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J ANIM SCI 2013, 91:5167-5176.

doi: 10.2527/jas.2013-6591 originally published online August 29, 2013

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<http://www.journalofanimalscience.org/content/91/11/5167>



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The influence of dietary restriction before and after 10 weeks of age on osteochondrosis in growing gilts¹

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ABSTRACT Osteochondrosis (OC) is one of the main causes of leg weakness causing premature culling in breeding sows and develops in a short time frame in young growing gilts. Dietary restriction may have different effects on OC prevalence depending on the age of the gilts. The aim of this study is to investigate age-dependent effects of dietary restriction, ad libitum vs. restricted (80% of ad libitum), on the occurrence of OC in gilts at slaughter (26 wk of age). At weaning (4 wk of age), 211 gilts were subjected to one of 4 treatments of a feeding regime. Gilts were administered either ad libitum feeding from weaning until slaughter (AA); restricted feeding from weaning until slaughter (RR); ad libitum feeding from weaning until 10 wk of age, after which gilts were switched to restricted feeding (AR); or restricted feeding from weaning until 10 wk of age, after which gilts were switched to ad libitum

feeding (RA). At slaughter, the elbow, hock, and knee joints were harvested. Joints were scored macroscopically for articular surface deformations indicative of OC. Gilts in the RA treatment had significantly higher odds of being affected by OC than gilts in the RR and AR treatments in the hock joint (OR = 3.3, $P = 0.04$ and OR = 8.5, $P = 0.002$, respectively) and at animal level (OR = 2.5, $P = 0.001$ and OR = 1.9, $P = 0.01$, respectively). Gilts in the AA treatment had higher odds of being affected by OC than gilts in the AR treatment in the hock joint (OR = 5.3, $P = 0.01$). The results indicate a possible pathway to reduce the prevalence of OC in breeding gilts that will have to last several parities. Switching from restricted feeding to ad libitum feeding after 10 wk of age increases OC prevalence as opposed to restricted feeding after 10 wk of age.

Key words: age, body weight, dietary restriction, gilts, osteochondrosis

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doi:10.2527/jas2013-6591

INTRODUCTION

Osteochondrosis (OC) in the epiphyseal growth cartilage involves a disturbance in the ossification

process of growing pigs, which can cause leg weakness (reviewed by Ytrehus et al., 2007) and reduced longevity in sows (Yazdi et al., 2000). As breeding gilts will have to last several parities, it is important that OC incidence is reduced to optimize health and welfare and thereby longevity and economic value of these gilts. A factor involved in reducing OC may be dietary restriction during rearing in gilts.

Several studies have found evidence of a positive relationship between dietary restriction and OC incidence (Glade and Belling, 1986; Carlson et al., 1988; van Grevenhof et al., 2011). However, other studies were unable to find similar relationships (Jørgensen, 1995; Donabédian et al., 2006). Variable results may be related to the duration and timing at which restrictions were administered. There are indications that the

¹This work was supported by the Science and Technology Foundation of the Netherlands Organization for Scientific Research (NWO-STW, grant number 11116), with cofinancers Institute for Pig Genetics BV (IPG BV) and Product Board Animal Feed (PDV). The authors would like to express their gratitude to the personnel of the research facility CARUS for their care of the animals and assistance throughout the experiment.

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Received April 15, 2013.

Accepted August 5, 2013.

sensitive time period for porcine OC development lies between 7 and 13 wk of age (Ytrehus et al., 2004a,b), which implies age-dependent effects of dietary restriction on OC development. However, the age-dependent effects of dietary restriction on OC in breeding gilts are yet to be established. The presence of age-dependent effects would imply that OC incidence could be reduced by taking preventative measures (adjustment of the amount of feed administered) at a young age.

The aim of this study was to investigate whether age-dependent effects of dietary restriction (ad libitum vs. 80% of ad libitum feeding) on OC incidence in breeding gilts at 26 wk of age can be identified, taking into account the abovementioned period of sensitivity for OC development. This will help elucidate the effect of dietary restriction on OC prevalence and assist in the development of feeding strategies that can be used in practice to reduce OC prevalence in breeding gilts.

MATERIALS AND METHODS

Ethical Note

Osteochondrosis can cause articular surface irregularities, possibly resulting in lameness that might affect the welfare of the gilts. Assessments to detect serious impairments of welfare in the gilts were therefore performed daily. Severely lame or wounded gilts were taken out of the experiment and euthanized. The experiment and all measurements were approved by the Animal Welfare Committee of Wageningen University and Research Centre in compliance with the Dutch Law on Animal Experimentation.

