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Evaluation of three acetabular measurement methods for total hip replacement in dogs

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Abstract

Objective: To compare three measurement methods for acetabular sizing and evaluate the influence of osteoarthritis (OA) on the accuracy of measurements.

Study design: Observational study.

Sample: Radiographic images of 73 hip joints from 60 dogs with cementless cups.

Methods: Radiographs were anonymized and measured independently by three observers. One observer measured 12 sets of radiographs three times. A best-fit acetabular circle (AC) and cranial-caudal acetabular line (AL) were measured on ventral-dorsal (VD) radiographic view and open leg lateral (OLL) view. A best-fit femoral head circle (FHC) was measured on VD, OLL, and craniocaudal horizontal beam (CCHB) views. Two observers scored the OA in each hip joint. Intra- and interobserver consistency and repeatability and bias relative to implanted cup size were calculated and analyzed.

Results: Intraobserver consistency and repeatability were excellent for all measurements. Interobserver consistency was excellent (ICC > 0.9) for AC_{VD} and AC_{OLL} and was good ($0.75 < ICC \leq 0.9$) for all other methods. Bias was small for AC and AL measurements (range, −0.46 to 0.45 mm) and large for FHC measurements (−3.58 to −2.42 mm). OA score significantly influenced bias for all acetabular measurement methods ($p < 0.05$).

Conclusion: All acetabular measurement methods were highly consistent within an observer. Interobserver consistency was highest for AC_{VD} and AC_{OLL}. FHC measurements underestimated cup size. Higher OA scores decreased the accuracy of all acetabular measurement methods.

Abbreviations: AC, acetabular circle; AL, acetabular line; BVA/KC, British Veterinary Association/Kennel Club; CCHB, craniocaudal horizontal beam; FHC, femoral head circle; ICC, interclass correlation coefficient; OA, osteoarthritis; OLL, open leg lateral; THR, total hip replacement; VD, ventral-dorsal.

The findings of this study were presented at the Veterinary Orthopedic Society Conference, 2024, in Lake Tahoe, California.

Clinical significance: Superimposing a circle on the acetabulum seen on VD radiographic view accurately measures the acetabulum before cementless cup placement.

1 | INTRODUCTION

Cementless total hip replacement (THR) is a surgical procedure that eliminates chronic pain and restores full limb use in dogs with osteoarthritis of the hip joint.[1,2] Planning total hip replacement commonly relies on radiographic templating.[3] Cup templating is done to predict the size, position, and orientation of a prosthetic cup,[4] to detect the presence of anatomic abnormalities, and to ensure component availability. Several radiograph-based acetabular measurement methods have been reported that rely on the acetate or digital superimposition of a line,[5] a circle,[6] or an implant-matching semicircle[3,7] on a radiographic projection of the acetabulum or femoral head. Little is known about the consistency within an evaluator and among evaluators and the predictive value of measurement methods for canine THR. One report of 52 canine THR found that the cup size was accurately predicted by the primary templating plan in 41 of 52 dogs (79%).[3] However, information about acetabular measurement accuracy and factors that may have influenced that accuracy was not provided.

The purpose of the study was to evaluate the consistency, repeatability, and predictive value of acetabular measurement methods relying on a circle fitted to acetabular landmarks, a line across the acetabulum, and a circle fitted to the femoral head on several radiographic projections. Our hypothesis was that fitting a circle to the acetabulum and drawing a line across the acetabulum on a ventrodorsal (VD) or open-leg lateral (OLL) radiographic projection would have excellent consistency, acceptable repeatability (i.e., a repeatability < 2 mm), and would be predictive of implanted cup size (i.e., would differ from implanted cup size by < 1 mm). We also hypothesized that fitting a circle to the femoral head on a VD, OLL, or craniocaudal horizontal beam (CCHB) view would also have excellent consistency and acceptable repeatability and would be predictive of implanted cup size. Our final hypothesis was that measurement accuracy would be negatively impacted by the severity of osteoarthritis (OA).

