THE INFLUENCE OF SUNLIGHT ON BONE DEVELOPMENT IN SWINE.

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A report has recently been made by the writers (1) on the dietary relationships and the pathology of a condition in swine popularly referred to as stiffness, paralysis, rickets, and by other terms. In this previous study the principal and constantly occurring lesions in the stiff pigs were found in the bones and these lesions were accompanied by a deficiency of calcium and phosphorus as shown by chemical analysis of the femurs. The stiffness was found to occur with a ration low either in calcium or in the factor aiding its assimilation. The correction of the ration with respect to these deficiencies was found effective for preventing or curing the trouble.

In this previous study the animals were housed in pens on the north side of the colony house and were never exposed to any direct sunlight. In view of the findings that the stiffness was apparently a result of faulty mineral nutrition the question naturally arose as to how the results would be modified where the pigs were exposed to sunlight. The results reported in the present paper deal with a study of this question.

EXPERIMENTAL.

The study consisted of two trials—one conducted in the summer of 1924, and one carried out the following winter.

The rations used are shown in Table I.

These rations contain digestible crude protein and total digestible nutrients in the proper relation for young pigs according to accepted feeding standards—though the protein, furnished entirely by plant sources, is not of sufficiently high quality for a maximum
rate of growth. In other respects the rations are believed to be adequate for the growth and normal development of swine with the exception of certain deficiencies with respect to mineral nutrition. The basal ration is very deficient in calcium. This deficiency is corrected in the other ration by the addition of the sources of calcium listed, thus making this ration approximately nine times higher in calcium than the basal ration and somewhat higher in phosphorus. Both rations are presumably low in the factor aiding calcium assimilation.

These same rations were used by the writers (1) in their previous study in which the pigs were so housed as to have no access to direct sunlight. The basal ration nearly always resulted in the development of the characteristic stiffness within 4 months, while on the ration with the added minerals no cases of stiffness resulted during the same period. The bones of the pigs on the latter ration showed a markedly higher content of calcium and of phosphorus and a more nearly normal histological picture than did the bones from the pigs on the basal ration.

The primary object of the study here reported was to ascertain whether the exposure of pigs fed the basal ration to sunlight would prevent the development of the stiffness, and result in a better assimilation of the limited amount of calcium present than would result in a similar group of pigs on the basal ration receiving no direct sunlight.

<table>
<thead>
<tr>
<th>Ration</th>
<th>Ingredients</th>
<th>Calcium (per cent)</th>
<th>Phosphorus (per cent)</th>
<th>Nutritive ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal</td>
<td>200 lbs. yellow corn-meal.</td>
<td>0.096</td>
<td>0.55</td>
<td>1:4.8</td>
</tr>
<tr>
<td></td>
<td>100 &quot; wheat middlings.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>75 &quot; oil meal.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot; plus minerals</td>
<td>200 &quot; yellow corn-meal.</td>
<td>0.795</td>
<td>0.71</td>
<td>1:4.8</td>
</tr>
<tr>
<td></td>
<td>100 &quot; wheat middlings.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>75 &quot; linseed oil meal.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 &quot; steamed bone meal.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 &quot; ground limestone.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The pigs used were pure bred Duroc-Jersey barrows farrowed in the University herd. They weighed from 20 to 30 pounds when placed on experiment. Only thrifty pigs were used and they were chosen with the object of having as many litter mates as possible distributed among the groups to be compared. By this method of distribution, opportunity was afforded for comparing the bones of litter mates, thus eliminating differences due to previous nutritional history and breeding. Since the litter mates had been fed alike from birth to the time they were placed on experiment and were approximately equal in weight at this time, it was considered that the variable factor of stored nutrient reserves was reduced to a minimum. At the start of the experiment all of the pigs were given two treatments of oil of chenopodium for intestinal parasites.

