphorus levels (75%, 100% and 125% of estimated requirements) and found that at the low phosphorus level, bone breaking strength was significantly reduced. However, breaking strength was not consistently increased when 125% phosphorus was fed. Maximum bone strength was found to be at the level of 125% calcium and 125% phosphorus inclusion in the diet. Some other workers (13) reported no effect of dietary phosphorus level on bone strength values. They compared two calcium/phosphorus levels (100% and 150% of estimated requirements) in gilts and sows and found no effect of dietary levels on bone strength. This

may have been because the increased calcium/phosphorus levels were only fed for a short duration whereas in the other trials diets were fed for a longer time.

CONCLUSION

From our experiment we can conclude that pig performance was significantly affected by dietary phosphorus level.

The low-phosphorus diet (2.4 g/kg changed to 1.6 g/kg digestible phosphorus) gave significantly poorer results than the adequate-phosphorus diet (diet 2.4 g/kg).

There were no beneficial effects of supplementing phosphorus at a level higher than 2.4 g/kg.

Legend:

1. ADIFO, Maldegem, Belgium
2. La Buvette, Charleville Nord, France
3. Stienen BU, Nederweert, The Netherlands
4. Шyблер 0.001mm скала, Mitutoyo Corp., Tokyo, Japan
5. HTE S-Series H25KS/05, Hounsfield Equipment Ltd., Redhill, U.K.
6. Christy & Norris Ltd., Broomfield road, Chelmsford, CMI ISA. England
7. Gallencamp Ltd., P.O.Box 290 Technic House, Christopher Street, London, EC2P 2ER
8. Leco Instruments UK Ltd., Newby Road, Hazel Grove, Stockport, SK 75DA
9. Tecator AB, Box 70, S-26301 Hogans, Sweden
10. A/S N. Foss Electric, Hillerod, Denmark
11. Holmen Chemicals Ltd., P.O.Box 2, Basing view, Basingstoke, Hampshire, RG21 2EB, U.K.

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