2 | MATERIALS AND METHODS

2.1 | Patient selection

Dogs were initially identified through an electronic medical record search of hospitalized patients that had the diagnosis of hip dysplasia between January 2019 and June 2021. Client consent was given as part of an institutional animal care and use protocol that authorizes the use of anonymized patient data. Dogs were excluded if they did not undergo THR with a cementless cup (BioMedtrix BFX), if preoperative ventrodorsal (VD), craniocaudal horizontal beam[8] (CCHB), and open-leg lateral[9] (OLL) radiographic views were not available, if a radiographic magnification marker was not included, if a 3-month reevaluation with radiographs of the operated hip was not available, or if a complication associated with the acetabular cup was observed, including infection, luxation, or lack of bone ingrowth. The cup templating and THR surgery was performed by a board-certified surgeon experienced in cementless total hip replacement (DML). Preoperative cup templating was done on a calibrated open-leg lateral radiograph by superimposing the smallest semicircle that covered the cranial and caudal aspect of the acetabulum using radiographic templating software (vPOP version 2.9.2, VetSOS Education).

2.2 | Radiographic measurements

Radiographs meeting inclusion criteria were downloaded and anonymized. The order in which radiographs were reviewed was randomized within each radiographic view type using a commercially available software program (Microsoft Excel, version 16.83, Microsoft). Three observers collected measurements using an open-source DICOM image viewer (Horos version 3.3.6, Horos Project). The observers were blinded to the original templated size, to the implanted cup size, and to measurements collected by other observers.

Three measurement methods were evaluated (Figure 1). A circle was fitted to the acetabulum (AC method),[6] a line was drawn from the cranial to the caudal aspect of the acetabulum (AL method),[5] and a circle was fitted to the femoral head (FHC method).[10] Geometric shapes were drawn such that they overlapped the subchondral bone. The AC method was used to template the VD (AC_{VD} method) and OLL radiographic views (AC_{OLL} method). For the AC method, a dot was placed at the cranial and caudal aspect of the acetabulum and at the medial (VD view) or dorsal (OLL view) acetabular wall, equidistant from the first two dots. A best-fit circle that joined the three dots was drawn. The circle diameter was

