Computed tomographic evaluation of growth-related changes in the hip joints of young dogs

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Objective—To evaluate changes in canine hip joint characteristics during growth via computed tomography (CT) and compare CT features of hip joints with and without laxity in young dogs placed in 2 imaging positions.

Animals—21 dogs (42 hip joints).

Procedures—From 2 to 12 months after birth, CT examinations of the acetabulum of each hip joint in simulated normal standing and simulated weight-bearing positions were performed monthly for all dogs. Acetabular angle, dorsal acetabular rim angle (DARA), and femoral head diameter (FHd) were analyzed as skeletal variables; the lateral center edge angle (LCEA), dorsolateral subluxation (DLS) score, and center distance (CD) index were analyzed as joint laxity variables. At 12 months, all dogs underwent the Ortolani test to assess hip joint laxity.

Results—Hip joint laxity was detected in 5 dogs (10 joints) at 12 months of age; from 2 months, the acetabular angle and FHd increased and DARA decreased significantly until 5 months and the LCEA and DLS score increased significantly until 6 months. In nonlax hip joints in both positions, the CD index decreased significantly until 4 months of age and became stable thereafter. In lax hip joints, the CD index increased from 4 through 12 months; between 8 and 12 months, these changes were significantly greater in the weight-bearing position than in the standing position.

Conclusions and Clinical Relevance—Results suggest that CT-detected abnormalities in the DARA and CD index during body weight loading might be useful indicators of hip dysplasia in 2- to 6-month-old dogs. (*Am J Vet Res* 2007;68:730–734)

Hip dysplasia in dogs is a common developmental condition characterized by subluxation and incongruity of the hip joint. Early diagnosis in dogs < 1 year old is important for identifying affected dogs and planning treatment. Hip dysplasia in dogs is often diagnosed on the basis of findings revealed by examination of a ventrodorsal radiographic view of the pelvis (obtained with the femurs extended). However, this procedure has limited application for diagnosis of hip dysplasia in juvenile dogs.[1-3] Other radiographic methods for diagnosis of hip dysplasia have been proposed, including measurement of hip joint laxity (as represented by the distraction index[1,4]) and measurement of DLS of the femoral heads during simulated weight bearing (as represented by the DLS score[5-10]). Also, the use of measurements of the acetabular angle and DARA in transverse CT images has been evaluated in young dogs.[11,12] For obvious reasons, it is advantageous to diagnose hip dysplasia in dogs as early in life as possible so that joint conservative treatment (eg, triple pelvic osteotomy) can be instituted and breeding of the dogs with hip dysplasia can be deterred. Currently available methods for hip dysplasia diagnosis are inaccurate at 4 months of age (except for use of the distraction index in German Shepherd Dogs[13,14]) because the hip joints are not fully developed until dogs are 8 months old,[15] and there are no reports, to our knowledge, of a correlation between changes in hip joint laxity and growth. The purpose of the study reported here was to evaluate changes in characteristics of canine hip joints during growth via CT and compare CT features of hip joints with and without laxity in young dogs placed in 2 imaging positions.

Abbreviations

DLS	Dorsolateral subluxation
DARA	Dorsal acetabular rim angle
CT	Computed tomography
SNS	Simulated normal standing
SWB	Simulated weight bearing
FHd	Femoral head diameter
LCEA	Lateral center edge angle
CD	Center distance

Materials and Methods

Dogs—Pelvic CT examinations were performed in 21 dogs (6 Beagles and 15 mixed-breed dogs) monthly from 2 to 12 months after birth. The final body weight of the dogs ranged from 6.4 to 12.0 kg. The study was approved by the Kagoshima University Animal Care and Use Committee.