Animals

The experiment was performed using 211 Topigs 20 (Dutch Large White × Dutch Landrace) gilts acquired from a commercial breeding company (Van Beek SPF Varkens BV, Lelystad, Netherlands). This crossbred line represents a large part of the commercially kept sows in the Netherlands that will produce finishing pigs. The gilts entered the experiment after weaning at, on average, 26 ± 1.5 (SD) d of age. Gilts were group housed in 8.37 m² pens consisting of 60% slatted floor (slatted synthetic-coated expanded metal) and 40% solid floor (epoxy-coated solid concrete floor). Gilts had access to various enrichment items (such as biting chains, burlap sacks, solid plastic balls, rubber mats) at all times, which were switched every 3 to 4 d. Gilts had ad libitum access to water at all times through a drinking nipple. Gilts were weighed at birth, 19 d of age, at weaning, and once every 2 wk after weaning until slaughter at an average of 189 ± 3.9 d of age.

Treatments

Gilts were mixed and housed after weaning in 32 pens of 6 to 7 individuals and divided in 4 treatment groups with respect to dietary restriction on the basis of an equal distribution of littermates and BW measured at 19 d of age (1 wk before the start of the experiment). The 32 pens were divided over 4 departments (8 pens per department) with an equal distribution of the treatments per department. Treatments consisted of 4 feeding regimes administered to pens to assess age-dependent effects of dietary restriction. Two of the treatments entailed a switch in the amount of feed administered at 10 wk of age (73 d of age). The switch was set at 10 wk of age so that the piglets were subjected to different dietary restrictions within the first and second halves of the possible sensitive time period of OC development between 7 and 13 wk of age (Ytrehus et al., 2004a,b). The experimental setup resulted in 8 pens per treatment. Treatments consisted of ad libitum feeding continuously from weaning until slaughter (**AA**); restricted feeding continuously from weaning until slaughter (**RR**); ad libitum feeding from weaning until 10 wk of age, after which gilts were switched to restricted feeding (**AR**); and restricted feeding from weaning until 10 wk of age, after which gilts were switched to ad libitum feeding (**RA**). Restricted feeding was calculated as 80% of the ad libitum uptake of the preceding week. Up to 10 wk of age, restricted feeding calculations were based on the 16 pens that received ad libitum feeding up to that age (AA and AR treatments). After 10 wk of age, restricted feeding was calculated using the 8 pens that were exposed to only ad libitum feeding (AA treatment) to ensure that calculations were based on a steady ad libitum feed intake. Ad libitum-fed gilts received feed using a dry feeder unit. The feed-restricted gilts received feed in 2 portions per day (0800 and 1600 h) in 2 troughs with ample feeding space and with metal bars separating individual feeding places.

After weaning, gilts received first a pelleted weaning diet (9.49 MJ NE/kg, 158 g/kg CP, 10.8 g/kg digestible lysine). Subsequently, gilts were changed to 3 successive diets, adapted to their feed uptake and age. Diets were switched gradually over 2 d in which diets were offered as a 50% mixture of the old and new diets. The successive diets included a standard pelleted grower diet (9.84 MJ NE/kg, 172 g/kg CP, 9.9 g/kg digestible lysine), to which the gilts were switched at approximately 43 d of age. Thereafter, the diet was changed to standard pelleted finishing diet 1 (9.58 MJ NE/kg, 162 g/kg CP, 8.9 g/kg digestible lysine) at approximately 75 d of age. Last, at approximately 115 d of age, gilts were switched to standard pelleted finishing diet 2 (9.23 MJ NE/kg, 145 g/kg CP, 6.9 g/kg digestible lysine).

Osteochondrosis Assessment

At the end of the experiment, gilts were slaughtered at a local slaughterhouse, and several joints were harvested for macroscopical evaluation of the irregularities of the articular surfaces, which are indicative of OC (Jørgensen and Nielsen, 2005; Busch and Wachmann, 2011). Slaughter was performed over a 1-wk period. Half of the population (equal distribution of treatments and pens) was slaughtered within 2 d at an average of 185 d of age. The other half of the population was slaughtered within 2 d at an average of 192 d of age. After slaughter, carcasses were stored according to standard slaughtering practices for 1 d at 4°C. All 4 legs from each gilt were collected through dissection of the shoulder and hip joints. After collection, the legs were stored again at 4°C for a maximum of 2 d, after which dissection of joints was performed.

The elbow, knee, and hock joints were dissected for macroscopical assessment for the presence and severity of OC on a total of 22 locations (Table 1). Joints were scored on a 5-point grading scale from 0 to 4 (as described by van Weeren and Barneveld, 1999), with a score of 0 indicating no abnormalities and 4 indicating severe abnormalities (for pictures of the different classifications, see van Grevenhof et al., 2011). Osteochondrosis was scored by a veterinarian specializing in orthopedics, who was unaware of the treatments and experienced in judging OC.

