The effects of housing system and feeding level on the joint-specific prevalence of osteochondrosis in fattening pigs

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Abstract

Osteochondrosis (OC) is seen as the main cause of leg weakness in pigs, leading to welfare problems and economic losses. Environmental factors in pig husbandry, such as the housing system and feeding strategy are expected to influence the prevalence of OC. Therefore, this study investigated the effects of housing system and feeding strategy on the prevalence and severity of OC.

In the experiment 345 pigs were used. At an age of 69 days intact boars and gilts were separated and assigned to groups of five or six individuals. A two by two factorial design of housing system and feeding strategy was applied. The housing system was either a conventional concrete floor partial slatted, or a deep litter floor with extra space allowance. The feeding strategy was either ad libitum or restricted to 80% of ad libitum. Pigs were slaughtered at the age of 161–176 days. In total, five joints of the left front and hind limbs were macroscopically assessed for OC on a five-point scale, ranged from no OC through (semi-)loose cartilage fragments.

The prevalence of OC in the experimental population was 41.4%, and 12.4% of the individuals had severe lesions. The tarsocrural joint was most affected (30.2%) by OC. OC scores between the different joints were not correlated. Medial sections of joints were most affected (63–100%). Boars were more affected than gilts in the elbow joint. Conventionally housed pigs were more affected than deep litter housed pigs. Ad libitum fed pigs had more OC than restrictedly fed pigs. OC was most prevalent with 57.5% in the pigs on the conventional floor with ad libitum feeding. OC was least prevalent with 33.7% in pigs kept in deep litter housing with restricted feeding. The sex, housing system and feeding strategy did not affect OC in the femoropatellar, metacarpophalangeal, and metatarsophalangeal joints.

Our results demonstrate that the OC prevalence can be reduced by applying deep litter floors with extra space allowance and/or restricted feeding in fattening pigs.

Keywords: Feed, Housing, Space, Joints, Osteochondrosis, Pigs

1. Introduction

Osteochondrosis (OC) is a disturbance of the endochondral ossification during skeletal growth, which occurs in many species including cattle, pigs, horses and humans (Crenshaw, 2006; Donabédian et al., 2006; Grøndalen, 1974a; Van Weeren, 2006; Ytrehus et al., 2007). Osteochondrosis is the main cause of leg weakness, a general term for leg problem in pigs (Grøndalen, 1974d; Jørgensen, 1995; Reiland et al., 1978; Kirk et al., 2008; Stern et al., 1995). Leg weakness may result in lameness, which reduces welfare of fattening pigs and is an important cause for premature culling in sows, as they reach higher age (Gresham, 2003; Dewey, 2006; Grøndalen, 1974b; Reiland et al., 1978). Leg weakness is caused by defects in the development and the differentiation of cartilage to bone, which can lead to an increased risk of injuries (Grøndalen, 1974b; Jørgensen, 1995; Reiland et al., 1978; Stern et al., 1995). The main cause of leg weakness is a disturbance of the endochondral ossification during skeletal growth, which occurs in many species including cattle, pigs, horses and humans (Crenshaw, 2006; Donabédian et al., 2006; Grøndalen, 1974a; Van Weeren, 2006; Ytrehus et al., 2007). Osteochondrosis is the main cause of leg weakness, a general term for leg problem in pigs (Grøndalen, 1974d; Jørgensen, 1995; Reiland et al., 1978; Kirk et al., 2008; Stern et al., 1995). Leg weakness may result in lameness, which reduces welfare of fattening pigs and is an important cause for premature culling in sows, as they reach higher age (Gresham, 2003; Dewey, 2006; Grøndalen, 1974b; Jørgensen, 1995; Reiland et al., 1978). Leg weakness is caused by defects in the development and the differentiation of cartilage to bone, which can lead to an increased risk of injuries (Grøndalen, 1974b; Jørgensen, 1995; Reiland et al., 1978; Stern et al., 1995).
Reduction of the prevalence of OC could, therefore, improve wellbeing, and could reduce economical losses due to premature culling.