CT examination—Each month, CT was performed with the dogs placed in 2 positions according to proce-

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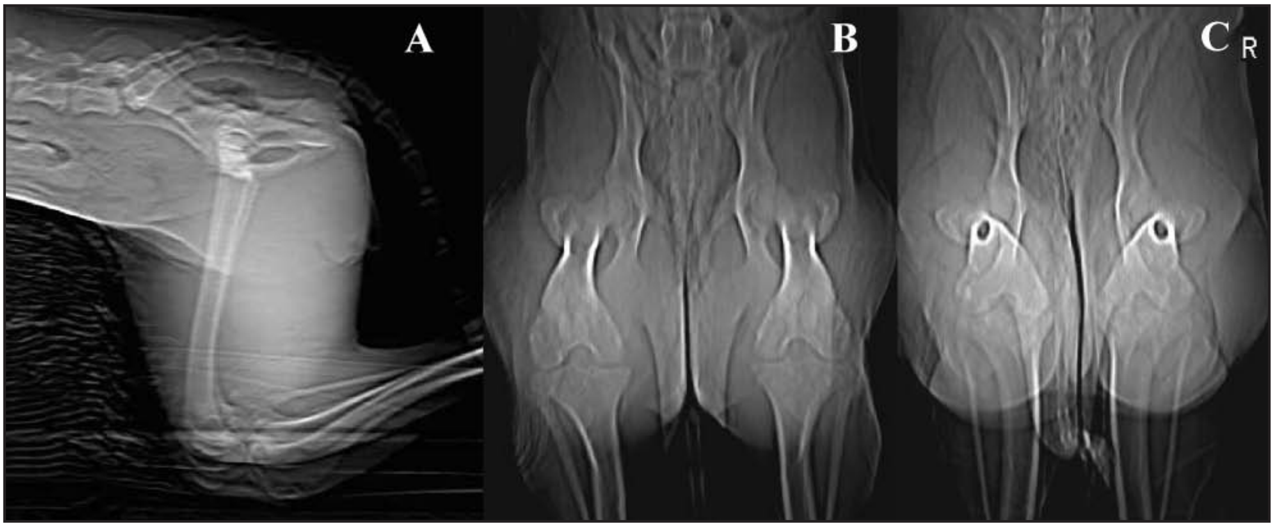

Figure 1—Representative CT images depicting the positioning of young dogs for CT scanning of the pelvis in a study of hip joint characteristics during growth. A—Lateral view of the pelvic region and hind limbs of a dog in the SNS or SWB position. B—Dorsoventral view of the pelvis of a dog in the SNS position. Notice that the stifle joints are placed the same distance apart as the hip joints. C—Dorsoventral view of the pelvis of a dog in the SWB position. In this position, the stifle joints are taped together in adduction. R = Right.

dures reported previously.[5,9,16] During isoflurane anesthesia, each dog underwent 2 CT scanning procedures monthly. In both procedures, the hip joints were bearing weight as if the dog was standing; the dog was positioned on the imaging platform in sternal recumbency such that it was balanced on its stifle joints with the vertebrae parallel to the platform. The stifle and tibiotarsal joints were flexed, and the body weight was borne by the femurs (**Figure 1**). The CT procedures were then performed while the dog was in an SNS position and an SWB position. For the SNS position, each dog had its stifle joints placed the same distance apart as the hip joints and both femoral shafts were parallel to each other in the lateral imaging view. The axes of both femurs were parallel to the imaging platform in CT transverse slices of the sacral region. In the SWB position, both femoral shafts were perpendicular to the imaging platform in the lateral imaging view and the stifle joints were taped together in an adducted position in the dorsoventral view. In the latter position, a transverse slice at the center of the hip joint was scanned with a width of 2 mm. The acetabular angle, DARA, and FHd were assessed as skeletal variables, and the DLS score and LCEA were assessed as laxity variables. The DARA was obtained by drawing 3 lines on the image: a central pelvic height line (a line drawn 90° to the central pelvic height line) and 2 intersecting lines, each superimposed on 1 dorsal acetabular subchondral articular surface.[11,12] The DSL score was determined from 2 images by measuring the percentage of the FHd that was medial to the lateralmost points of the cranial and dorsal acetabular rims. Two lines were then drawn perpendicular to that line: 1 at the lateral aspect of the dorsal acetabular rim and 1 at the medial aspect of the femoral head.[5,7,9] The LCEA was defined as the angle determined by the dorsal edge of the acetabulum, the center of the femoral head, and a horizontal line on CT images.[16,17] The CD index was calculated as the distance between the center of the femoral head and the center of the acetabulum, divided by the measured radius of the femoral head[18] (**Figure 2**). At 12 months of age, all dogs were assigned to 1 of 2 groups on the basis of whether they did or did not have hip joint laxity (designated as the lax hip joint group and nonlax hip joint group, respectively) as determined by use of the Ortolani test. Furthermore, these groups were each divided into subgroups according to the CT positioning; data from dogs with no apparent

