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Interobserver Repeatability of Measurements on Computed Tomography Images of Lax Canine Hip Joints from Youth to Maturity

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Abstract

Objectives—To determine interobserver repeatability of measurements on computed tomography (CT) images of lax canine hip joints at different ages and in the presence of degenerative joint disease at maturity.

Study Design—Longitudinal observational investigation.

Animals—Sibling crossbreed hounds.

Methods—Pelvic CT was performed at 20, 24, 32, 48, 68, and 104 weeks of age. Measures were performed on 3 contiguous two-dimensional (2D) transverse CT images of both hips at each time point by 3 investigators. Center-edge angle (CEA), horizontal toit externe angle (HTEA), ventral (VASA), dorsal (DASA), and horizontal (HASA) acetabular sector angles, acetabular index (AI), and percent femoral head coverage (CPC) were measured. Interobserver repeatability was quantified with the intraclass correlation coefficient (ICC). Satisfactory repeatability was considered when ICC ≥ 0.75.

Results—DASA, CEA, and CPC were repeatable in all age groups. HASA and HTEA were repeatable for all but 1 time point. At 20 weeks of age, all measures but AI were repeatable, and at 104 weeks of age, DASA, CEA, CPC, and HASA were repeatable. Measures were repeatable in hips with and without degenerative changes with the exceptions of AI and HASA in normal hips and VASA and HTEA in osteoarthritic hips.

Conclusions—Most 2D CT measurements examined were repeatable regardless of age or joint disease.

Clinical Relevance—Two-dimensional CT measures may augment current techniques for assessing joint changes in lax canine hips.

INTRODUCTION

Research has focused on developing techniques that provide precise and accurate imaging of canine hip dysplasia (HD).^{1–4} Human developmental dysplasia of the hip (DDH) is a hip

joint condition that is detectable in early childhood and, if left untreated, can result in significant osteoarthritis.⁵ Because of their similarities, canine HD is an acceptable animal model for DDH.⁶ Nonweight bearing pelvic CT imaging for hip joint assessment has been used in children for > 20 years.^{7–9} Use of CT imaging to screen canine hips for signs of HD and subsequent sequela, such as osteoarthritis, is relatively new and has been used largely for investigative purposes.^{2,3,10,11} However, a recent report confirmed a strong relationship between articular cartilage microstructural damage and measures made on two-dimensional (2D) and 3D canine pelvic CT images in lax adult canine hip joints.¹² Application of CT imaging in the dog is novel, so further characterization and evaluation of the imaging modality is necessary to derive the most benefit from the available information.

CT permits sequential, internal imaging of bony structures that is not available with other imaging modalities. This capability permits measurements on images unique to CT that are useful for diagnosis, therapeutic assessment, and surgical planning.¹³ Joint immaturity and degenerative joint changes often interfere with landmark identification required for such measurements.¹⁴ Inconsistent localization of the femoral head center contributes to low repeatability of measurements that include the landmark in people.¹⁵ Repeatability is defined as the strength of agreement between repeated measurements obtained under similar circumstances.^{16–18} The repeatability of standard CT hip measurements routinely performed in people for diagnostic purposes are well established.^{9,19} However, given the novelty of the use of standard human CT hip measures in the dog,¹² repeatability of the same measures in the species has received little attention.

The human hip joint is routinely assessed on 2D CT images with a series of standard measures including the center-edge angle (CEA), ventral acetabular sector angle (VASA), dorsal acetabular sector angle (DASA), horizontal acetabular sector angle (HASA), horizontal toit externe angle (HTEA), acetabular index (AI), and CT percentage femoral head coverage (CPC). As mentioned previously, use of the same measures on 2D CT canine hip images was described recently.¹² This study was designed to test 2 hypotheses. The 1st hypothesis was that measurements relying on the use of the center of femoral head as a landmark would be less repeatable than those that did not. The 2nd, 2 part hypothesis was that advancing age would positively affect repeatability of the measures whereas significant osteoarthritis would negatively affect measure repeatability. To test the hypotheses, the 7 measurements described above were performed by independent investigators on 2D CT images of lax canine hip joints generated at regular intervals from 20 to 104 weeks of age. The intraclass correlation coefficient (ICC) of each measurement was determined to assess repeatability.