Environmental factors like housing system and feeding strategy affect the development of OC, but have not been studied intensively, and the outcome of studies shows substantial inconsistency (Carlson et al., 1988; Goedegebuure et al., 1980; Grøndalen, 1974c; Jørgensen, 1995; Nakano et al., 1987; Ytrehus et al., 2007). Housing systems affect leg condition and cause local overload within joints (Nakano et al., 1987). Pigs housed on straw bedding showed less leg weakness (lameness, etc., with OC as a major cause) compared to pigs housed on conventional floors (Jørgensen, 2003; Scott et al., 2006, 2007).

High growth rates, either due to genetic selection or feeding, cause disturbances in bone metabolism and thereby increase the prevalence of OC (Grøndalen, 1974a; Busch et al., 2006; Kadarmideen et al., 2004; Nakano et al., 1987; Ytrehus et al., 2007). High feeding levels may, therefore, increase the prevalence of OC. In contrast, a deep litter floor with additional space allowance will stimulate activity and may thereby decrease the prevalence of OC.

Public concern and legislation gradually change the housing systems in which pigs are kept (LNV, 2010). Current systems commonly have barren, partially concrete, floors, with little space per pig. The systems that will be common in the future are likely to have more space per pig and floors covered with a substrate such as straw or deep litter. An important question is whether this shift in housing systems will indeed reduce welfare problems such as OC.

This work, therefore, investigates the effects of two housing systems and feeding strategies on prevalence and severity of OC in joints of front and hind limbs of fattening pigs. The housing system was either a concrete, partially slatted, floor, or a deep litter floor with extra space allowance, whereas feeding was either ad libitum or restricted.

### 2. Material and methods

#### 2.1. Materials

A total of 345 pigs divided in two batches were exposed to a two by two factorial design of a housing and feeding treatment. The 187 pigs from batch 1 were Tempo”Topigs 40 crossbreds, descending from 23 dams. The 158 pigs from batch 2 were Pietrain”Topigs 40 crossbreds, descending from 18 dams. Litters were equally divided over the treatment groups, to avoid confounding of genetic effects with treatment effects. Pigs of both batches originated from an intermitted suckling experiment, in which pigs were either weaned conventionally at three weeks of age, or weaned at varying ages (Gerritsen et al., 2008). After weaning each litter was housed in a conventional pen with a 50% concrete, 50% metal slatted floor. This type of housing system together with ad libitum feeding is the common way to keep this genetic line during the fattening period.

Intact boars (56%) and gilts (44%) were separated at an age of 69 days. In total, 64 groups were composed of five or six individuals, based on a balanced distribution of intermitted suckling treatment, sex, litter mates, and bodyweight at the age of 42 days. Each treatment group of the two by two factorial design contains 16 pens — 8 female and 8 male pens.

#### 2.2. Experimental design

The treatments, conventional or deep litter housing, and ad libitum or restricted feeding, were applied to the pigs, assigned to groups of five or six individuals. A conventional pen consisted of a 50% metal slatted (ridged round bars), 50% solid concrete floor over 5 m². A deep litter pen consisted of a solid concrete floor with approximately 25–50 cm of wood shavings over 8.5 m². In the following, we will use the label “deep litter” to refer to the system having deep litter floors with 8.5 m² floor area per pen. Water was available ad libitum for all treatment groups by two drinking nipples per pen. Pigs were fed three succeeding diets: standard pelleted, dry grower and finisher diet with decreasing protein content (respectively, 176, 160 and 152 g crude protein/kg feed). These diets are usually fed to these ad libitum fed, crossbred, and fattening pigs. At days 107 and 108 feed 1 was changed to feed 2, and at days 140 and 141 feed 2 was changed to feed 3. When changing feed, a mixture of 50% of each feed was supplied for two days. The ad libitum fed pigs had unlimited access to feed using an automatic feeding unit. The restricted fed pigs received two equal portions of feed each day per group, in a trough covered by a rack ensuring individual feeding places, at 8 am and 4 pm. The amount of feed supplied to restricted fed pigs was 80% (in kg) of the ad libitum average daily intake in the preceding week.