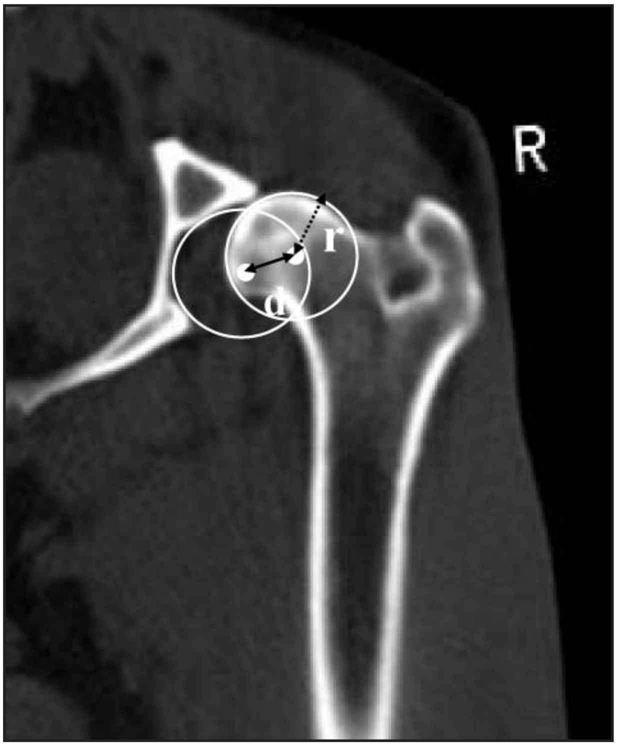

Figure 2—Computed tomographic image of a cross section at the right femoral head and acetabulum of a young dog included in a study of hip joint characteristics during growth illustrating the measurements used to determine the CD index. The CD index was calculated as the distance between the femoral head center and acetabular center (d) divided by the measured radius of the femoral head (r) *See* Figure 1 for remainder of key.

hip joint laxity were grouped as non-SNS or non-SWB, and data from dogs with lax hip joints were grouped as lax-SNS or lax-SWB.

Statistical analysis—All data obtained from joints are expressed as mean ± SD. Comparisons of each variable in 2 CT positions between nonlax and lax hip joint groups were made. The significance of differences was assessed by use of an ANOVA, and the Scheffe method was used for simultaneous multiple comparisons. Differences were considered significant at a value of $P < 0.05$.

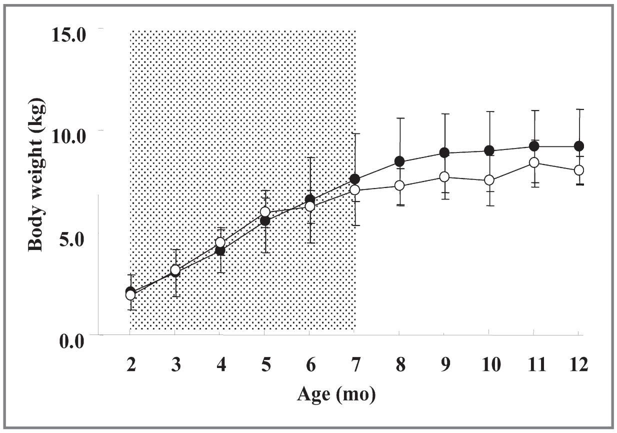

Figure 3—Mean ± SD body weight during growth (2 through 12 months after birth) in dogs with (white circles; n = 5) and without (black circles; 16) hip joint laxity (determined at 12 months). Shaded area identifies values that were significantly ($P < 0.05$) different from the 2-month value within each group.