Statistics

Body Weight Statistical Model. Body weight progression per treatment and measurement was analyzed and is presented. Measurements were analyzed on pen level, which is the experimental unit. Several BW measurements were performed per gilt within an experimental unit pen, which cannot be viewed as independent observations. Therefore, a repeated measures analysis was performed using PROC MIXED in SAS 9.2 (SAS Inst. Inc., Cary, NC). Homogeneous variance of BW in growing animals cannot be attained, and therefore, a heterogeneous covariance structure was applied (SAS Inst. Inc.). The statistical model used for BW is as follows:

$$Y_{ijkl} = \mu + \text{Treat}_i + \text{Meas}_j + (\text{Treat} \times \text{Meas})_{ij} + \text{Pen}_{k(i)} + \varepsilon_{ijkl}$$

where Y_{ijkl} represents the $ijkl$ th BW observation. The mean is represented by μ . Treat_i represents the fixed class effect of treatment administered ($i = \text{AA, AR, RA, RR}$). The time points at which BW were measured are represented by the fixed class effect Meas_j ($j = \text{measurement } 0, 1, \dots, 13$). Interaction between treatments and measurements is represented by the fixed class effect $(\text{Treat} \times \text{Meas})_{ij}$ to assess differences between treatments within each measurement. $\text{Pen}_{k(i)}$ represents

Table 1. The locations within joints assessed for osteochondrosis

Joint	Joint location
Elbow joint	Medial humeral condyle
	Lateral humeral condyle
	Anconeal process
	Proximal edge of radius
	Synovial fossa of radius
	Other locations
Knee joint	Lateral femoral trochlea
	Medial femoral trochlea
	Sulcus distal femur
	Patella
	Lateral femoral condyle
	Medial femoral condyle
Hock joint	Other locations
	Sagittal ridge of distal tibia
	Lateral trochlea of talus
	Medial trochlea of talus
	Lateral malleolus of tibia
	Medial malleolus of tibia
	Base of talus
	Lateral tibial cochlea
	Medial tibial cochlea
	Other locations

the random effect of the experimental unit pen ($k = \text{pen } 1, 2, \dots, 32$) nested within treatment and is used to assess the BW measurements on pen level. As mentioned, a repeated measures analysis was performed with gilts as the subject. A heterogeneous first-order autoregressive covariance structure was applied to this repeated structure, indicating that ε_{ijkl} is normally distributed, but where measurements are correlated over time with a heterogeneous covariance structure per gilt within an experimental unit pen. The addition of other components to account for environmental influence (such as dam from which the gilts descended and department in which gilts were housed) did not result in further improvement of the model. Results are displayed as the least squares means \pm SE.

Osteochondrosis Affected Locations. The locations within joints in which no OC was found for all gilts were omitted from the analyses as these locations are uninformative. Indications of bilateral symmetry of OC lesions between joints of the bilateral homologues of a gilt were calculated using Spearman's rank correlations. These correlations were not calculated for the medial humeral condyle, sagittal ridge of the distal tibia, and lateral femoral condyle, as this was deemed inappropriate because the number of OC-affected locations was less than or equal to 5 observations for each location.

Grouping of Osteochondrosis Scores. Osteochondrosis was scored on an ordinal scale of 0 to 4. Although the possibility exists to take into account ordinal data us-

ing ordinal logistic regression (Stokes et al., 2000), this was deemed an inappropriate analysis for the current data set. The required sufficient number of observations of each combination of treatment and OC score to apply ordinal logistic regression was not attained (Stokes et al., 2000), which provided some convergence problems. The statistical analysis that was appropriate in the current situation was binary logistic regression. To accommodate binary logistic regression, the OC scores from the macroscopic evaluation of the joints were grouped into a variable with scores of 0 and 1, where 0 indicates no abnormalities (OC score of 0) and 1 indicates an OC score higher than 0.

Osteochondrosis Statistical Model. The OC scores were analyzed at the pen level, which is the experimental unit. Osteochondrosis was scored on several locations per joint, and therefore, observations within a gilt within a pen are not independent. A repeated measures analysis was performed using PROC GLIMMIX in SAS 9.2. The statistical model used to assess treatment effects on OC prevalence is as follows:

$$\text{Logit } P(y_{ijklm} = 1) = \alpha + \text{Treat}_i + \text{Dept}_j + \text{Pen}_{k(ij)} + \text{Gilt}(\text{Dam})_l + \varepsilon_{ijklm}$$

where the model estimates the probability (P) that the $ijklm$ th observation of OC (y) for a joint or at the animal level (all joints combined) is 1 (OC score greater than 0). Logit is the link function used to model the mixed linear regression analysis. The α component represents the estimate of the log odds of being affected with OC disregarding the independent variables (baseline odds; Kleinbaum and Klein, 2010). Treat_i represents the fixed class effect of treatments administered ($i = \text{AA, AR, RA, RR}$). Dept_j represents the fixed class effect of the department in which gilts were housed ($j = \text{department 1, 2, 3, 4}$) and is used to account for environmental variation. $\text{Pen}_{k(ij)}$ represents the random effect of the experimental unit pen ($k = \text{pen 1, 2, \dots, 32}$) nested within treatment and department and is used to assess OC scores at the pen level for the treatment effects. A random term was added that consists of gilts nested within dams from which the gilts originated to account for dam effects [$\text{Gilt}(\text{Dam})_l$; $l = \text{dam 1, 2, \dots, 46}$]. As mentioned, a repeated measures analysis was performed with gilts as the subject, indicating that the random residual term from a logit distribution (ε_{ijklm}) shows the dependency of the joint locations assessed for OC within each gilt within an experimental unit pen. The addition of other components to account for environmental influence (such as birth weight and slaughter age) did not result in further improvement of the model. The prevalence of OC is presented on the ordinal scale and as the total number of OC-affected joint locations