MATERIALS AND METHODS

Dogs

Three mixed breed sibling hounds (2 females, 1 male), mean $\pm$ SEM weight of 13.9 ± 1.04 kg (range, 12.7–14.5 kg) at 20 weeks of age and $24.5 \text{ kg} \pm 0$ at 104 weeks of age were studied. A PennHIP (PennHIP, School of Veterinary Medicine, University of Pennsylvania, Philadelphia, PA) distraction index (DI) of 0.4 in both hips at 20 weeks of age was required for inclusion in the study. Dogs were housed in individual $4 \times 6 \text{ m}^2$ runs with concrete floors for the duration of the study.

CT Evaluation

Each dog was anesthetized at 20, 24, 32, 48, 68, and 104 weeks of age, and CT images of the pelvis were obtained. Hips were extended as described previously.¹² Briefly, the dogs were placed in dorsal recumbency with both rear legs extended, adducted, and rotated

slightly internally. Tape was placed around the femurs to maintain their positions. External rotation of the tarsometatarsal joints and stifle extension was maintained with sandbags.

Transverse pelvic CT scans were performed using 1.5 mm slice widths (GE Hilight Advantage, General Electric Medical Systems, Milwaukee, WI). Images were stored on optical disks (DC-502A, Pioneer Communications of America Inc., Upper Saddle River, NJ) and transferred to a computer workstation (Sun Sparc 10, Sun Microsystems Inc., Santa Clara, CA). All images were printed on radiographic film. From each series, 3 contiguous slices were selected per hip based on the presence of the acetabular fossa, a well-defined sourcil (curved area of dense bone on the weight-bearing surface of the acetabulum), well-rounded femoral heads, and the presence of the fovea capitis (Fig 1).¹² Selected images were digitized at 400×400 dots/inch and an 8-bit depth of gray scale by means of a transparent scan bed of a high-resolution scanner (Agfa HiD dual-bed flatbed scanner, Agfa Corp., Wilmington, MA) at full size. Images were exported as uncompressed tagged-image file format. A graphics software program was used to obtain all measurements (Adobe Photoshop, version 5.5, Adobe Systems Inc., Seattle, WA) on the three 2D images from each hip.

Radiography

Immediately after CT imaging, hip-extended and distraction radiographs were obtained by established techniques at 20 and 104 weeks of age.²⁰ Radiographs were submitted to PennHIP for objective evaluation. Personnel at PennHIP scored hip joint confirmation and degenerative joint disease by use of a standardized system.³ The PennHIP degenerative joint disease classification³ included 4 categories: none, mild, moderate, or severe.

CT Measures

Images were leveled on the computer screen before measuring. Leveling was confirmed with a 180° horizontal line drawn through the center of both femoral heads. The femoral head center was determined as described.¹² In short, the center of the femoral head considered the midpoint of a line drawn perpendicular to a straight line that connected the caudal articular cartilage margins on the dorsal and ventral articular surfaces. Three participants trained by 1 investigator (K.D.) made a series of seven measures on the 3 CT slices of both hip joints from all dogs at each time point (20, 24, 32, 48, 68, and 104 weeks of age). Study measurements were performed by the participants after presentation of an illustration and explanation for each measurement. No further training took place to avoid bias.^{17,18}

All measurements were performed in accordance with methods routinely used for images obtained from people and as previously described in dogs.^{8,12,21} For those measures requiring it, the horizontal axis of the pelvis was defined as a line through the center of both femoral heads. Briefly, the CEA was measured between a line that extended from the center of the femoral head to the dorsolateral point of the labrum and a line perpendicular to the horizontal axis of the pelvis that extended dorsally through the labrum from the center of the femoral head (Fig 2A). VASA was the acute angle measured between the horizontal pelvic axis and a line that extended ventrally from the center of the femoral head to the lateral edge of the acetabular rim. DASA was measured between a line that extended dorsally from the center of the femoral head to the lateral edge of the acetabular rim and horizontal pelvic axis. HASA was the sum of the 2 aforementioned angles and was measured between the ventral line of the VASA and dorsal line of the DASA (Fig 2A). HTEA was measured between a line that extended from the medial edge of the sourcil to the lateral edge of the dorsal acetabular rim and a line that extended laterally from the medial edge of the sourcil parallel to the horizontal pelvic axis (Fig 2B). A ratio of acetabular depth/width $\times 100$ was