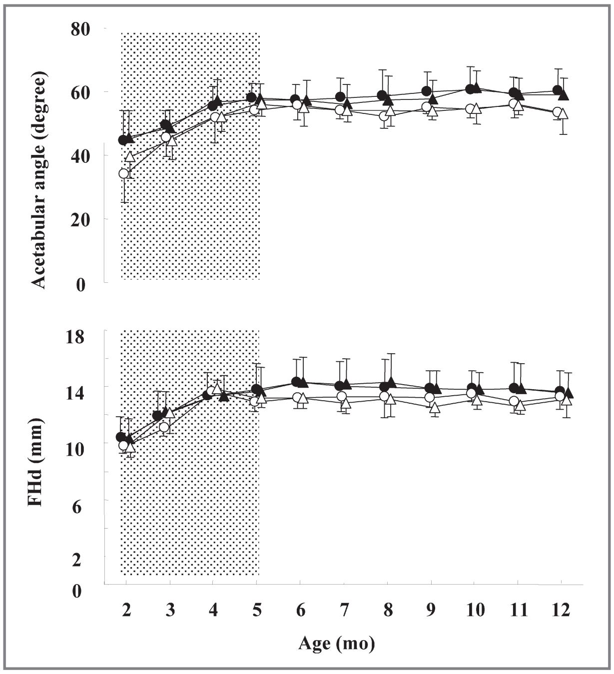

Figure 4—Mean ± SD values of acetabular angle and FHd during growth (2 through 12 months after birth) in dogs with (white symbols; n = 10 joints) and without (black symbols; 32 joints) hip joint laxity (determined at 12 months) that were evaluated in an SNS position (circles) and SWB position (triangles). Shaded area identifies values that were significantly ($P < 0.05$) different from the 2-month value within each group.

Results

At 12 months of age, hip joint laxity was identified via the Ortolani test in 5 dogs (10 joints). Nonlax hip joints were identified in 16 dogs (32 joints).

Body weight—From initiation of the study, body weight increased significantly until dogs were 7 months old (**Figure 3**). Final mean body weights in the nonlax and lax hip joint groups were 9.2 ± 1.8 kg and 8.2 ± 0.65 kg, respectively (range, 6.4 to 12.0 kg).

Evaluation of skeletal changes—In both the SNS and SWB positions in dogs with nonlax hip joints and dogs with lax hip joints, the acetabular angle and FHd increased significantly ($P < 0.05$), compared with the 2-month values, during growth until 5 months of age. However, there was no significant difference in acetabular angle or FHd between the 2 positions or between the nonlax and lax hip joint groups at any time point (**Figure 4**). At 4 months, these measurements were 95% of the value at 12 months in all groups.

In both the SNS and SWB positions, DARA decreased significantly ($P < 0.05$), compared with the 2-month values, during growth until 6 months after birth; thereafter, DARA did not change in either position (**Figure 5**). In the lax hip joint group, DARA was significantly ($P < 0.05$) larger than that in the nonlax hip joint group at all time points from 2 to 12 months. At 4

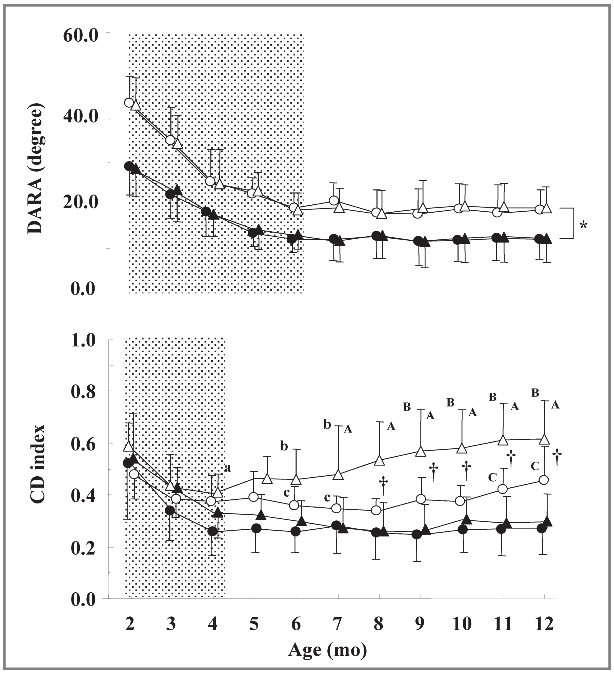

Figure 5—Mean ± SD values of DARA and CD index during growth (2 through 12 months after birth) in dogs with (white symbols; n = 10 joints) and without (black symbols; 32 joints) hip joint laxity (determined at 12 months) that were evaluated in an SNS position (circles) and SWB position (triangles). Shaded area identifies values that were significantly ($P < 0.05$) different from the 2-month value within each group. *Significant ($P < 0.05$) difference between values in the nonlax and lax hip joint groups when in the SWB position. †Significant ($P < 0.05$) difference between values in lax hip joint group when in the SWB and SNS positions at 8 through 12 months. Values marked with superscript letters a, b, and c are significantly ($P < 0.05$) different from values marked A, B, and C, respectively.