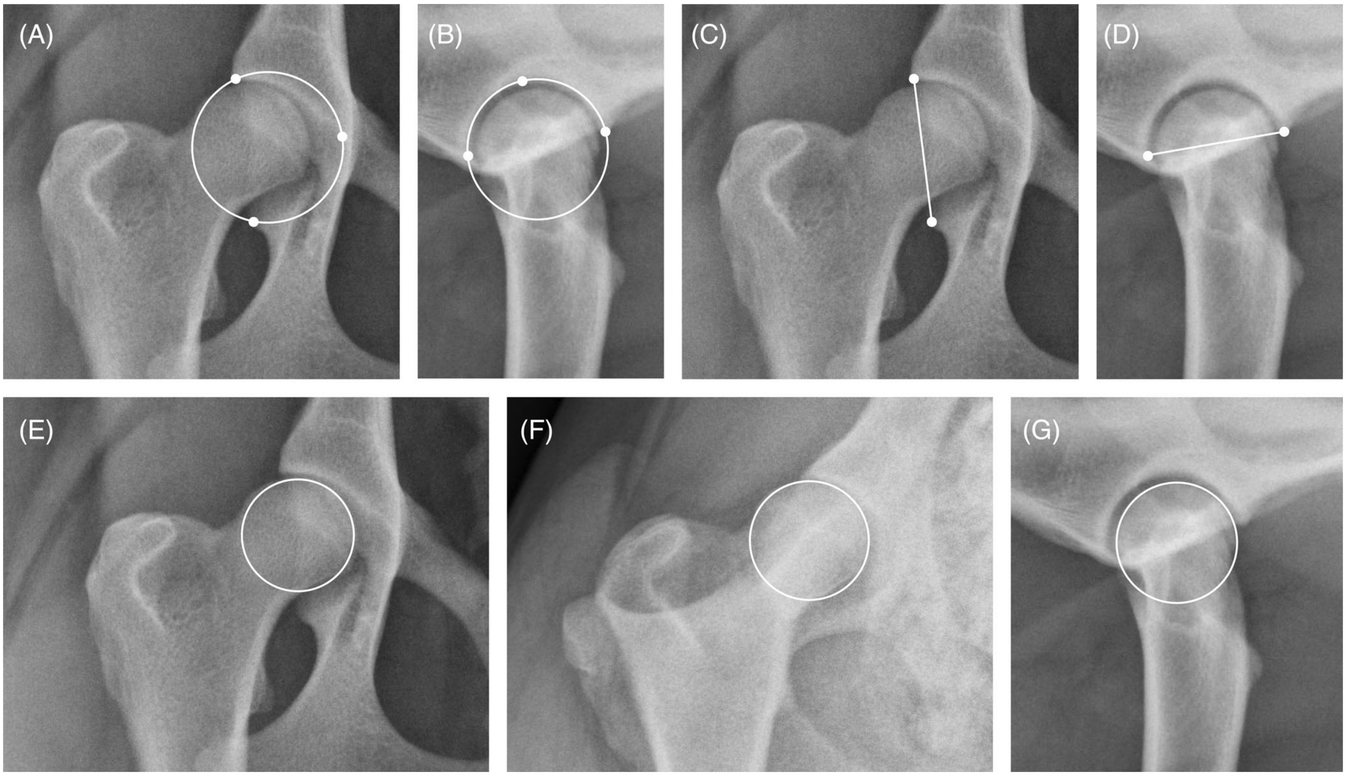

FIGURE 1 The seven measurement methods evaluated included drawing a circle on the acetabulum on a ventrodorsal (AC_{VD} method, A) and open leg lateral radiographic view (AC_{OLL} method, B), drawing a line joining the cranial and caudal aspects of the acetabulum on a ventrodorsal (AL_{VD} method, C) and open leg lateral view (AL_{OLL} method, D), and drawing a circle on the femoral head on a ventrodorsal (FHC_{VD} method, E), craniocaudal horizontal beam (FHC_{CCHB} method, F), and open leg lateral radiographic views (FHC_{OLL} method, G). For the AC_{VD} method, points are placed at the craniolateral and the caudolateral aspects of the acetabulum. A third point equidistant to the first two points is placed on the medial wall. A circle is drawn that joins the three points. For the AC_{OLL} method, points are placed at the cranioventral and the caudoventral aspects of the acetabulum. A third point equidistant to the first two points is drawn tangential to the dorsal acetabular edge. A circle is drawn that joins the three points.

recorded. The AL method was used to template the VD (AL_{VD} method) and OLL radiographic views (AL_{OLL} method). For the AL methods, a dot was placed at the cranial and the caudal aspect of the acetabulum. A line was drawn that joined the two dots. The length was recorded. The FHC method was used to template the VD (FHC_{VD} method), OLL (FHC_{OLL} method), and CCHB radiographic views (FHC_{CCHB} method). For the FHC method, a best-fit circle was drawn on the femoral head. The diameter of the circle was recorded. To evaluate intraobserver consistency, one observer measured 12 randomly selected hip joints from the joints included in the study two additional times. The size of the implanted acetabular cup was recorded.

The severity of hip dysplasia and osteoarthritis on the VD radiographic view was scored using a modified British Veterinary Association/Kennel Club (BVA/KC) hip dysplasia scoring scheme.[11] Scoring was done by consensus between two ACVS Diplomates (BF, DML).

Eight of the nine BVA/KC scoring scheme categories were scored: subluxation, cranial acetabular edge, dorsal acetabular edge, cranial effective acetabular rim, acetabular fossa, caudal acetabular edge, femoral head and neck exostoses, and femoral head recontouring.[12] The Norberg angle was not measured. The maximum possible score, indicative of the most severe form of hip dysplasia and osteoarthritis, was 47.

2.3 | Statistical analysis

Statistical analysis was performed using statistical software (SAS version 9.4, SAS Institute). The three measurement methods were assessed for consistency and repeatability. Consistency for repeated readings from one observer and consistency among observers was calculated using an interclass correlation coefficient (ICC).[13] ICC values < 0.5 represented poor consistency, values ≥ 0.5 and <0.75 represented moderate consistency, values ≥ 0.75 and <0.9 represented good consistency, and values ≥ 0.90 were represented excellent consistency.[14] Intraobserver repeatability was calculated as the standard deviation from a linear mixed model.[15,16] Repeatability < 2 mm was considered acceptable. Bias between templated and implanted cup sizes and 95% limits of agreement were determined using the Bland–Altman method.[17,18] Bias < 1 mm was considered acceptable. The association of bias and OA severity was determined using correlation analysis. Pearson coefficients were used if data were normally distributed and Spearman coefficients if data were not normally distributed. For all analyses, values of $p < .05$ were considered statistically significant.