used to give AI. The width was measured on a line drawn between the dorsolateral and ventrolateral points of the acetabulum, and the depth was measured from the medial edge of the sourcil to the width line (Fig 2B). CPC was measured with 3 vertical lines drawn perpendicular to the horizontal pelvic axis (Fig 2B). The 1st line passed along the medial edge of the acetabulum, the 2nd along the lateral edge of the acetabulum, and the 3rd along the lateral edge of the femoral head. The ratio of the distance between the 1st and 2nd and 1st and 3rd lines was multiplied by 100 to yield the CPC.

Statistical Analysis

A total of 2268 values were available for statistical analysis. Intraclass correlation coefficients were calculated for measures performed on 3 contiguous 2D CT slices from both hips.²² Specifically, the values from each of the 3 investigators on the 3 individual CT slices from the same hips in each dog were compared. This translates to a total of 9 values/hip for a total of 18 values/dog to give 54 values for each of the 7 measures at each time point. The narrow range of raw data obtained for the AI resulted in ICC values that precluded comparison with other CT measurements, which varied dramatically with time. To resolve this, the data was anchored by providing a high endpoint that was equal in magnitude to variation observed in the CPC.²² The repeatability of each measure exclusive of age was assessed by combining values from all time points together to compose a single time point. Individual measure ICCs were calculated at each age to evaluate changes in repeatability of each measure associated with age.

In addition, values from all measures at each time point were combined to give a single outcome variable at the various ages to assess the overall repeatability of the measures when they were used together versus individually. The repeatability of the measures in joints with and without degenerative changes was assessed at 104 weeks of age. An ICC score of 0 indicates no correlation between observers and poor repeatability, whereas a score of 1 indicates perfect correlation and excellent repeatability.²² Based on previous reports, ICC values ≥ 0.75 were considered acceptable for purposes of this study.^{17,23} All statistical analysis was performed with commercially available software (SAS v8.2, SAS Institute Inc., Cary, NC).

RESULTS

Effect of Skeletal Maturity

DASA, CEA, and CPC had ICCs >0.75 in all age groups from 20 to 104 weeks of age (Table 1). HASA and HTEA had ICCs >0.75 for all but 1 time point each (24, and 104 weeks, respectively). AI was the least repeatable measure within age groups followed by VASA. At 20 weeks of age, all measures but AI were highly repeatable, and at 104 weeks of age, DASA, CEA, CPC, and HASA had ICCs >0.75 . The ICC was ≥ 0.75 for CEA, DASA, HTEA, AI, and CPC and 0.57 for VASA when all time points were combined (Table 2). Repeatability was ≥ 0.99 at all ages, when measures were combined ($n = 378$ values/time point).

Effect of Osteoarthritis

Mean ($\pm$ SD) DI scores of the 6 hip joints studied were 0.60 ± 0.12 (range, 0.48–0.74) at 20 weeks of age and 0.71 ± 0.22 (range, 0.44–0.96) at 104 weeks. At 20 weeks of age, none of the joints had radiographically evident degenerative changes on the basis of PennHIP osteoarthritis scores. At 104 weeks of age, 3 joints had no osteoarthritis, 1 joint had moderate osteoarthritis, and 2 joints had severe osteoarthritis. The majority of measures had ICCs >0.75 in hips with and without radiographic changes with the exceptions of the AI

(0.56) and HASA (0.63) in normal hips and the VASA (.034) and HTEA (0.70) in hips with osteoarthritis (Fig 3).

DISCUSSION

Current knowledge supports the use of CT instead of standard radiography to evaluate early joint changes characteristic of DDH in humans and HD in dogs.^{1,2,12,24} Planning of operative or conservative treatment of HD and outcome studies after treatment is largely based on joint imaging. Standardized examination and good reproducibility are prerequisites for appropriate application of all imaging modalities. A recent study highlights the use of CT measures performed on 2D and 3D images of lax adult canine hips to predict microstructural articular cartilage changes.¹² Given the relatively new application of CT measures originally designed for human hip joints to canine hip joints, there is little information surrounding measure repeatability. Our results indicate good repeatability of standard CT measures in lax canine hip joints from youth to maturity and in adult joints with and without degenerative joint changes.