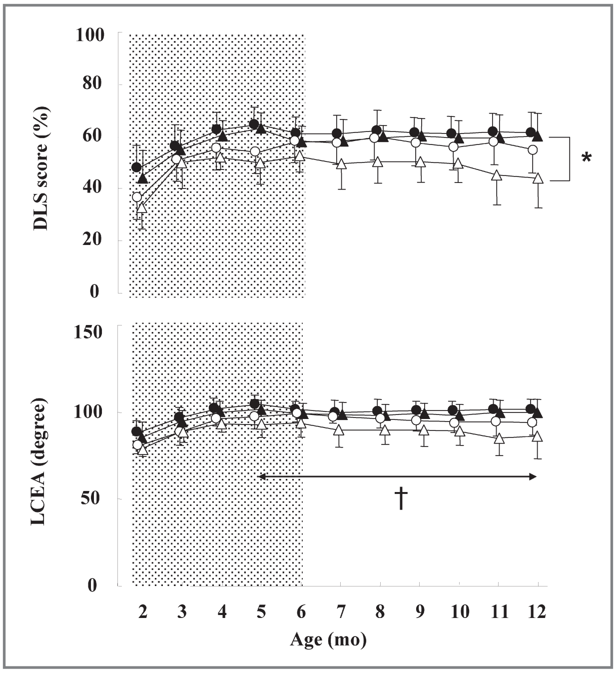

Figure 6—Mean ± SD values of DLS score and LCEA during growth (2 through 12 months after birth) in dogs with (white symbols; n = 10 joints) and without (black symbols; 32 joints) hip joint laxity (determined at 12 months) that were evaluated in an SNS position (circles) and SWB position (triangles). Shaded area identifies values that were significantly ($P < 0.05$) different from the 2-month value within each group. †Significant ($P < 0.05$) difference between values in lax hip joint group when in the SWB and SNS positions at 5 through 12 months. *See* Figure 5 for remainder of key.

months, the DARA measurement was 83% of the value at 12 months in all groups. Among all dogs, maturity (ie, value from which no further change was detected) for this variable was reached at 6 months.

Evaluation of joint laxity—Five dogs (10 joints) had hip joint laxity (as determined by use of the Ortolani test) at 12 months. The DLS score and LCEA increased significantly ($P < 0.05$) from the 2-month value until 5 months after birth; thereafter, these variables did not change in any of the 4 groups **(Figure 6)**. In the lax hip joint group (lax-SNS or lax-SWB), the LCEA and DLS score were lower than those values in the nonlax hip joint group (non-SNS or non-SWB) at all time points during the first 12 months after birth. There was a significant ($P < 0.05$) difference in DLS score between the dogs in the non-SWB and lax-SWB subgroups at each time point during the study. The LCEA values for those 2 subgroups were significantly ($P < 0.05$) different only at 5 to 12 months of age. Among all dogs, maturity for the DLS scores and LCEA measurements was reached at 4 months.

In all groups, the CD index decreased significantly ($P < 0.05$) at 3 and 4 months after birth, compared with the 2-month values (Figure 5). In the SNS and SWB positions in the nonlax hip joint group, the values gradually became stable at 12 months. In the lax hip joint group, the CD index for the lax-SNS subgroup increased during the period from 8 to 12 months (values at 6 and 7 months were both significantly [$P < 0.05$] different from values at 11 and 12 months). Also the CD index for the lax-SWB subgroup progressively increased during the period from 4 to 12 months; compared with the 4-month value, the CD index was significantly ($P < 0.05$) greater at each time point. Between 8 and 12 months, these changes in CD index values were significantly ($P < 0.05$) greater in the lax-SWB subgroup, compared with the lax-SNS subgroup.