The predictive accuracy of each measurement method for each observer was evaluated by rounding the acetabular measurement using three rounding methods (closest integer, rounding down to the closest integer, and rounding up to closest integer) and adding a millimeter if the result was an odd number to adjust the value to the closest even integer (cup size). The prediction was deemed accurate if the adjusted value was equivalent to the cup used in surgery. The frequency of equivalence was reported as a percent.

3 | RESULTS

A total of 174 dogs were initially identified. A total of 114 dogs were excluded because THR with a cementless cup was not performed ($n = 95$), surgery was performed elsewhere ($n = 3$), the dogs were misidentified as having hip dysplasia within the study period ($n = 12$), or the dogs had postoperative complications ($n = 4$). A total of 60 dogs met the inclusion criteria. Of these, 13 dogs had undergone bilateral THR, for a total of 73 hip joints included in the study. Mean ± SD bodyweight at the time of surgery was 34.8 ± 12.9 kg. Median final acetabular cup size was 24 mm (range 18–30 mm).

Intraobserver consistency was excellent for all measurement methods, with ICC ranging from 0.900 to 0.992 (Table 1). Intraobserver repeatability ranged from 0.39 to 1.03 mm and was acceptable. Interobserver consistency was excellent for the AC_{VD} (ICC = 0.929) and AC_{OLL} methods (0.912) and was good for the AL_{VD}, AL_{OLL}, FHC_{VD}, FHC_{OLL}, and FHC_{CCHB} methods (ICC ranging from 0.754 to 0.893). Interobserver repeatability ranged from 0.85 to 1.17 mm and was acceptable. Bias ranged from −0.47 to 0.41 mm for AC and AL measurements methods on each radiographic view and was acceptable. Conversely, bias for the FHC method ranged from −2.42 to −3.58 mm and was considered unacceptable.

The median hip score was 27 points (range, 3–43 points). The hip score influenced bias for all measurement methods (p ranging from <.001 to .034). An increase in the severity of hip dysplasia and OA led to an increase in bias for the FHC_{VD} method ($r = 0.201$, $p = .003$) but not for other methods (r ranging from −.090 to .124, p ranging from .067 to .573). Bias for five measurement methods correlated statistically with OA changes in specific categories. Bias of AC_{OLL} and AL_{OLL} methods correlated with changes at the cranial acetabular edge. Bias of the FHC_{CCHB} method correlated with changes at the cranial effective acetabular rim and caudal acetabular edge. Bias of the FHC_{OLL} method correlated with changes at the caudal acetabular edge. Bias of the FHC_{VD} method correlated with changes at the cranial effective acetabular rim, acetabular fossa, caudal acetabular edge, femoral head exostoses, and femoral head contour.

TABLE 1 Intra- and interobserver consistency and repeatability and bias relative to implanted cup size for three cup measurement methods evaluated on three radiographic views of 73 canine hip joints from 60 dogs.

Method	Intraobserver ICC[a]	Intraobserver repeatability[b] (mm)	Interobserver ICC	Interobserver repeatability (mm)	Bias[c] (mm)
AC_{VD}	0.941	1.03	0.929	0.85	0.136
AC_{OLL}	0.962	0.90	0.911	0.94	0.446
AL_{VD}	0.991	0.39	0.881	1.17	−0.460
AL_{OLL}	0.972	0.72	0.893	0.87	0.083
FHC_{VD}	0.900	1.02	0.754	1.22	−3.576
FHC_{CCHB}	0.954	0.72	0.797	1.07	−3.175
FHC_{OLL}	0.983	0.43	0.870	0.89	−2.420

Abbreviations: AC, acetabular circle; AL, acetabular line; CCHB, craniocaudal horizontal beam; FHC, femoral head circle; ICC, intraclass correlation coefficient (consistency); OLL, open leg lateral; VD, ventrodorsal.

[a]Consistencies ≥ 0.9 are considered excellent and ≥0.75 and <0.9 are considered good.

[b]Repeatabilities <2 mm are considered acceptable.