This longitudinal observational study included dogs with lax hip joints that developed different degrees of hip osteoarthritis at maturity to allow evaluation of measure repeatability at different ages and in joints with and without radiographically evident joint disease. The likelihood of developing hip osteoarthritis characteristic of CHD increases somewhat proportionately with DI scores 0.30.²⁰ It has been suggested previously that CT measures may provide valuable information relative to joint condition for purposes such as monitoring response to therapy or assessing disease progression.¹² The methods we described will have the greatest practical application in dogs predisposed to or affected by hip joint degeneration. Additionally, the inherent challenges associated with completing measurements in lax hips are unlikely to have the same magnitude in normal joints. Our study focus was therefore limited to lax canine hips. Further studies are necessary to assess repeatability of the measurements we used in different dog breeds and normal canine hips.

The repeatability of measures we evaluated are comparable to those reported for the same measures in people with HD.^{15,25–27} Identification of landmarks for measurement purposes is a common source of error that contributes to poor repeatability within imaging modalities.¹⁴ Landmarks are often obscured by immaturity as well as degenerative bony changes. Common sources of error in immature human hips are identification of the femoral head center and determination of acetabular depth.¹⁴ Eccentricity of the ossific nucleus in children complicates consistent identification of the center of the femoral head.¹⁵ For our study, the center of the femoral head was localized without identification of the ossific nucleus.¹² Of the 4 measures in our study that required identification of the femoral head, VASA was the only measure with low repeatability over the range of ages included in the study. In contrast, DASA and CEA were highly repeatable over the entire course of the study, and HASA was highly repeatable over most of the study. Based on this information, the center of the femoral head could be consistently identified in 2D CT images of immature and mature canine hips for measurement purposes in this study.

The sourcil is a curved area of dense bone on the weight-bearing surface of the acetabulum. Difficulty in identification of the medial margin of the sourcil to measure acetabular depth reportedly contributes to low repeatability of the AI in children.²⁸ AI was not highly repeatable in the most ages evaluated in this investigation in canine hips; however, the source of the difficulty in AI measurement was not likely because of identification of the sourcil in this case, because other measures that relied on identification of the landmark, the HTEA and CPC, were highly repeatable. Identification of the ventral margin of the acetabulum is required for measurement of AI and VASA, both of which showed the lowest

repeatability over all age groups. In humans, rounding of the acetabular edges in dysplastic hips complicates identification of the margins.¹⁵ This is the most likely source of landmark identification disparity in our study.

Osteoarthritic joint changes can mask landmarks necessary for measures on 2D CT images.^{15,29,30} To assess the effect of osteoarthritis-mediated joint alterations on measure repeatability, a homogenous set of dogs with radiographically evident osteoarthritic joint changes ranging from none to severe was selected. Overall, measure repeatability was comparable between normal and osteoarthritic hips. The poor repeatability of the VASA in the osteoarthritic hips and the AI and HASA in hips without osteoarthritis was likely related to difficulties in precise localization of the ventral acetabular margins as mentioned above. Initial canine hip joint degeneration is usually localized in the dorsal acetabulum.⁶ Hence, identification of landmarks for HTEA measure was likely compromised in osteoarthritic hip joints. This is additionally supported by the lower ICC of the HTEA in the 104-week age group versus the other age groups evaluated. The moderate ICC score in osteoarthritic joints in our study does not necessarily preclude use of the measure in osteoarthritic canine hip joints because CEA, HTEA, and DASA measured on 2D CT images had the strongest relationship with canine hip joint microstructure in a previous study.¹² The exceptional repeatability of the CEA and DASA and moderate to high repeatability of the HTEA over the ages and joint conditions evaluated in our study support their application to predict articular cartilage microstructural changes in lax canine hip joints as described previously.