**Trial 1.**

On June 10, 1924, four pigs were placed on each of the rations listed in Table I in pens on the north side of the colony house. A third group of four was placed on the basal ration in a pen on the south side of the house, opening on a cement runway, 7 by 12 feet. Thus this group was permitted to go outside at will and actually spent a considerable portion of each sunny day outdoors. On the other hand the other groups were never outside and were never exposed to any direct sunlight. The group which was allowed outdoors had somewhat larger quarters by reason of the runway, but it is not believed that the other two groups were hampered in activity or in other respects by the size of their quarters. The group in the pen with the runway was somewhat more active but it is believed that this was due to the stimulus of being outside rather than to their larger quarters.

The two groups on the basal ration, one with access to sunlight and the other not, furnished an opportunity for ascertaining whether the sunlight would increase the assimilation of calcium on this low calcium ration, as judged by comparative chemical and histological studies of the bones. The group on the basal ration plus the added sources of calcium was included in the trial with the expectation, based on previous results, that nearly normal bones would thus be available as a further basis for comparison in studying the effect of the sunlight.
The pigs were fed all they would eat three times a day. They were weighed periodically and were constantly watched for the development of the characteristic stiffness.

One of the pigs of the no-sunlight group on the basal ration developed the stiffness toward the end of the 3rd month and the other pigs in this group became stiff during the 4th month. On the other hand, none of the pigs exposed to sunlight showed any signs of the trouble at the end of the 4th month, nor did any of the animals receiving the ration with the added minerals.

With the exception of the first pig to become stiff, which was killed for examination at the end of the 3rd month, the animals in the no-sunlight group were held on the experiment until the close of the 4th month, by which time the stiffness had become greatly aggravated. At this time both these stiff pigs and their litter mates in the other two groups were killed for comparative study. Each animal was given a general pathological examination and then one femur was taken for histological study, while the other femur was reserved for chemical analysis.

**Bone Analysis.**—For the chemical analysis the femur was freed from adhering flesh, partially dried at 50° to 60°C. and then dried to constant weight over sulfuric acid. The bone was next pulverized in a bone cutter, sampled, and the sample ignited at dull redness in an electric muffle furnace to determine the ash. The results are shown in Table II.

Pigs 651, 654, and 652 were litter mates killed on the same day. In the last column of the table it is shown that the femur of the pig exposed to sunlight had a much higher ash content than that of its litter mate which became stiff on the basal ration without sunlight, indicating that the sunlight caused an increased assimilation of the very limited amount of calcium supplied in the ration. The bone of the litter mate on the ration containing the added sources of calcium is seen to be the highest in ash of the three.

A similar relationship is seen to exist for the next three litter mates—Nos. 631, 634, and 635. As noted from the figures for age, the stiff pig, No. 631, was killed 46 days earlier than the other two. This was the pig that became stiff much sooner than any of the others and which was autopsied at the end of the 3rd month. Since one object of the study was to ascertain the influence of sunlight in preventing the development of the stiffness, it seemed
desirable to give the litter mates of No. 631 further opportunity to develop the trouble. In so doing the comparison of the results of the bone analysis in the case of these three litter mates was rendered open to the criticism that ash content increases with age. It is not believed however that the fact that Pig 634 was 194 days old when killed while Pig 631 was only 148 days old could possibly explain the increase of approximately 60 per cent in the ash content of the bone of the former.