and gilts. When significant treatment effects are present, odds ratios (OR) are presented to indicate the extent of the effect.

RESULTS

Four out of the 211 gilts were euthanized before the end of the experiment because of health problems. The joints were assessed for OC status after the animals were euthanized, and the result was taken into account in the analyses. Two gilts were taken out of the experiment because of a rectal prolapse. Two gilts were taken out of the experiment because of severe lameness. No joint surface irregularities indicative of OC were present at the assessment of the joints within these 4 gilts.

Body Weight

The BW progression per treatment and measurement is displayed in Fig. 1A, confirming that the treatments indeed produced the intended contrasts in BW. To clearly visualize the contrasts per treatment group, Fig. 1B shows the same BW per treatment, but compared with the population mean BW.

Significant differences ($P < 0.05$) in BW between the ad libitum-fed gilts (AA and AR treatments) and the feed-restricted gilts (RA and RR treatment) up to 10 wk of age (73 d of age) were present from approximately 40 d of age onward (approximately 14 d after the start of the experiment; Fig. 1). After 10 wk of age, the mean BW of the AR-treated gilts approached the mean BW of the RR-treated gilts, whereas the mean BW of the RA-treated gilts approached the mean BW of the AA-treated gilts. Significant differences ($P < 0.05$) in gilt BW between all treatments were present from 96 d of age onward (24 d after the switch at 10 wk of age), except for the AR and RA treatments at 110 d of age, where both groups showed a similar mean BW, as at this moment in time the BW curves cross. The final average BW of gilts was 132 ± 1.4 kg for those receiving the AA treatment, 128 ± 1.4 kg for the RA treatment, 111 ± 1.4 kg for the AR treatment, and 107 ± 1.4 kg for the RR treatment.

Osteochondrosis Prevalence

The locations affected by OC in the elbow joint (total of 6 locations) were the medial humeral condyle (bilateral homologues), the lateral humeral condyle (bilateral homologues), and the anconeal process (bilateral homologues); in the hock joint (total of 5 locations) they were the sagittal ridge of the distal tibia of the right hind leg, lateral trochlea of talus (bilateral homologues), and the medial trochlea of talus (bilateral homologues), and in the knee joint (total of 5 locations) they were the lateral femoral condyle (bi-

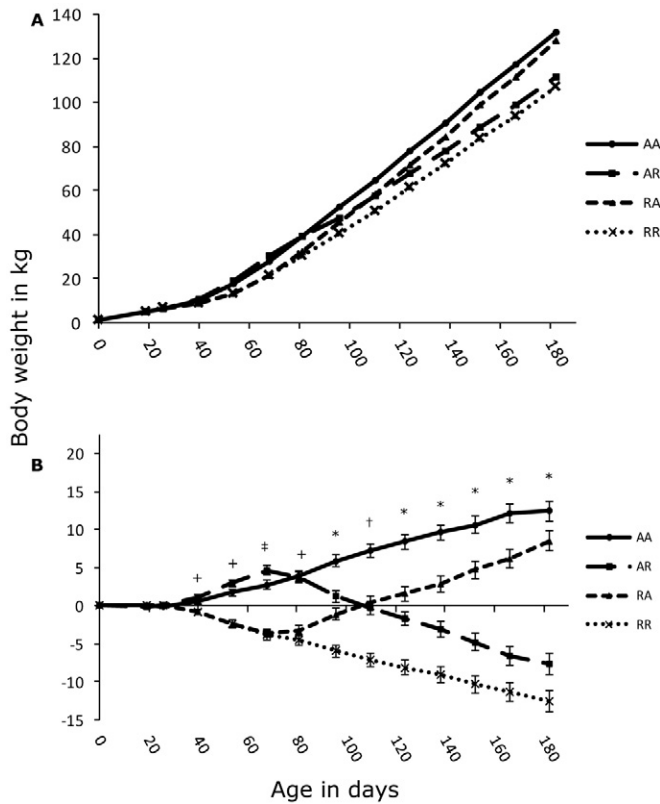


Figure 1. Body weight progression per treatment and measurement. (A) The least squares (LS) means of each treatment per measurement. (B) To visualize the contrasts between treatments more clearly, the same LS mean \pm SE BW of each treatment per measurement compared with the population BW mean. Treatments are AA = ad libitum feeding from weaning until slaughter; AR = ad libitum feeding up to 10 wk of age, after which feeding was switched to restricted (80% of ad libitum uptake); RA = restricted feeding up to 10 wk of age, after which feeding was switched to ad libitum; RR = continuously restricted feeding from weaning until slaughter. Significant differences ($P < 0.05$) between treatments are indicated with a symbol for each measurement where significant differences were found. Symbols indicate the following significant differences, where no common superscript is found: + = AA^a, AR^a, RA^b, RR^b; ‡ = AA^a, AR^b, RA^c, RR^c; † = AA^a, AR^b, RA^b, RR^c; * = AA^a, AR^b, RA^c, RR^d.