[c]Difference with implanted cup size. Differences < 1 mm are considered acceptable.

Including measurements from all observers, when rounding the measured acetabular sizes to the closest integer and adding 1 if the number was odd, the predictive accuracy was 45% for the AC_{VD} method, 34% for the AC_{OLL} method, 47% for the AL_{VD} method, 37% for the AL_{OLL} method, 12% for the FHC_{VD} method, 24% for the FHC_{OLL} method, and 12% for the FHC_{CCHB} method. When rounding up to the next integer and adding 1 if the number was odd, the predictive accuracy was 37% for the AC_{VD} method, 32% for the AC_{OLL} method, 42% for the AL_{VD} method, 29% for the AL_{OLL} method, 13% for the FHC_{VD} method, 30% for the FHC_{OLL} method, and 21% for the FHC_{CCHB} method. When rounding down to the next integer and adding one if the number was odd, the predictive accuracy was 49% for the AC_{VD} method, 37% for the AC_{OLL} method, 48% for the AL_{VD} method, 39% for the AL_{OLL} method, 9% for the FHC_{VD} method, 17% for the FHC_{OLL} method, and 10% for the FHC_{CCHB} method. For all seven measurement methods and all three rounding methods, differences in predictive accuracy among observers ranged from 1% to 21% (median difference, 7%).

4 | DISCUSSION

Intraobserver consistency was excellent for all methods and interobserver consistency was excellent for the AC method and good for AL and FHC methods. We therefore accepted the hypothesis that fitting a circle to the acetabulum on a VD or OLL radiographic view would have excellent consistency. The hypothesis that fitting a line to the acetabulum on a VD or OLL radiographic view or fitting a circle to the femoral head on a VD, OLL, or CCHB was rejected because interobserver consistency was not excellent. The results of the current study are in agreement with a previous study evaluating the AC_{VD} templating method in which the reported accuracy was 95.9% and interobserver reliability of 97.6%.[6] However, in that study, the accuracy of the AC_{VD} method was not compared to the accuracy of other cup templating methods. The findings in the current study indicate that a best fit acetabular circle drawn on either VD or OLL radiographic views was least influenced by the observer and can be considered when measuring for acetabular cup size in dogs.

The hypothesis that all measurement methods would be repeatable was accepted. Based on bias being <1 mm, the hypothesis that measurement methods would be predictive of the size of the implanted cup was accepted for AC and AL methods on both VD and OLL radiographic views and was rejected for FHC methods on the VD, OLL, and CCHB views. AC_{VD} and AL_{OLL} most closely predicted realized cup size. While the bias was small, overall predictive accuracy, as assessed by rounding the measurement up or down to the closest integer and comparing this to the implanted cup size, was relatively low, ranging from 30% to 50% for acetabular circles and lines and from 10% to 30% for femoral head circles. Measurement accuracy varied among observers. The findings of the current study show lower predictability than the findings of a previous study that reported accurate cup size prediction in 79% of 52 dogs undergoing THR.[3] The difference in cup predictability between these studies may be the result of differences in surgeon approaches to cup reaming. Approaches to cup reaming could prioritize bone preservation[19] or could aim to maximize cup size or prosthetic head size. In the current study, cancellous bone preservation was prioritized. In surgery, no effort was made to remove cancellous bone once subchondral bone was removed on the cranial and caudal aspect of the acetabulum. If maximizing implant size was a priority, the measurements would have probably underestimated implant size in a larger fraction of patients. The relatively low predictability of cup sizing identified in the current study suggests the need to further investigate the cup templating process to increase its predictability. For example, geometric shapes could be positioned beyond the subchondral bone during templating, leading to larger measurements that would likely be more predictive of implant size. In human THR, the reported accuracy of digital templating for THR ranges between 42% and 83%.[20–23] That accuracy is influenced by surgical experience of the performing physician, potentially because surgeon approaches, specifically prioritization of bone preservation or implant size, can shift over time.