**TABLE II.**

*Ash Content of Femurs.*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>days</td>
<td>kg.</td>
<td></td>
<td>gm.</td>
<td>Dry matter. per cent</td>
</tr>
<tr>
<td>651</td>
<td>190</td>
<td>41.3</td>
<td>Basal.</td>
<td>127.4</td>
<td>44.35</td>
</tr>
<tr>
<td>654</td>
<td>196</td>
<td>50.0</td>
<td>+ sunlight.</td>
<td>147.2</td>
<td>56.45</td>
</tr>
<tr>
<td>652</td>
<td>196</td>
<td>38.1</td>
<td>+ minerals.</td>
<td>120.5</td>
<td>57.59</td>
</tr>
<tr>
<td>631</td>
<td>148</td>
<td>26.8</td>
<td></td>
<td>96.5</td>
<td>44.5</td>
</tr>
<tr>
<td>634</td>
<td>194</td>
<td>50.3</td>
<td>+ sunlight.</td>
<td>164.0</td>
<td>61.10</td>
</tr>
<tr>
<td>635</td>
<td>194</td>
<td>45.4</td>
<td>+ minerals.</td>
<td>140.0</td>
<td>58.00</td>
</tr>
<tr>
<td>619</td>
<td>220</td>
<td>50.0</td>
<td></td>
<td>146.2</td>
<td>51.37</td>
</tr>
<tr>
<td>603</td>
<td>225</td>
<td>55.3</td>
<td>+ sunlight.</td>
<td>170.6</td>
<td>60.14</td>
</tr>
<tr>
<td>665</td>
<td>204</td>
<td>56.5</td>
<td>+ minerals.</td>
<td>187.0</td>
<td>62.62</td>
</tr>
<tr>
<td>609</td>
<td>189</td>
<td>45.8</td>
<td></td>
<td>148.0</td>
<td>50.74</td>
</tr>
</tbody>
</table>

Pigs 619, 603, and 665 were not litter mates but are grouped together in the table because they were approximately of the same size and age at the start of the experiment and were nearly the same age when killed. Here again with the basal ration the beneficial effect of the sunlight in increasing the ash content is seen, and again the highest ash content resulted where minerals were added.

Pig 609 was the fourth pig that became stiff on the basal ration fed indoors. The remaining pig on each of the other rations which was scheduled to be killed for comparison with No. 609 was particularly desired for teaching purposes at the time and thus was not slaughtered. This was seen to be unfortunate when the
ash content of the bone of No. 609 was determined. This pig was very stiff when killed, but the table shows the ash content of its femur to be markedly higher than the figure for any of the other stiff pigs and to be comparable with the figures for the pigs in the sunlight group. Even though the figure for No. 609 is thus comparatively high, it is entirely possible that its litter mate in the no-sunlight group developed a bone of still higher ash content. In the absence of the opportunity to check this possibility because of the previously mentioned failure to kill the litter mate in question the figure for No. 609 must stand as an apparent exception to the otherwise consistent results in Table II.

It is seen in Table II that the pigs exposed to the sunlight were uniformly heavier when killed than the pigs on the same ration kept inside. This observation, which may seem to indicate that the sunlight had a beneficial effect on growth as measured by body weight, is of limited significance because the pigs fed the basal ration inside usually remained stationary in weight or declined during the period intervening between the beginning of the stiffness and the time of slaughter. It is true that the periodic weighings indicated that, as a whole, the sunlight group grew faster, but no weight records are reported because it was not the intention to make any comparison of rate of growth, nor could such a comparison be significant with the small number of animals involved.

The figures for "weight of fresh bone" in Table II show that the bones were uniformly heavier for the pigs in the pen with the outdoor runway as compared with those inside on the same ration. Similarly the bones of the pigs exposed to the sunlight were higher in dry matter. These figures for dry matter have been included in the table primarily to indicate, as can be proven by calculation, that the conclusions drawn as to ash content would not be affected if the figures for ash were compared on a moisture-free basis.

Pathological Examinations.—On routine pathological examination, the stiff pigs in the no-sunlight group showed hemorrhage in groups of lymph nodes, and the kidneys or the mucosae of the urinary bladders contained petechiae. The same changes were found in the pigs in the other groups but to a markedly lesser degree.

Pneumonic lesions were found in four of the animals: Nos. 654,
652, 634, and 609. Since three out of four of the stiff pigs, namely Nos. 651, 631, 619, were free from pneumonia it is clear that this disease was not a complicating factor affecting the definiteness of the results obtained.

On examination of the femurs it was found that the bones of the pigs in the no-sunlight group were markedly less dense, as indicated by the ease of sawing, than the bones of the pigs in the other two groups. The changes found for the femurs of the stiff pigs, both in the gross and under the microscope, were similar to those previously reported by the writers (1). The bone marrow was reddened throughout, or near the epiphyseal cartilage. The latter was irregular and much thicker than normal. The cortical bone was soft and porous. Under the microscope the constant lesions found were: imperfect calcification, granulation tissue, degenerated and proliferating areas of articular cartilage, osteoclasts along the trabeculae, irregularity in the zone of provisional calcification, and hemorrhage under both the articular and epiphyseal cartilages.

