Three-Dimensional Morphometry of the Canine Pelvis: Implications for Total Hip Replacement Surgery

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Abstract

Objectives Two-dimensional measurements of acetabular geometry are widely used for the assessment of acetabular component orientation following total hip replacement (THR). With the increasing availability of computed tomography scans, there is an opportunity to develop three-dimensional (3D) planning to improve surgical accuracy. The aim of this study was to validate a 3D workflow for measuring angles of lateral opening (ALO) and version, and to establish reference values for dogs.

Methods Pelvic computed tomography scans were obtained from 27 skeletally mature dogs with no radiographic evidence of hip joint pathology. Patient-specific 3D models were built, and ALO and version angles were measured for both acetabula. The validity of the technique was determined by calculating intra-observer coefficient of variation (CV, %). Reference ranges were calculated and data from left and right hemipelves were compared using a paired *t*-test and symmetry index.

Results Measurements of acetabular geometry were highly repeatable (intra-observer CV 3.5–5.2%, inter-observer CV 3.3–5.2%). Mean (± standard deviation) values for ALO and version angle were 42.9 degrees (± 4.0 degrees) and 27.2 degrees (± 5.3 degrees) respectively. Left-right measurements from the same dog were symmetrical (symmetry index 6.8 to 11.1%) and not significantly different.

Conclusions Mean values of acetabular alignment were broadly similar to clinical THR guidelines (ALO of 45 degrees, version angle of 15–25 degrees), but the wide variation in angle measurements highlights the potential need for patient-specific planning to reduce the risk of complications such as luxation.

Keywords
- computed tomography
- total hip replacement
- hip
- pelvis or acetabulum
- dog

Introduction

Total hip replacement (THR) is a highly effective technique for the management of hip dysplasia and other diseases of the coxofemoral joint in dogs.[1] However, several potentially challenging complications have been reported following the procedure, including luxation, implant loosening, infection and femoral fracture.[2–5] Luxation has been described as the most common complication,[3,4,6–8] with a reported incidence of between 1.1 and 15.8%.[1,4,5,7]

A variety of patient-related and technical factors have been postulated as determinants of the risk of luxation in dogs, including breed, conformation, implant sizing and implant positioning.[4,6,9] Of these, the most attention has been paid to the role of acetabular cup positioning (angles of lateral opening [ALO] and cup version).[4,6] Manufacturer's recommendations for acetabular positioning range from 35 to 45 degrees for ALO[4] and 15 to 25 degrees for version angle.[10,11] However, these angles are not intended to be breed-specific. Given the variation in pelvic size and

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conformation seen in dogs that are candidates for THR, it is unlikely that population-based average values will be appropriate for all dogs. Additionally, the published guidance does not take into consideration any pelvic pathology that may affect acetabular conformation and orientation. Based on the current state of knowledge, it is apparent that a more complete description of normal reference values for acetabular orientation across different breeds and over a range of pathologies could be helpful in better defining optimal implant position and reducing the risk of postoperative complications following THR.

Two-dimensional measurements have been widely used to describe acetabular geometry.[12–14] However, plain radiographs do not account for pelvic rotation or tilting, and perfect projections are necessary for accurate and repeatable measurements.[15] Measurements of acetabular morphometry utilizing computed tomography (CT) have also been reported.[16] With CT becoming more accessible and accepted as a routine diagnostic modality in veterinary medicine, there is potential to obtain more accurate and precise measurements. Three-dimensional (3D), CT-derived bone models give detailed information on acetabular morphometry and are relatively insensitive to variation in patient positioning during the CT scan procedure.[17]

The specific aim of this study was to determine ALO and version angles of the native canine acetabulum in a heterogeneous population of dogs to establish reference values for dogs using 3D *in-silico* models derived from CT scans, and to validate this method by determining intra-observer coefficient of variation. We hypothesized that measurements made on 3D models are repeatable and that ALO and version angles are more variable than the range recommended by implant manufacturers.