During the experiment, pigs were weighed once every two weeks until slaughter. Pigs of batch 1 (n = 187) were slaughtered at an age ranging from 165 to 176 days. Pigs of batch 2 (n = 158) were slaughtered at an age between 161 and 165 days. The carcasses were stored at 4 °C for one day. For each individual, the left limbs were dissected in the shoulder and hip joints, tagged, and stored at −21 °C until further dissection and scoring of the joints. Since OC prevalence in the left and right joints of pigs showed correlations close to one in a previous study (Jørgensen and Andersen, 2000), only the left limbs were used in this study.

#### 2.3. Scoring

Pigs were scored for OC in five joints of the left front and hind limb. In the front limb, the elbow and metacarpophalangeal joint were scored. In the hind limb, the femoropatellar, the tarsocural, and metatarsophalangeal joint were scored. In total, the five joints were scored on 24 locations (Table 1). The cartilage of a location was macroscopically scored on a categorical scale from A–E, as used in a previous study for macroscopic OC examination in horses (Van Weeren and Barneveld, 1999). Score A represented no abnormalities, score B flattening of cartilage, score C slight irregular cartilage, score D severe irregular cartilage, and score E ‘classic’ lesion with osteochondrotic cyst (Fig. 1). Score B and score C are referred to as mild OC, and score D and score E are referred to as severe OC. An experienced veterinarian who is a specialist in judging OC (P. R. V. W.), scored all joints without knowing the experimental treatment.
Table 1
Mean slaughter weights in kg (at 163–164 days), including SD and number of animals per sex, batch, and treatment group.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Mean final weight, kg (SD)</th>
<th>Number of pigs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boars</td>
<td>103 ± 16</td>
<td>181</td>
</tr>
<tr>
<td>Gilts</td>
<td>101 ± 15</td>
<td>147</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Batch*</th>
<th>Mean final weight, kg (SD)</th>
<th>Number of pigs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>108 ± 14</td>
<td>173</td>
</tr>
<tr>
<td>2</td>
<td>95 ± 14</td>
<td>155</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment*</th>
<th>Mean final weight, kg (SD)</th>
<th>Number of pigs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ad libitum fed x Conventional housed</td>
<td>110 ± 15</td>
<td>76</td>
</tr>
<tr>
<td>Ad libitum fed x Deep litter housed</td>
<td>98 ± 12</td>
<td>85</td>
</tr>
<tr>
<td>Deep litter housed x Ad libitum fed</td>
<td>110 ± 11</td>
<td>79</td>
</tr>
<tr>
<td>Deep litter housed x Restrictedly fed</td>
<td>93 ± 14</td>
<td>88</td>
</tr>
</tbody>
</table>

*Significant difference of P < 0.05 between treatments or batches.

2.4. Prevalence

The prevalence of OC was determined for each location within a joint, for each joint (joint level) and for OC within the entire pig (animal level). The prevalence of OC on location level was expressed as the frequency of score A, score B, score C, score D and score E at that location. To present prevalences at joint and animal level, animals were grouped based on their worst OC-score. The prevalences of OC on animal and joint level are presented as: A, the percentage of pigs with only scores A in all joint locations; ≤B, the percentage of pigs with at least one score B but no scores C, D, or E; ≤C, the percentage of pigs with at least one score C, but no scores D or E; ≤D, the percentage of pigs with at least one score D, but no score E; and ≤E, the percentage of pigs with at least one score E.

2.5. Data transformation

To use the OC-scores in a statistical analysis, we transformed the categorical observations into quantitative traits. Each categorical score was transformed into the mean liability value for that score (Falconer, 1965). This procedure resulted in 6 quantitative traits, one for each of the five joints and one for the entire animal. Values on animal or joint level were calculated by summing the values of all locations within that animal or joint. For example, the calculation of the value for the tarsocrural joint (nine locations) is as follows: An animal was scored five times a score A, two times a score B, one time a score C, zero time a score D, and one time a score E, resulting in a quantitative OC value of 5(A) − 0.085 + 2(B) ∗ 1.82 + 1(C) ∗ 2.15 + 0(D) ∗ 2.81 + 1(E) ∗ 3.37 = 8.74 for the tarsocrural joint of this animal. The quantitative OC value on animal level was calculated by adding the values of the four other joints.