The femurs of the pigs on the basal ration receiving the sunlight were more nearly normal in all cases than were the femurs of their litter mates in the no-sunlight group, just described. The reddening in the shaft was much less and the epiphyseal cartilage was thinner and more regular in all cases. The articular cartilage was normal. The cortical bone was denser and of a finer texture. Under the microscope there were much less hemorrhage and granulation tissue than were found in the bones of the litter mates on the basal ration. Similarly there were fewer areas of imperfect calcification and the zone of provisional calcification was more nearly normal.

**Trial 2.**

The second trial was begun November 21, 1924, and extended over a 4 months period. The study was repeated, not only to secure further data, but also to ascertain whether the beneficial effect of sunlight which was indicated in the trial carried out in summer would hold for winter conditions. In practice, stiffness is much more prevalent in winter than at other seasons. A partial explanation of this lies in the fact that the ration is apt to be more restricted in the winter time. However, even with similar rations
and with the animals always housed inside, the writers (1) in their previous study found that a larger percentage of stiffness occurred in winter.

Of more direct significance with relation to the present study is the fact that the winters are so severe in this latitude that on many days the weather is not suitable for the pigs to remain long outdoors. Further, there are fewer sunny days. Another consideration that has an important bearing is the fact that, as shown by Dorno (2), the ultra-violet solar radiation is much lower in winter than in summer.

The second trial was limited to a comparison of a group on the basal ration fed inside and a group on the same ration in the pen connected with the runway outdoors. The pigs in this latter group were fed out in the runway to make sure that they actually went outside at least three times a day. During the coldest weather the trap-door connecting the pen with the runway was kept closed except at feeding time, lest the excessive cold and exposure result in pneumonia and the significance of the data be limited thereby. With the exception of approximately 15 days the trap-door was always open and the pigs spent a varying amount of time outdoors, depending on the weather. During the latter part of February and early March a period of unseasonably warm weather resulted in the pigs spending a relatively large proportion of each day out in the runway towards the end of the trial. However, for the trial as a whole the average number of hours per day that the pigs were exposed to sunlight was certainly very much less than was the case in the previous summer. According to the records of the Ithaca office of the United States Department of Agriculture Weather Bureau, the average number of hours of sunlight per day for the period covered by the summer trial was 8.96 and for the winter trial, 4.87.

In Trial 2 every pig in one group had a litter mate in the other. Two of the pigs in the no-sunlight group became stiff toward the end of the 3rd month of the experimental period and were very stiff when they were killed early in the 4th month. The other two pigs in this group were slightly stiff by the middle of the 4th month. At the end of the month both were killed. One had become very stiff by this time, but in the case of the other one, No. 27, the stiffness had not become any more severe than when it was first noted.
The pigs in the sunlight group were killed at the same time as their litter mates previously mentioned. One of them, killed at the end of the 4th month, showed some indications of the characteristic stiffness, but the other three appeared entirely normal when slaughtered.

**Bone Analysis.**—Following the procedure of the previous trial the pigs were given a routine pathological examination as they were killed and then the femurs were taken for chemical and histological examination. The results of the chemical analyses are shown in Table III.