lateral homologues), the medial femoral condyle (bilateral homologues), and a location on the lateral side of a lateral femoral condyle from the right hind leg. The majority of OC scores (data not shown) found in the elbow joint were on the lateral humeral condyle (54.8%, of which 58.8% were scored as a 3 or 4); the majority of OC scores in the hock joint were on the medial trochlea of the talus (65.5%, of which 5% were scored as a 3 or 4); the majority of OC scores in the knee joint were on the medial femoral condyle (95.6%, of which 20.8% were scored as a 3 or 4).

Significant positive correlations ($P < 0.001$ for all correlations) of OC prevalence and severity between the joint locations of the bilateral homologues were found for the lateral humeral condyle (correlation of 0.41), anconeal process (correlation of 0.85), lateral trochlea of talus (correlation of 0.38), medial trochlea of talus (correlation of 0.56), and medial femoral condyle (correlation of 0.56).

Joint Level Osteochondrosis Prevalence. The prevalence of OC per location assessed per joint and at the animal level is shown in Table 2. The knee joint displayed the highest total number of affected locations (OC score higher than 0) but not the highest number of locations affected with OC scores 3 and 4 (28 affected locations). The elbow joint had the lowest total number of affected locations but the highest number of locations affected with OC scores 3 and 4 (36 affected locations). The prevalence of OC scores 3 and 4 was generally lower compared with OC scores 1 and 2. The ratio of the prevalence of OC scores 3 and 4 to OC scores 1 and 2 was approximately 0.11 for the hock joint, 0.26 for the knee joint, and 0.37 at the animal level. Only in the elbow joint was the prevalence for OC scores 3 and 4 higher than that of OC scores 1 and 2 (ratio of 1.38).

Animal Osteochondrosis Prevalence. The number of locations affected with OC does not necessarily represent the number of gilts affected with OC, as a gilt may have multiple locations within a joint affected with OC. Therefore, Table 3 shows the prevalence of gilts affected with their maximum OC score. For example, if a gilt is scored on a joint at 6 locations with OC scores 0, 1, 2, 3, 3, 4, then that gilt is counted within the OC score 4 category (maximum OC score present within a joint or gilt). The total prevalence of gilts with OC scores 3 and 4 was generally lower compared with those with OC scores 1 and 2. The ratio of the prevalence of OC scores 3 and 4 to OC scores 1 and 2 was approximately 0.16 for the hock joint, 0.35 in the knee joint, and 0.59 at the animal level. Only in the elbow joint was the prevalence of scores 3 and 4 higher than that of OC scores 1 and 2 (ratio of 1.71).

Treatment Effects

Gilts in the RA treatment showed the highest overall prevalence of OC in all joints and at the animal level (Tables 2 and 3). Except for the hock joint, gilts in the RA treatment also displayed the highest prevalence of OC scores 3 and 4 compared with the other treatments. The lowest prevalence of OC-affected gilts was generally found in the RR and AR treatments. Looking at the animal level (Tables 2 and 3), the order of treatments from high to low OC prevalence is RA, AA, AR, RR.

Significant treatment effects at the pen level on the prevalence of OC were found for the hock joint and at the animal level and are indicated in Table 3. No significant effect was present for the elbow and knee joint. Significant differences were found between the comparisons of the RA treatment with the RR and AR treatments in the hock joint (OR = 3.3, $P = 0.04$ and OR = 8.5, $P = 0.002$, respectively) and at the animal

Table 2. Prevalence (number and percentage) of osteochondrosis (OC) on the locations within joints assessed per treatment and total prevalence.¹