Materials and Methods

Study Population

This was a descriptive study of CT images from client-owned dogs. Dogs were included if they were skeletally mature (as determined by closed growth plates), had a CT scan of the entire pelvis and had no radiographic evidence of hip joint disease. The CT scans of immature dogs or dogs with pelvic or hip pathology were excluded from the study. Owners provided informed consent for the use of their dog's imaging data in this study. Three-dimensional data (slice thickness <1 mm) were exported in Digital Imaging and Communications in Medicine (DICOM) format to medical engineering software (MIMICS version 24.0; Materialise, Leuven, Belgium) to build the *in-silico* pelvic models. The models were segmented on a bone algorithm, smoothed (2 cycles at 0.4) and wrapped (smallest detail 1 mm, gap closing 0.5 mm) to minimize artifacts from CT that could affect measurements. The pelvic models were exported further as Standard Tessellation Language (STL) files to a mesh-based 3D measurement and design software (3-Matic version 16.0; Materialise, Leuven, Belgium) for analysis.

Anatomical Measurements from CT Scans

For the purpose of measurement, anatomical pelvic landmarks and reference planes were established. Four standardized landmarks were identified to define the alignment plane of the pelvis – the cranial dorsal iliac spines on the left and right sides and the ischial tuberosities on the left and right sides (►**Fig. 1A**). The dorsal plane of the pelvis was defined by creating a datum plane that intersected with three of the four landmark points (►**Fig. 1B**). This plane ran along the ilioischial line and at right angles to the median plane. The median plane of the pelvis was defined by creating a datum plane that bisected the line between the two ischial landmarks (►**Fig. 1C**). The third pelvic plane, the transverse plane, was defined by creating a datum plane that intersected with the two ischial points and that was perpendicular to the dorsal pelvic plane. This plane was set at right angles to both the median plane and the dorsal pelvic plane (►**Fig. 1D**).

The acetabulum was defined by marking triangles along the lunate surface of the acetabulum (►**Fig. 2A**) and defining a best fit sphere (►**Figs. 2B**). The centre of the acetabulum was identified by a point, representing the coordinates of the centre of the best-fit sphere inside the acetabulum (►**Figs. 2C**).

The orientation of the ventral acetabular rim was defined by marking the triangles that form the cranial and caudal rims of the ventral acetabulum (►**Fig. 3A**). A plane – the ventral acetabular plane – was then defined by best fitting to these highlighted triangles (►**Fig. 3B**). The acetabular orientation plane was defined as a plane that was perpendicular to both the ventral acetabular plane and the dorsal pelvic plane, and that passed through the centre point of the acetabulum (►**Fig. 3C**).

The version angle was measured as the angle formed between the acetabular orientation plane and the transverse plane (►**Fig. 4A**).

The ALO, the angle formed between the ventral acetabular plane and the median plane, was measured in the transverse plane for the left and right acetabula (►**Fig. 4B**).

Data Handling and Statistical Analysis

All data were collated and analysed using a commercial spreadsheet (Microsoft Excel for Mac version 16.62; Microsoft Corporation, Seattle, Washington, United States). The mean and standard deviation were calculated for ALO and version angles for each hemipelvis. Left-right differences were evaluated using a paired *t*-test, with significance set at p less than 0.05, and with the symmetry index, according to the following formula:

$$\text{Symmetry index} = 100 \,^{*}\, (\text{Right-Left})/(0.5^{*}(\text{Right} + \text{Left}))$$

For the determination of intra-observer repeatability, six hemipelves were each measured three times and the coefficient of variation (%) calculated for both ALO and version. For the determination of inter-observer reproducibility, six hemipelves were measured independently by two investigators (MJA and ABF) and the coefficient of variation (%) calculated.

Results

Twenty-seven dogs fulfilled the inclusion criteria. Breeds in this study included Boerboel ($n = 2$), Leonberger,