### Table III.

**Ash Content of Femurs.**

<table>
<thead>
<tr>
<th>Fig No.</th>
<th>Age.</th>
<th>Live weight.</th>
<th>Ration.</th>
<th>Weight of fresh bone.</th>
<th>Composition of fresh bone.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>days</td>
<td>kg.</td>
<td></td>
<td>gm.</td>
<td>Dry matter.</td>
</tr>
<tr>
<td>44</td>
<td>164</td>
<td>35.8</td>
<td>Basal.</td>
<td>124.9</td>
<td>49.89</td>
</tr>
<tr>
<td>46</td>
<td>164</td>
<td>36.7</td>
<td>&quot; + sunlight.</td>
<td>121.5</td>
<td>57.20</td>
</tr>
<tr>
<td>43</td>
<td>190</td>
<td>42.2</td>
<td>&quot;</td>
<td>170.5</td>
<td>53.61</td>
</tr>
<tr>
<td>42</td>
<td>184</td>
<td>50.0</td>
<td>&quot; + sunlight.</td>
<td>182.6</td>
<td>62.65</td>
</tr>
<tr>
<td>31</td>
<td>164</td>
<td>36.7</td>
<td>&quot;</td>
<td>120.7</td>
<td>52.11</td>
</tr>
<tr>
<td>37</td>
<td>164</td>
<td>42.2</td>
<td>&quot; + sunlight.</td>
<td>146.2</td>
<td>63.71</td>
</tr>
<tr>
<td>27</td>
<td>170</td>
<td>38.1</td>
<td>&quot;</td>
<td>125.0</td>
<td>51.92</td>
</tr>
<tr>
<td>26</td>
<td>164</td>
<td>43.5</td>
<td>&quot; + sunlight.</td>
<td>152.2</td>
<td>55.52</td>
</tr>
</tbody>
</table>

It is noted in Table III that in the case of each of the first three pairs the ash content of the femur of the pig exposed to sunlight is markedly higher than that of its litter mate fed indoors. Thus the results are in agreement with those secured in Trial 1. In the case of the fourth pair, however, the ash content of the bone of Pig 26 receiving sunlight is no higher than that of its litter mate, Pig 27. While all of the other animals in the no-sunlight group were markedly stiff when killed Pig 27 was only slightly affected. From this fact it might be expected that the chemical analysis would show the bone of this pig to have a higher ash content than the bones of the other pigs on the basal ration, as was
actually the case. However, as is described further on in this paper, the pathological examination showed the changes to be more marked in the bone of Pig 27 than in that of its litter mate, the beneficial effect of the sunlight being evident with this pair as with the other pairs studied in this trial. Thus the results of the chemical analysis for Pigs 26 and 27 constitute an exception to the other results secured in Trial 2.

It is noted in Table III that, as was the case in the previous trial, the pigs receiving the sunlight were uniformly the heavier when killed and had heavier femurs in three out of four cases, and that these femurs were uniformly higher in dry matter.

Pathological Examinations.—On routine pathological examination the occurrence of hemorrhagic lymph nodes, and of petechiae in the kidneys or mucosa of the urinary bladders was noted as in the previous trial, the changes occurring to a much greater degree in the no-sunlight group. Pneumonia was found in only one case, Pig 31.

As in the previous trial the femurs of the pigs in the no-sunlight group showed the following characteristic changes in the gross: bone marrow reddened throughout; spongy, porous cortical bone; an irregular and thickened epiphyseal cartilage, and hemorrhages under both the articular and epiphyseal cartilages. Under the microscope the zone of provisional calcification was irregular, with a marked proliferation of cartilage cells. Granulation tissue was present instead of bone and there were a large number of osteoclasts along the trabeculae. In the cortical bone under the periosteum there was granulation tissue instead of bone, and areas of hemorrhage in the marrow spaces of the medullary bone were noted.

As in the previous trial, the femurs of the litter mates in the sunlight group showed a pathological picture much less advanced. The cortical bone was denser, the epiphyseal cartilage was less irregular, and there was less hemorrhage. The changes in the zone of provisional calcification were less extensive. The changes involving the formation of granulation tissue and of osteoclasts along the trabeculae did not extend as far into the diaphysis. In the case of Pigs 46 and 42 no granulation tissue was found while in Pigs 44 and 43 the formation had advanced to a considerable extent. Although in No. 26 the zone of provisional calcification
was irregular and there was hemorrhage under the articular cartilage as well as under the epiphyseal cartilage in the diaphysis, in No. 27 these changes were far more advanced and extended for a greater distance into the diaphysis. In the bone of Pig 31 more granulation tissue was present than was the case with Pig 37, bone calcification had not advanced as far, and the epiphyseal and articular cartilages were thicker.