Item	Treatment ²								Total	
	AA		AR		RA		RR		n	%
	n	%	n	%	n	%	n	%		
OC score elbow										
0	302	95.0	309	97.2	290	91.2	303	97.1	1,204	95.1
1	0	0.0	1	0.3	3	0.9	3	1.0	7	0.6
2	5	1.6	4	1.3	8	2.5	2	0.6	19	1.5
3	8	2.5	3	0.9	10	3.1	2	0.6	23	1.8
4	3	0.9	1	0.3	7	2.2	2	0.6	13	1.0
Affected ³	16	5.0	9	2.8	28	8.8	9	2.9	62	4.9
OC score hock										
0	246	92.8	259	97.7	238	89.8	251	96.5	994	94.2
1	9	3.4	3	1.1	15	5.7	5	1.9	32	3.0
2	6	2.3	3	1.1	12	4.5	2	0.8	23	2.2
3	2	0.8	0	0.0	0	0.0	2	0.8	4	0.4
4	2	0.8	0	0.0	0	0.0	0	0.0	2	0.2
Affected	19	7.2	6	2.3	27	10.2	9	3.5	61	5.8
OC score knee										
0	232	87.5	225	84.9	221	85.0	236	90.8	914	87.0
1	21	7.9	30	11.3	22	8.5	22	8.5	95	9.0
2	4	1.5	3	1.1	6	2.3	0	0.0	13	1.2
3	6	2.3	7	2.6	8	3.1	1	0.4	22	2.1
4	2	0.8	0	0.0	3	1.2	1	0.4	6	0.6
Affected	33	12.5	40	15.1	39	15.0	24	9.2	136	13.0
OC score animal										
0	780	92.0	793	93.5	749	88.9	790	95.0	3,112	92.3
1	30	3.5	34	4.0	40	4.7	30	3.6	134	4.0
2	15	1.8	10	1.2	26	3.1	4	0.5	55	1.6
3	16	1.9	10	1.2	18	2.1	5	0.6	49	1.5
4	7	0.8	1	0.1	10	1.2	3	0.4	21	0.6
Affected	68	8.0	55	6.5	94	11.2	42	5.0	259	7.7

¹OC was assessed on a 5-point grading scale, where 0 indicates no OC and 4 indicates the severest form of OC. The locations affected with OC were as follows: in the elbow joint (6 affected locations) the medial humeral condyle, the lateral humeral condyle, and the anconeal process; in the hock joint (5 affected locations) the sagittal ridge of the distal tibia, lateral trochlea of talus, and the medial trochlea of talus; and in the knee joint (5 affected locations) the lateral femoral condyle, the medial femoral condyle, and the lateral side of a lateral femoral condyle.

²AA = ad libitum feeding from weaning until slaughter; AR = ad libitum feeding up to 10 wk of age, after which feeding was switched to restricted (80% of ad libitum uptake); RA = restricted feeding up to 10 wk of age, after which feeding was switched to ad libitum; RR = continuously restricted feeding from weaning until slaughter.

³Affected is the total number of locations with an OC score higher than 0.

level (OR = 2.5, $P = 0.001$ and OR = 1.9, $P = 0.01$, respectively). The OR results indicate that gilts in the RA treatment had significantly higher odds of being affected with OC than gilts in both the AR and RR treatments in the hock joint and at the animal level. A significant difference was furthermore found in the comparison between the AA and AR treatments in the hock joint (OR = 5.3, $P = 0.01$). The OR result indicates that gilts in the AA treatment had higher odds of being affected with OC than gilts in the AR treatment in the hock joint.

Last, at the animal level, tendencies ($0.05 < P < 0.1$) were found (data not shown) for the comparisons between the AA and RA treatments (OR = 0.7; $P = 0.09$) and the AA and RR treatments (OR = 1.7; $P = 0.06$). The OR results indicate that gilts in the AA

treatment had a tendency to have lower odds of being affected with OC than gilts in the RA treatment but higher odds of being affected with OC compared with gilts in the RR treatment.

DISCUSSION

The aim of this study was to investigate age-dependent effects of dietary restriction, ad libitum vs. restricted (80% of ad libitum uptake), on OC prevalence in breeding gilts from weaning until slaughter. Results indicate that there were age-dependent effects of dietary restriction on OC prevalence in breeding gilts after 10 wk of age. A possible factor involved in the differences seen in OC prevalence may be differences in BW between treatments.

Table 3. Prevalence (number and percentage) of a maximum OC score present within a gilt per treatment and total prevalence¹