2.6. Statistical analysis

To investigate the relationship between OC in different locations and joints, Pearson’s correlation coefficients of the quantitative OC values were estimated between joints, and between locations within a joint. To investigate the effects of the treatments, all above described parameters were tested in a linear model.

Records on pigs from the same pen may show statistical dependency, which calls for either applying the analysis at pen rather than pig level, or including pen as a random effect in the model. However, the estimate for the random effect of pen was practically zero, indicating that pen members are independent. The interest was not in resulting variance estimates, but in appropriate hypothesis testing of model terms of interest. Moreover, an analysis using pen as the experimental unit yielded nearly identical results compared to treating pigs as the experimental unit. We, therefore, used pigs as experimental unit.

The following linear mixed model was used to estimate the treatment and animal effects on the quantitative OC values, both on animal and joint level,

\[ Y_{ijkl} = \mu + \text{Housing}_i + \text{Feeding}_j + \text{Sex}_k + \text{Housing} \times \text{Feeding}_{ij} + e_{ijkl} \]

where \( Y_{ijkl} \) is the quantitative OC value (animal or joint level) of pig \( l \), with housing system \( i \), feeding strategy \( j \), sex \( k \), and \( \mu \) is the mean; Housing \( i \) is the fixed class effect of housing system (\( i = \) conventional, deep litter); Feeding \( j \) is the fixed class effect of feeding strategy (\( j = ad \) libitum, restricted); Sex \( k \) is the fixed class effect of sex (\( k = \) boar, gilt); Housing*Feeding \( ij \) is the fixed interaction effect of housing system and feeding strategy; \( e_{ijkl} \) is the random residual of pig \( l \).

3. Results

In compliance with the regulations of the animal experimental committee, 11 of 345 pigs had to be euthanized prematurely for welfare reasons. Some of these pigs suffered from lameness, or were severely injured by pen mates. The majority of these problems appeared shortly after mixing of the animals at the start of the experiment, and seemed to be related to behavioural interactions, not to OC. Later euthanizations were due to tail biting or disease, not OC. The euthanized pigs were nearly equally distributed over the treatments.

Mean slaughter weight of the total experimental population was 102 kg (SD 15.2) (results not shown). Differences in mean slaughter weights were found between batches and treatments (Table 1). Conventionally (110 kg) or deep litter housed (110 kg) \( ad \) libitum fed pigs were significantly heavier than conventionally (98 kg) or deep litter housed (93 kg) restrictedly fed pigs.

3.1. Prevalences

Fifty-nine percent of the animals had score A at all locations (Table 2). Animals with scores B to E had either one location (33%), two locations (8%) or three locations (1%) affected, of which 12% of the animals showed severe OC (score D or E).

For each joint, the prevalences of OC are presented in Table 3. The tarsocrural joint was most frequently affected by OC, with a prevalence of 30.2% scores B–E. The femoropatellar joint was most severely affected with a prevalence of 7.7%.
a) View of the distal articular surface of the femur showing normal cartilage (Score A)

b) Flattening of the articular cartilage on the lateral and medial condyles of the humerus (Score B)

c) Irregular articular cartilage on the medial trochlea of the talus (Score C)

d) Severe irregularity on the medial condyle of the femur (Score D)

e) Severe lesion with (semi-)loose fragments and bone cyst at the medial femoral condyle (Score E)
3.2. Interactions and correlations

There were no significant effects of intermitted suckling treatment, or interaction effects of sex and feeding strategy nor sex and housing system. Random effects of mother and batch were non-significant ($p>0.2$) and therefore excluded from the model. The absence of significant effects due to intermitted suckling treatment and mother indicate that age at weaning did not significantly affect OC.