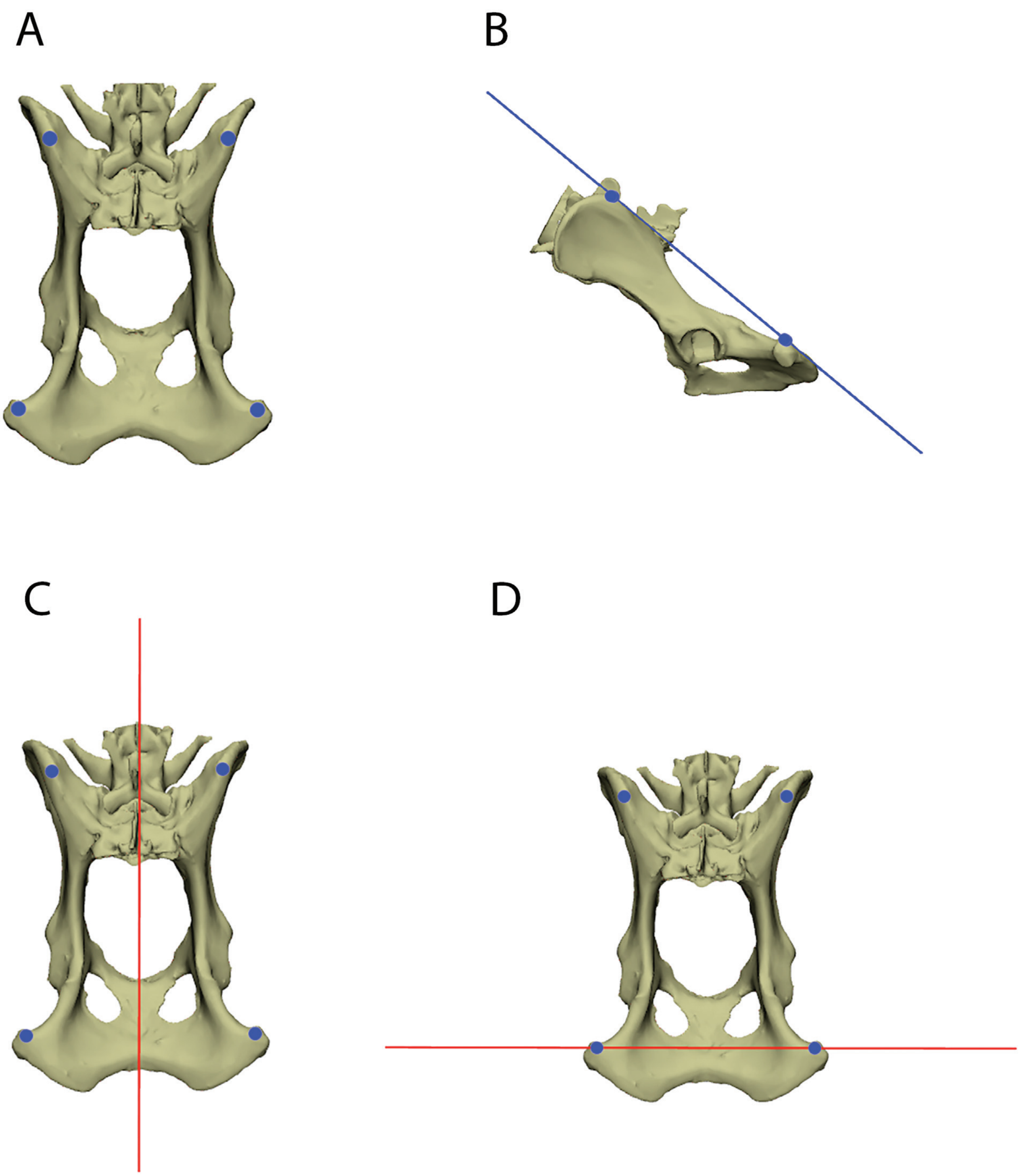

Fig. 1 Anatomical landmarks and reference planes. (A) Four pelvic points were defined on the left and right ilia, and the left and right ischia. These landmarks were then used to define the three reference planes: dorsal pelvic plane (B), median plane (C) and transverse plane (D).

Staffordshire Bull Terrier, Lurcher, Greyhound ($n = 3$), Rhodesian Ridgeback ($n = 2$), Golden Retriever ($n = 2$), Great Dane, cross-breed ($n = 3$), Caucasian Shepherd dog, German Shepherd dog, Doberman, Bullmastiff, American Bulldog, Pyrenean Mountain dog, Bernese Mountain dog, Weimaraner, Labrador Retriever ($n = 2$) and Siberian Husky. There were 14 males (10 entire, 4 neutered) and 13 females (5 entire and 8 neutered). The median age was 7 years, 5 months (range: 9 months to 12 years, 2 months) and the median body weight was 35.8 kg (range: 21–79 kg).