	Treatment ²								Total	
	AA		AR		RA		RR		n	%
	n	%	n	%	n	%	n	%		
OC score elbow										
0	43	81.1	46	86.8	38	71.7	46	88.5	173	82.0
1	0	0.0	1	1.9	2	3.8	1	1.9	4	1.9
2	3	5.7	3	5.7	3	5.7	1	1.9	10	4.7
3	5	9.4	2	3.8	4	7.5	2	3.8	13	6.2
4	2	3.8	1	1.9	6	11.3	2	3.8	11	5.2
Affected ³	10	18.9	7	13.2	15	28.3	6	11.5	38	18.0
OC score hock										
0	39	73.6	49	92.5	36	67.9	44	84.6	168	79.6
1	5	9.4	2	3.8	9	17.0	4	7.7	20	9.5
2	5	9.4	2	3.8	8	15.1	2	3.8	17	8.1
3	2	3.8	0	0.0	0	0.0	2	3.8	4	1.9
4	2	3.8	0	0.0	0	0.0	0	0.0	2	0.9
Affected	14 ^{a,b}	26.4	4 ^c	7.5	17 ^a	32.1	8 ^{b,c}	15.4	43	20.4
OC score knee										
0	32	60.4	30	56.6	27	51.9	36	69.2	125	59.5
1	13	24.5	17	32.1	13	25.0	14	26.9	57	27.1
2	1	1.9	1	1.9	4	7.7	0	0.0	6	2.9
3	5	9.4	5	9.4	6	11.5	1	1.9	17	8.1
4	2	3.8	0	0.0	2	3.8	1	1.9	5	2.4
Affected	21	39.6	23	43.4	25	48.1	16	30.8	85	40.5
OC score animal										
0	21	39.6	23	43.4	11	21.2	29	55.8	84	40.0
1	10	18.9	17	32.1	13	25.0	14	26.9	54	25.7
2	7	13.2	6	11.3	10	19.2	2	3.8	25	11.9
3	9	17.0	6	11.3	10	19.2	4	7.7	29	13.8
4	6	11.3	1	1.9	8	15.4	3	5.8	18	8.6
Affected	32 ^{a,b}	60.4	30 ^a	56.6	41 ^b	78.8	23 ^a	44.2	126	60.0

¹OC was assessed on a 5-point grading scale, where 0 indicates no OC and 4 indicates the severest form of OC. The locations affected with OC were as follows: in the elbow joint the medial humeral condyle, the lateral humeral condyle, and the anconeal process; in the hock joint the sagittal ridge of the distal tibia, lateral trochlea of talus, and the medial trochlea of talus; in the knee joint the lateral femoral condyle, the medial femoral condyle, and the side of a lateral femoral condyle.

²AA = ad libitum feeding from weaning until slaughter; AR = ad libitum feeding up to 10 wk of age, after which feeding was switched to restricted (80% of ad libitum uptake); RA = restricted feeding up to 10 wk of age, after which feeding was switched to ad libitum; RR = continuously restricted feeding from weaning until slaughter.

³Affected is the total number of gilts with an OC score higher than 0. Within a row, the prevalence of OC differs significantly if there is no common superscript ($P < 0.05$).

Body Weight

A higher feeding level leads to a higher BW, which may impose higher loading pressures on joints carrying the weight, especially at a young age. Joint loading has previously been suggested to play a role in OC development (Nakano and Aherne, 1988; Carlson et al., 1991; Ytrehus et al., 2004b,c). As this factor was known to potentially play a vital role in OC development, it was essential that the applied dietary restrictions provided significant contrasts in BW at a relatively young age. This was the case, as the dietary restrictions applied provided significant contrasts in BW before and after 10 wk of age in the expected direction. The results of the BW progression hence indicate that the intended effect of the treatments was attained and point at a pos-

sible pathway that could be implicated in the differences found in the OC prevalence between treatments in the current study.

Osteochondrosis Prevalence

Overall, almost 60% of the gilts in the current study showed an OC score higher than 0 in at least one of the joints assessed. Differences in OC prevalence between studies exist and can range from 10% to 80%, depending on the joints assessed (Jørgensen et al., 1995; Jørgensen and Andersen, 2000; Ytrehus et al., 2004c; Luther et al., 2007; Busch and Wachmann, 2011; van Grevenhof et al., 2011). Differences in OC prevalence between studies may arise from differences in susceptibility for OC between

breeds and sexes (Lundeheim, 1987; van der Wal et al., 1987). In the current study, the overall prevalence of OC was 60%. The OC prevalence could have been higher if the unfavorable treatment (RA treatment in the current study) had been administered to all gilts. For example, the RA treatment showed an OC prevalence of almost 80% (highest prevalence), whereas in the RR treatment group the OC prevalence was 43% (lowest prevalence).

Osteochondrosis lesions have previously been suggested to show bilateral symmetry, as genetic correlations of OC lesions in pigs between bilateral homologues are reported to approach 1 (Jørgensen and Andersen, 2000). In the current study, correlations of OC lesions between bilateral homologues ranged from 0.38 to 0.85, depending on the location assessed. Van Weeren and Barneveld (1999) have indicated that bilateral symmetry in horses is dependent on the joints assessed, which is similar to the results of the current study in gilts. In addition, van Weeren and Barneveld (1999) also indicated that bilateral symmetry of OC lesions at a young age is more prevalent than at an older age. This may indicate that the occurrence of bilateral symmetry of OC lesions is influenced by variation in the effect of environmental factors related to the aging of the animal.

Treatment Effects

The treatments applied showed significant effects at the pen level on the prevalence of OC. Overall, the RA-treated gilts showed significantly higher odds of being affected with OC than the AR- and RR-treated gilts in the hock joint and at the animal level. The AA-treated gilts showed significantly higher odds of being affected with OC in the hock joint compared with the AR-treated gilts. Overall, the order of treatments from high to low OC prevalence in the gilts was RA, AA, AR, and RR.