Discussion

In the present study, acetabular angle, FHd, and DARA developed until the dogs were 5 months old and no significant changes in skeletal variables were evident with differences in CT scan positioning. Although DARA in dogs with lax hip joints was larger than that in dogs with nonlax hip joints, the significant change detected between lax and nonlax hip joint groups during the early phase of 2 to 4 months appears to indicate that hip dysplasia in dogs is associated with a postnatal ossification abnormality of the acetabulum. Madsen et al[19] and Todhunter et al[20] reported that dogs with hip dysplasia may have abnormalities in endochondral ossification. Our CT data also suggested that the difference in DARA at 2 months of age in dogs in the nonlax and lax hip joint groups might indicate such abnormalities.

The LCEA and DLS score, as indices of hip joint laxity, increased significantly from the 2-month value until 5 months of age and coverage of the acetabulum increased with growth in all 4 study groups. Although the LCEA and DLS score were lower in the lax hip joint group (compared with the nonlax hip joint group) within the first 12 months after birth, significant differences in these variables between the 2 groups were evident only in the SWB position. Lateral laxity of the CD index was less than the distraction index because the direction of laxity is dorsolateral in the CD index; in contrast, the direction of passive laxity is lateral in the distraction index. Therefore, in the dogs of this report, the changes in DLS score and LCEA were smaller than reported values, which suggested that evaluation of the LCEA and DLS score with self weight loading might result in underestimation. As reported by other researchers, the evaluation of the DLS score under dorsally applied hip joint loading would be a more effective method of joint laxity detection in young dogs.[5,7-10]

In a previous study[18] conducted by our group, we investigated the use of CD index to evaluate mobility of the femoral head in dogs with joint laxity via CT examination. The CD index evaluates joint laxity as effectively as the distraction index and is only slightly affected by the shape of the acetabulum. When DLS score and LCEA are measured from images, the dorsal acetabular rim is an important landmark. Therefore, insufficiency of acetabular formation may lead to overestimation of joint laxity. In the present study, the CD index decreased from 2 to 4 months of age in dogs with nonlax and lax hip joints and there was no significant difference between values in those 2 groups. Nonlax hip joints appeared to become stable after 5 months, but the CD index in the lax hip joint group increased significantly from 4 to 12 months, especially in the lax-SWB subgroup. It is possible that joint laxity might increase with activity and weight loading during growth. Also, a significant difference in CD index developed in the ax-SNS subgroup after dogs were 5 months old, which suggests that alteration of the CT scanning position was effective for detection of joint laxity in growing dogs. The SWB position might provide a more sensitive index for detection of joint laxity than the SNS position.

The results of our study have suggested that joint formation in puppies is accomplished within 5 or 6 months after birth, reflecting our previous findings that the serum keratan sulfate concentration in young dogs was high until 4 months of age, after which the concentration decreased before becoming stable at 9 months.[21] Furthermore, in children, foals, and puppies, serum keratan sulfate concentration is higher than that in their adult counterparts.[22-24] Also, keratan sulfate may play an important role in collagenous calcification during intramembranous ossification by trapping calcium ions through its negative charge.[25] These findings indicate that anatomic structuring of hip joints occurs during a period of high epiphyseal cartilage activity and keratan sulfate turnover and that the mature phase is consistent with the period of stable serum keratan sulfate concentration after dogs reach 9 months of age. Because acetabulum formation is delayed in young dogs with hip dysplasia, the CD index determined in the SWB position increases after 5 months of age. Except for DARA, which matured at 5 months, the other variables evaluated in our study reached mature values at 4 months of age. When the mechanical stresses increase with activity and body weight increases, joint instability may continue subsequently. Joint instability affects endochondral ossification in integrated joint formation because the acetabular cartilage does not receive adequate mechanical load for ossification.[26] As mentioned previously, misalignment at the stage of bone growth and increasing mechanical stress in the hip joint might trigger hip joint dysplasia in young dogs and might be related to endochondral ossification of the acetabulum.

In a young dog, it is suggested that evaluation of the hip joint laxity during growth by use of the CD index derived from CT images would be useful as early as 4 months after birth, if the dog is evaluated in a weight-bearing position, and abnormality of the DARA detected via CT during the 2- to 6-month period might be useful for assessment of hip dysplasia. Overall, the DARA and CD index obtained from CT images obtained during body weight loading seem to be useful for hip joint evaluation in young dogs.

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