Femoral head circle methods were not predictive of the size of the implanted cup on all radiographic views because they underestimated cup size by 2.5–3.5 mm. That underestimation is likely the consequence of the fact that femoral head measurements do not account for the thickness of the articular cartilage of the femoral head and acetabulum. In one study, the mean thickness of the articular cartilage of the femoral head in dogs was 0.67 ± 0.01 mm in normal femoral heads, 1.17 ± 0.03 mm in femoral heads with moderate OA, and 0.91 ± 0.04 in femoral heads with severe OA.[24] Another study reported the mean maximal cartilage thickness in the dog femoral head and acetabulum to be 1.19 mm.[25] The sum of the articular cartilage thickness in the acetabulum and femoral head would be expected to be approximately 2 mm and is likely to be responsible for the fact that measurements of femoral head underestimated acetabular cup size. Templating cup size using the femoral head may still offer benefits in patients with severe acetabular OA or abnormalities, as long as a size underestimation of 2–3 mm is accounted for.

For all methods, measurement accuracy was influenced by OA severity. Therefore, the hypothesis that an increase in OA severity negatively impacted cup measurement was accepted. This finding likely results from the fact that OA obscures and transforms the anatomic landmarks used for radiographic measuring. This suggests that cup measurements should be trusted less in dogs with severe OA. For these patients, the use of three-dimensional computed tomography planning could be considered.[17]

The current study had limitations. A template shape matching the implanted cup shape[3] was not used. Since cup-shaped templates are hemispheric, the use of a circle instead of a semicircle is unlikely to have influenced the findings of the current study. The purpose of this study was to compare the accuracy of simple geometric shapes to measure the acetabulum, therefore, the use of lines and circles appeared most appropriate. As mentioned above, the surgeon approach to cup insertion prioritized cancellous bone preservation.[19] Surgeon preferences that likely influence cup size include the templating method, the type of reamer used, the reaming method, and the preservation of cancellous bone and the medial acetabular wall. In this study, preoperative cups were measured on the open-leg lateral view. This method was selected because, subjectively, the clinician perceived that the cranial and caudal aspects of the cup could be seen more clearly than on the VD view, particularly in patients with severe osteoarthritis. The accuracy of templating using an open-leg lateral view, however, had not been evaluated before the current study. The influence of surgeon factors on templating accuracy cannot be determined from the current study since all surgeries were overseen by a single surgeon. Also, it is unclear how the findings of the current study apply to cemented acetabular cups, since surgeon approaches to bone removal during the implantation of a cemented cup likely vary from cementless cups. Measurements of acetabular sizes relied on the accurate placement of a radiographic magnification marker in all radiographic views. In one study of 112 human THR, magnification errors led to differences between measured prosthetic head diameters and actual prosthetic head diameters ranging from 0% to 26% (median error, 5.7%).[26] It is possible that consistent errors in magnification marker position influenced the findings of the current study. A 100-mm-long magnification marker was used in the current study. In human THR, the use of a ball magnification marker instead of a linear marker improves accuracy.[26,27] However, since the findings in the current study were highly consistent across multiple radiographic views, systematic errors resulting from faulty positioning of magnification markers in specific views were unlikely.

In the future, the development and validation of stepwise approach to cup templating in canine THR should be considered. In human THR, a structured templating process has been shown to improve both surgical success and postoperative outcome.[10,28] Also, the use of computed tomography and 3D computer planning is likely to enhance THR templating since these steps have been shown to improve accuracy compared with digital radiography.[29–32] The development of criteria for the choice of a THR planning method in patients with specific hip pathology is warranted.

In conclusion, the results of the current study showed that all acetabular measurement methods were consistent. The method of drawing a best-fit acetabular circle drawn on a VD or OLL radiographic view was least influenced by the observer and most closely predicted realized cup size. Femoral head measurements were poor predictors of cup size because they consistently underestimated cup size. For all methods, an increase in OA severity decreased the accuracy of the acetabular measurement.

AUTHOR CONTRIBUTIONS

Wilson JN, DVM: Involved in study design, data collection, data interpretation, and manuscript preparation and revision. Filliquist B, DVM, MAS, DACVS-SA, DECVS: Involved in study design, data collection, data interpretation, and manuscript preparation and revision. Garcia TC, MS: Performed the statistical analyses and was involved in the data interpretation and manuscript preparation and revision. Marcellin-Little DJ, DEDV, DACVS, DACVSMR: Involved in study design, data collection, data interpretation, and manuscript preparation and revision. All authors approved of the final publication submission.

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