To the authors' knowledge, no study has yet been performed that directly investigated age-dependent effects of dietary restriction on OC prevalence. In a previous experiment (van Grevenhof et al., 2011), dietary restrictions (ad libitum vs. restricted) were applied to pigs that were similar to the AA and AR treatments in the current study, resulting in a significantly higher prevalence of OC for the ad libitum-fed pigs. In the current study, differences between the AA and AR treatments were not significant except in the hock joint. Carlson et al. (1988) also showed an increased incidence of OC in pigs fed ad libitum from weaning to slaughter. However, Jørgensen (1995) was not able to show effects of dietary restriction on OC prevalence in pigs. In that study, restrictions were applied from 25 kg BW onward, which is close to 10 wk of age (the switching point in the current study). That study does not indicate what type of feeding was applied before 25 kg BW. If ad libitum feeding was applied

before 25 kg BW, the absence of significant differences between the ad libitum and restricted feeding groups after 25 kg BW would be in line with the results from our study. There are indications that the age interval from 7 to 13 wk of age is important for the development of OC in pigs (Ytrehus et al., 2004a,b). It is clear that if different dietary restrictions are applied at an early age (well before 10 wk of age), the contrasts in BW will be more pronounced during the time window of OC susceptibility. Possibly, if different dietary restrictions are applied at an age after the most sensitive period, effects of dietary restriction on BW may not be as pronounced and, consequently, may have less impact on OC development.

Possible Mechanism of Treatment Effects

Joint loading has been implied in the development of OC (Nakano and Aherne, 1988; Carlson et al., 1991; Ytrehus et al., 2004b,c). An explanation for the treatment effects in the current study may indeed be the difference in joint loading applied due to differences in BW. The development of growth cartilage within joints is most likely responsive to the demands that the environment (BW in the current study) places on the joints. An important component of the extracellular matrix of growth cartilage involves proteoglycans, which are produced by chondrocytes and which provide compressive strength to the tissue (reviewed by Greenwald et al., 1978; Kheir and Shaw, 2009). Studies have indicated that (dynamic) loading of articular cartilages increases proteoglycan contents (Buschmann et al., 1995; Little and Ghosh, 1997; Quinn et al., 1999; Spiteri et al., 2010). In addition, there are indications that proliferation of chondrocytes, which has been suggested to be an aspect involved in reparative responses of OC (Ytrehus et al., 2004b,d; reviewed by Ytrehus et al., 2007), can be reduced by mechanical compression of chondrocytes (Alberly et al., 1993; Stokes et al., 2007). Thus, loading of joints may lead to a higher proteoglycan content of the growth cartilage, which can be seen as beneficial. However, when the loading passes a certain threshold or perhaps increases too rapidly, the growth cartilage may not be able to adapt quickly enough, leading to compression of chondrocytes. These loading stresses on the joint can be detrimental to chondrocyte function (Ytrehus et al., 2004d).

In the RA treatment, feeding increased from restricted to ad libitum. After the switch, the BW of those gilts increased rapidly and relatively quickly differed significantly from the continuously restricted fed gilts. This increase in BW may result in a sudden increase of joint loading and may surpass the adaptive capacity of the growth cartilage and chondrocytes that were developed under restricted feeding. In the AR treatment, the feeding, in contrast, decreased from ad libitum to restricted.

Those joints were likely adapted to cope with higher loads at a young age and were subject to relatively lower loads after the switch in feeding regime compared with ad libitum-fed gilts. Those joints are hence under relatively less strain compared to what they had adapted to and may therefore develop less OC. The AA-treated gilts have a gradual increase in BW and loading pattern. The growth cartilage develops under ad libitum conditions at a young age to cope with the ad libitum conditions after 10 wk of age; the growth cartilage therefore experiences similarly high loading pressures throughout development. This continuity is likely the crucial difference between the AA and RA treatments, with the RA treatment initiating the development of cartilage before 10 wk of age that is not able to withstand the sudden increase of loading due to ad libitum feeding after 10 wk of age. The group of gilts in which the lowest number of affected gilts were found was the RR treatment. These gilts continuously experienced less strain placed on the joints compared with ad libitum-fed gilts and could therefore be less likely to develop OC.

Conclusion

This study showed the existence of an influence of age on the effects of dietary restriction on OC prevalence. The results show that gilts fed a restricted diet up to 10 wk of age and then switched to ad libitum feeding (RA treatment) have the highest prevalence of OC affected gilts. The treatments with the lowest OC prevalence were the continuously feed-restricted gilts (RR treatment) and those switched to restricted feeding after 10 wk of age (AR treatment). If the dietary restriction that the animals are subjected to at a young age does not match the dietary restriction at later age, the adaptive capacity of the joints may be surpassed. In practice, OC prevalence can be lowered by continuously restricted feeding or by switching to restricted feeding at 10 wk of age.

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