No significant correlations ($p<0.05$) between OC scores for different joints were found (data not shown). Within a joint, only a few significant correlations between OC scores at different locations were found. In the elbow joint, an intermediate correlation of 0.30 was found between score for the medial humeral condyle and score for the proximal edge of radius. In the tarsocrural joint, a significant correlation of 0.15 was found between the lateral trochlea of talus and the lateral tibial condyle.

3.3. Treatments

OC was most prevalent (57.5%) in the pigs that received the treatment conventional floor with ad libitum feeding (Table 2). OC was least prevalent (33.7%) in pigs kept in deep litter floor with restricted feeding. Though overall prevalence was highest with conventional floors, score E was more frequent with deep litter floors and extra space. On average, ad libitum fed pigs showed the highest prevalence of OC, and restrictedly fed pigs showed lowest OC. For all treatments and sexes, the prevalence of severe OC was greater than 10% at animal level. The total OC prevalence (B–E) was 43.4% in boars and 38.9% in gilts. Boars had more severe OC (D–E) (14.3%) than gilts (10.1%).

3.3.1. Housing system, feeding and sex

Table 4 summarizes effects that were significant. Because the analysis was performed on the liability scale, absolute values of the estimated effects are difficult to interpret. We, therefore, present the estimated effects in standard deviation units and in a graphical manner in Fig. 3a and b. Fig. 3a and b show a clear interaction between the two treatments. The housing treatment had a large effect on OC in ad libitum fed pigs, but only a small effect in restricted fed pigs. Comparison of Fig. 3a and b indicates that the overall OC-value on animal level is largely determined by the treatment effects on the tarsocrural joint. The influence of the treatment effects on the other joints was small.

Housing system affected on OC in the elbow and the tarsocrural joint. Conventionally housed pigs were significantly (0.19 SD units; $p=0.068$) more affected with OC than deep litter housed pigs in the elbow joint. Feeding strategy only had a significant effect on the tarsocrural joint and on animal level. In the tarsocrural joint and on animal level, ad libitum fed pigs were significantly ($p=0.0004$ and $p=0.003$ respectively) more affected with OC than restrictedly fed pigs. The combination of conventional floor with ad libitum feeding showed the highest OC, both at animal level and at the tarsocrural joint. In the tarsocrural joint, the change from conventional housing to deep litter when pigs are fed ad libitum decreased OC with more than 1 SD ($p<0.05$) (Fig. 2b).

Sex affected OC only in the elbow joint. Boars were significantly (0.34 SD units; $p=0.002$) more affected than gilts (data not shown). Sex had no effect on animal level and on the other joints.

4. Discussion

Based on the prevalences of OC found in our study, we conclude that the elbow joint, femoropatellar joint and tarsocrural joint are most severely affected by OC, compared to the MCP and MTP joints, especially in the medial sections of the joints. These joints are, therefore, the most important joints to focus on when studying OC in pigs. Deep litter housed pigs, in combination with a higher space allowance, showed less OC than conventionally housed pigs. Restricted feeding decreased the prevalence of OC, mainly in the tarsocrural joint. Housing system and feeding strategy affected OC prevalence in pigs, but the effects differed between joints.

4.1. Prevalence

4.1.1. Animal

Overall, the prevalence of OC from mild to severe lesions (scores B–E) on animal level was 41.4%. This prevalence is lower than prevalences found in previous studies varying from approximately 80 to 100% in pigs at slaughter (Crenshaw, 2006; Grøndalen, 1974a). However, all studies varied largely in approach and results. Between studies, large differences exist in the number of examined joints and locations within the joints, breed, sex, age, and the scale on which OC is scored. Furthermore, prevalences within this study can be expected to be lower than normal, because the treatment of restricted feeding and deep litter floor decreased the prevalence of OC. The treatment conventional floor and ad libitum feeding, currently a common way of pig housing, had the highest prevalence of OC, 57.5%. In this study, however,
the pigs housed on conventional floors had a somewhat larger floor area (0.8–1 m² per pig) than common in commercial herds of fattening pigs (0.65–0.8 m²; European Food Safety Authority, 2007). This may explain some of the differences found between studies.