Despite apparent interobserver repeatability differences in individual measures among age groups, the ICC of a combination of all measures included in this study was 0.99 at each time point. These values correspond to a variation of 1% attributable to interobserver differences. Additionally, when all time points were combined, the ICCs were all > 0.83 with the exception of VASA. This is consistent with interobserver differences 17%. These values are comparable to the repeatability of currently available diagnostic measures on radiographic images.¹⁷ In people with DDH, radiographic measures performed on the images of young children are different than those performed on adults and adolescents.¹⁴ This is primarily because of progressive changes in the cartilaginous composition of the hip joint that influence landmark identification. Our results support use of the same measurements in dogs 20 weeks of age, consistent with the earliest age recommended for hip evaluation in the mid-size dogs included in this study.^{31,32}

Transverse CT images of canine hip joints permit evaluation at various levels within the articular structures that is not possible with standard radiographic imaging. The 2D CT measures applied in our study reflect canine hip joint articular cartilage microstructural changes.¹² The repeatability of the measures in normal and osteoarthritic hips from youth to maturity in our study were comparable to the same measures in human hip images. This supports further validation of the measures for research and clinical applications in dogs with passive hip joint laxity. The 2D CT measures evaluated in this report have the potential to provide valuable information to augment current techniques for assessing joint changes in lax canine hips.

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Fig 1. Two-dimensional computed tomography image of a canine hip joint. The margins of the acetabular fossa (A) are indicated with light grey arrows, the fovea capitis (FC) margins on the femoral head (F) indicated with black arrows, and the sourcil is outlined with dark grey arrows.

Fig 2.

(A) The center-edge angle (CEA) was measured between a line that extended from the center of the femoral head to the dorsolateral point of the labrum and a line perpendicular to the horizontal axis of the pelvis that extended dorsally through the labrum from the center of the femoral head. The ventral acetabular sector angle (VASA) was measured between the horizontal pelvic axis and a line extending from the femoral head center to the ventrolateral acetabular rim. The dorsal acetabular sector angle (DASA) was measured between a line extending from the femoral head center to the dorsolateral edge of the acetabular rim and the horizontal pelvic axis. The horizontal acetabular sector angle (HASA) was measured between the ventral line of the AASA and the dorsal line of the PASA. (B) The horizontal toit externe angle (HTEA) was measured between a line from the medial edge of the sourcil to the lateral edge of the dorsal acetabular rim and a line extending laterally from the medial edge of the sourcil parallel to the horizontal pelvic axis. To determine the acetabular index (AI), the acetabular width (W) and depth (D) was measured, and AI was calculated as $D/W \times 100$. Computed tomography percentage femoral head coverage (CPC) was calculated as $A/B \times 100$.

Fig 3.

Graphic representation of the intraclass correlation coefficients for computed tomography (CT) measures performed on 2D CT images of canine hip joints with no, moderate, or severe radiographically evident osteoarthritis at 104 weeks of age ($n = 27$ values/measure for no osteoarthritis; $n = 27$ values/measure for moderate to severe osteoarthritis).

Table 1

Intraclass Correlation Coefficients for CT Measures Performed on 2D CT Images of Lax Canine Hip Joints from 20 to 104 Weeks of age. (n = 54 Values/Measure/Time Point)

CT Measure	Age (Weeks)					
	20	24	32	48	68	104
DASA	0.94	0.92	0.96	0.93	0.99	0.99
CEA	0.94	0.92	0.97	0.93	0.99	0.99
CPC	0.77	0.81	0.84	0.93	0.95	0.98
HASA	0.88	0.53	0.90	0.92	0.88	0.97
AI	0.31	0.73	0.52	0.30	0.53	0.57
HTEA	0.93	0.91	0.92	0.86	0.79	0.69
VASA	0.76	0.79	0.61	0.77	0.29	0.52

ICC, intraclass correlation coefficient; DASA, dorsal acetabular sector angle; CEA, center-edge angle; CPC, computed tomography percent femoral head coverage; HASA, horizontal acetabular sector angle; AI, acetabular index; HTEA, horizontal toit externe angle; VASA, ventral acetabular sector angle; CT, computed tomography; 2D, two-dimensional.

Table 2.

Intraclass Correlation Coefficients for CT Measures Performed on 2D CT Images of Lax Canine Hip Joints from 20 to 104 Weeks of Age when all Time Points were Combined to Assess Repeatability Exclusive of Age (n = 324 Values/Measure)

CT Measure	ICC
DASA	0.98
CEA	0.98
CPC	0.93
HASA	0.92
AI	0.85
HTEA	0.83
VASA	0.57

See Table 1 for key.