Sections taken at the lumbar enlargement of the spinal cord of Pigs 46 and 31 were examined by Nissl’s method and appeared to be normal except for a slight amount of hyperemia in individual vessels and a slight amount of coagulum in the central canal. One case of congestion of the pia-arachnoid of the spinal cord was previously reported by the writers (1) in their earlier publication. Otherwise, the former observations of the writers were confirmed.

DISCUSSION OF RESULTS.

The results of Trials 1 and 2 are in accord in showing that sunlight has a markedly favorable influence on the mineral nutrition of growing pigs fed a ration low in calcium and presumably low also in the factor aiding calcium assimilation. All of the pigs fed this ration without access to direct sunlight, a total of eight animals, developed the characteristic stiffness within 4 months, while seven out of the eight pigs receiving the same ration with sunlight showed no signs of this trouble over the same period. The remaining animal exposed to sunlight, a member of the winter group, was apparently slightly stiff at the end of the 4 months period.

The results in Tables II and III are in agreement in showing that the sunlight has in general a marked effect in increasing the ash content of the bones. This influence of the sunlight was clearly shown in six out of seven of the comparisons made.

It is believed that the comparisons between the litter mates constitute the best method of presenting and of judging the significance of the results secured. However, in view of the fact that in one comparison the sunlight was apparently without influence on the ash content, it is to the interest of accurate interpretation of results to ascertain how these figures, which are out of line with the rest, affect the significance of the mean values which may be computed for each group. Calculation shows that the
average ash content for the femurs of the eight pigs in the no-
sunlight group is 14.41 per cent ± 0.701, computing the probable
error by Peter's formula. The average in the case of the seven
pigs examined from the sunlight group is 18.28 per cent ± 0.257.
The difference between the average's thus becomes 3.87 per cent
± 0.747, clearly a significant figure.

The results of the histological studies were in agreement with
the findings of the chemical analyses in showing that a more nearly
normal bone was produced where the animals were exposed to
sunlight.

The bones of the animals in the sunlight group were by no means
normal either in ash content or histologically, nor were they as
good in these respects, according to Trial 1, as the bones from pigs
receiving the basal ration plus the added sources of calcium, but
not having access to direct sunlight. However, the bones of this
last group were still below normal, both in ash content and histo-
logically, as compared with the bones of pigs fed a ration rich in
minerals on pasture, studies of which were previously made by
the writers. Thus it would be reasonable to expect that a still
better state of calcium nutrition would have resulted if a group
had been fed the ration with the extra sources of calcium and
exposed to sunlight also. In fact it has been recently shown
both by Steenbock, Hart, and Jones (3) and by Zilva, Golding,
and Drummond (4) that with a ration amply supplied with cal-
cium and phosphorus but low in the antirachitic factor a better
bone development will result where the animals are housed with
access to sunlight.

A comparison of the results of the two trials shows no certain
evidence that the sunlight produced any greater effect in summer
than it did in winter. It is true that in the winter trial one of
the comparisons did not show any advantage for the sunlight.
Further, one of the pigs in this trial apparently became slightly
stiff despite the sunlight. However, a comparison with a much
larger number of animals than was used in the present study is
needed to ascertain definitely whether certainly better results
would be obtained in the summer. Clearly the summer group
received much more sunlight and a sunlight of higher efficiency,
but the winter sunlight may have been sufficient in amount and
efficiency to produce the maximum possible effect on assimilation
of calcium, with the small amount of the latter supplied.
From a practical standpoint the results indicate that the common observation, that both growing pigs and brood sows keep in better condition and are less likely to develop stiffness on pasture than when they are housed inside, may be explained on the basis of sunlight as well as of feed. It is also indicated that it is good practice to let the pigs spend a part of each day outdoors, in winter as well as summer, whenever the weather is not too severe, and that healthier and better nourished animals may result thereby.

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