4.1.2. Joints

In our study, the prevalence of OC in the elbow was 6%, and in the femoropatellar joint 11%, which is low compared to other studies, although still within reported ranges. In literature, the prevalence of OC in the elbow joint varied between 2–56% (Grøndalen, 1974a; Jørgensen and Andersen, 2000; Jørgensen and Nielsen, 2005; Klimiene and Klimas, 2006; Luther et al., 2007) and in the femoropatellar joint between 10–84% (Grøndalen, 1974a; Jørgensen and Andersen, 2000; Kadarmideen et al., 2004; Klimiene and Klimas, 2006; Luther et al., 2007).

In our study, the metacarpophalangeal and metatarsophalangeal joints were least affected with OC; only 1.8% and 0.3% was affected. In literature, no results were found about the prevalence of OC in these joints.

The medial sections of a joint were found to be more affected. This is possibly caused by the locally higher loading of the medial aspect of the joints in the limbs due to the closer position to the centre of gravity and the related differences in moment on the medial and lateral joint surfaces and is in agreement with findings from previous studies (Carlson et al., 1988; Grøndalen, 1974b; Nakano et al., 1987; Ytrehus et al., 2007).

The positive correlations between locations, such as between the lateral trochlea of talus and the lateral tibial cochlea, are likely caused by physical contact between lesions, so called ‘kissing lesions’.

4.2. Factors influencing OC

4.2.1. Sex

In our study, boars were significantly more affected by OC in the elbow joint than gilts. Based on literature, boars and barrows were often more affected than gilts and sows (Goedegebuure et al., 1988; Jørgensen, 2003; Luther et al., 2007; Stern et al., 1995; Ytrehus et al., 2004; Kadarmideen et al., 2004). The higher weight of boars is considered to be more affected with OC in the tarsocrural joint compared to restrictedly fed pigs. As expected, pigs that were ad libitum fed, regardless the housing system, were heavier at slaughter. Ad libitum fed pigs might have, besides a higher weight, a higher muscular growth in relation to the skeletal development, leading to an imbalanced development. This imbalanced development may cause local overload, which may result in a higher frequency of skeletal problems (Weiler et al., 2006). Higher feed intake

4.2.2. Housing system

Conventionally housed pigs were significantly more affected with OC in the elbow and tarsocrural joint than deep litter housed pigs. In a study of young pigs walking on different wet concrete floors, front limbs of pigs slipped more and longer compared to their hind limbs (Applegate et al., 1988). The effect of weight bearing in combination with a more slippery floor, gives the elbow joint extra disadvantage, leading to more cartilage damage. Slipping, correcting a slip, or more careful walking, probably can change a pig’s posture and lead to local overloading of articular cartilage (Jørgensen, 2003; Nakano et al., 1987). The negative effects of a conventional floor on the tarsocrural might also be due to the slippery properties. Figs. 2b vs. 3a shows that the effect of housing system is greatest in the tarsocrural joint. Surprisingly, the effect of housing system on OC in the tarsocrural joint has not been investigated previously.

Pigs kept on deep litter with a higher space allowance, were found to be more active in our study (results not shown) and previous studies (Scott et al., 2006, 2007). Bone growth, strength and metabolism are positively affected by exercise or physical activity, which is reduced in situations with limited opportunities for locomotion (Jørgensen, 2003; Weiler et al., 2006). Consequently for our study, the positive effects on bone development of deep litter housing and higher space allowance could possibly have decreased OC. Other studies found that pigs with more space were less aggressive and had fewer injuries (Randolph et al., 1981; Weng et al., 1998).

4.2.3. Feeding

Ad libitum fed pigs were significantly more affected with OC in the tarsocrural joints compared to restrictedly fed pigs. As expected, pigs that were ad libitum fed, regardless the housing system, were heavier at slaughter. Ad libitum fed pigs might have, besides a higher weight, a higher muscular growth in relation to the skeletal development, leading to an imbalanced development. This imbalanced development may cause local overload, which may result in a higher frequency of skeletal problems (Weiler et al., 2006). Higher feed intake

Table 2

Observed prevalences of OC (in % at animal level) of scores A–E in the experimental population, within treatment and sex.

<table>
<thead>
<tr>
<th>Prevalence</th>
<th>Treatment</th>
<th>Sex</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional floor</td>
<td>Deep litter floor</td>
<td>Boars</td>
</tr>
<tr>
<td></td>
<td>Ad libitum</td>
<td>Restricted</td>
<td>Ad libitum</td>
</tr>
<tr>
<td>=A</td>
<td>42.5</td>
<td>64.8</td>
<td>59.3</td>
</tr>
<tr>
<td>≤B</td>
<td>7.5</td>
<td>2.3</td>
<td>8.6</td>
</tr>
<tr>
<td>≤C</td>
<td>36.2</td>
<td>22.7</td>
<td>18.5</td>
</tr>
<tr>
<td>≤D</td>
<td>6.3</td>
<td>4.5</td>
<td>1.2</td>
</tr>
<tr>
<td>≤E</td>
<td>7.5</td>
<td>5.7</td>
<td>12.4</td>
</tr>
</tbody>
</table>

* The prevalence of OC per treatment and sex was as follows: = A, the percentage of pigs with only scores A in all joint locations; ≤ B, the percentage of pigs with at least one score B but no scores C, D, or E; ≤ C, the percentage of pigs with at least one score C, but no scores D or E; ≤ D, at least one score D, but no score E; ≤ E, the percentage of pigs with at least one score E.
could disturb the metabolism of bone growth, because high feed intake or high carbohydrate intake is suggested to cause metabolic changes by increasing IGF-1 and negatively affecting endochondral osseous formation in pigs, dogs and horses (Dammrich, 1991; Nakano et al., 1987; Ralston, 1996; Savage et al. 1993).

5. Conclusion

The OC prevalence of the total population was 41.4%, of which 12.4% was severely affected. Based on the prevalences of OC found in our study, and the findings in literature, it can be concluded that the elbow, femoropatellar and tarsocrural joints are most affected by OC, especially in the medial sections of the joints. Therefore, the elbow, femoropatellar and tarsocrural joints are considered to be the most important joints to focus on when studying OC in pigs. OC was rare in the metacarpophalangeal and metatarsophalangeal joints.

Deep litter housed pigs, in combination with a higher space allowance, showed less OC than conventionally housed pigs. Restricted feeding reduced the prevalence of OC, mainly in the tarsocrural joint. The prevalence of OC in conventionally housed ad libitum fed animals was 57.5%. Prevalence reduced to 33.7% when applying deep litter housing with more space and restricted feeding. The housing system, feeding strategy and sex affected OC in different joints. The results at animal level were largely determined by the treatment effects on the tarsocrural joint. The influence on the other joints is small. The results show that OC in pigs can be reduced by applying a housing system with deep litter floors and more space and/or restricted feeding.

Acknowledgement

The authors thank the Dutch Product Board of Animal Feed for financial support in this project.

Table 3
Prevalences on joint location level, in %. The scores A, B, C, D and E per joint are expressed in the frequency of the total number of examined locations of the experimental population. The total joint percentages are the average of the location percentages.

<table>
<thead>
<tr>
<th>Joint</th>
<th>Elbow</th>
<th>Metacarpophalangeal</th>
<th>Femoropatellar</th>
<th>Tarsocrural</th>
<th>Metatarsophalangeal</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>93.8</td>
<td>97.9</td>
<td>89.0</td>
<td>69.2</td>
<td>99.4</td>
</tr>
<tr>
<td>B</td>
<td>1.2</td>
<td>0.0</td>
<td>0.9</td>
<td>4.4</td>
<td>0.0</td>
</tr>
<tr>
<td>C</td>
<td>1.5</td>
<td>1.5</td>
<td>1.8</td>
<td>21.9</td>
<td>0.3</td>
</tr>
<tr>
<td>D</td>
<td>0.6</td>
<td>0.3</td>
<td>1.5</td>
<td>3.0</td>
<td>0.0</td>
</tr>
<tr>
<td>E</td>
<td>2.3</td>
<td>0.0</td>
<td>6.2</td>
<td>0.9</td>
<td>0.0</td>
</tr>
<tr>
<td>ND*</td>
<td>0.6</td>
<td>0.3</td>
<td>0.6</td>
<td>0.6</td>
<td>0.3</td>
</tr>
</tbody>
</table>

* ND* means not determinable: this percentage showed the part of the joints in which OC could not be scored (for instance because of the presence of trauma).

Table 4
The effect of housing system, feeding strategy and sex on the quantitative OC values, based on all five joints on animal level, and joint level. The results from the modelb are expressed as p-values.

<table>
<thead>
<tr>
<th>Level</th>
<th>Animal</th>
<th>Joint a</th>
<th>Elbow</th>
<th>Tarsocrural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional&lt;deep litter</td>
<td>0.021</td>
<td>0.068</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>Ad libitum&lt;restricted</td>
<td>0.003</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gilts&lt;boars</td>
<td></td>
<td>0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing*Feeding c</td>
<td>0.040</td>
<td>0.047</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Femoropatellar, metacarpophalangeal and metatarsophalangeal joints showed no significant effects of treatments (p > 0.10).

b The model is: Yijkl = μ + Housing i + Feeding j + Sex k + Housing*Feeding ij + e ijkl.

Fig. 2. a) The interaction effects of treatment on the quantitative OC value at animal level. The results are expressed in SD units. b) The interaction effects of treatment on the quantitative OC value at the tarsocrural joint. The results are expressed in SD units.
representing the transformed OC categories (of standard deviations) expressed on the liability scale (Falconer, 1965), 60
Busch, M.E., Christensen, G., Wachmann, H., Olsen, P., 2006. Osteochondrosis liability value below 1.78, and showing discrete phenotypic categories (Falconer, 1965). In liability model is a common way to analyze polygenic traits not mean that we assumed the categorical scores to follow a normal distribution, but rather that the observed categorical tentative values, we assumed a continuous normally distributed Appendix A
Fig. 3. Example of a normal distribution (numbers on x-axis indicate number of standard deviations) expressed on the liability scale (Falconer, 1965), representing the transformed OC categories (scores A to E) to their linear OC value of the tarsocural joint (Van Grevenhof et al. 2009).

For the transformation of categorical scores into quantitative values, we assumed a continuously normally distributed liability underlying the categorical scores (Fig. 3). This does not mean that we assumed the categorical scores to follow a normal distribution, but rather that the observed categorical scores depend on an unobservable normally distributed liability underlying the categorical observations. Such a liability model is a common way to analyze polygenic traits showing discrete phenotypic categories (Falconer, 1965). In this model, liability values within a certain range correspond to a particular phenotypic category of an OC score, the range being determined by the incidence of that category. In Fig. 3, for example, a score A of the tarsocural joint corresponds to a liability value below 1.78, and score B corresponds to a liability between 1.78 and 1.87. Observed categorical scores were transformed into the mean liability value for that score. For example, in Fig. 3, score A occurred in 96.23% of the cases, represented by the area below a liability value of 1.78. The mean liability value of this area is −0.085. Thus, score A was transformed into a value of −0.085. Fig. 3 indicates the remaining transformed values for B through E. Note that Fig. 3 depicts an example for the tarsocural joint; liability values will differ for other joints. (Using transformation to a liability scale, rather than transforming A through E simply into 1 through 5, has the advantage that the differences between the resulting values follow from the observed incidence in the data. A transformation into 1 through 5 would imply that the difference between, e.g., B and C equals the difference between, e.g., D and E). The incidence at specific locations within a joint was too low to enable reliable transformation to a liability scale for each of the locations separately.

References