Complete data for ALO and version angles in the 27 pelves are presented in ►**Table 1**. The mean (±standard deviation) values for the ALO of left and right acetabula were 42.60 ± 4.15 degrees and 43.14 ± 3.92 degrees, respectively. Mean version angles for the left and right acetabula were 27.51 ± 4.81 degrees and 26.85 ± 5.82 degrees. There were no significant differences between left and right acetabula for ALO ($p = 0.43$) or version angle ($p = 0.43$) and the symmetry index was acceptable (6.8% for ALO, 11.1% for version angle). The intra-observer coefficient of variation was 3.5%

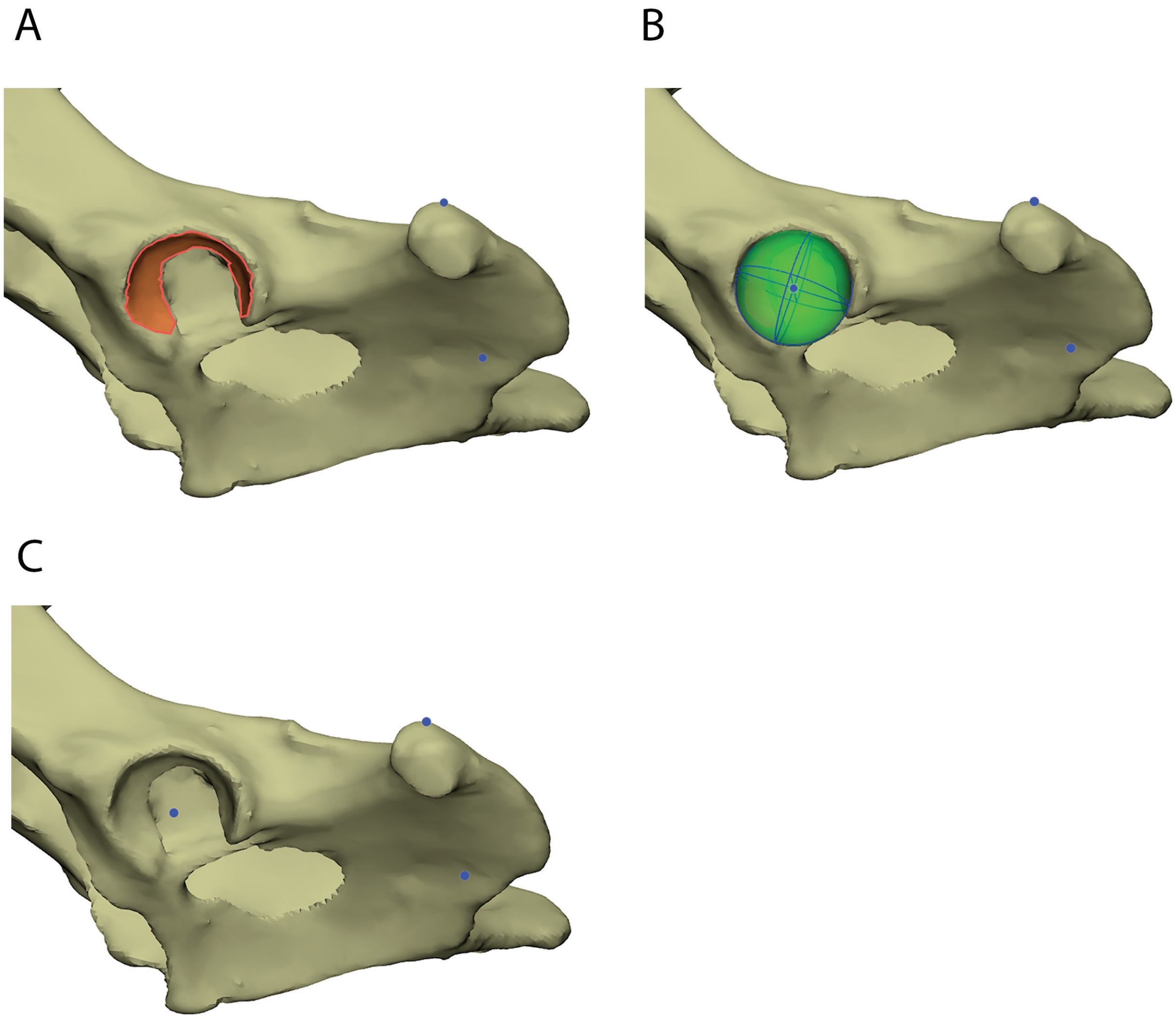

Fig. 2 Acetabular geometry was defined by marking triangles on the lunate surface of the acetabulum (A), defining a best-fit sphere (B) and then calculating the centre of the sphere (C).

for ALO and 5.2% for version angle (►**Table 2**). The inter-observer coefficient of variation was 3.3% for ALO and 5.2% for version angle.

Discussion

The current study demonstrates that measurements of ALO and version angle using 3D models based on CT data are repeatable and offer a practical approach to quantifying the orientation of the acetabulum. The morphological data may be helpful in better defining optimal acetabular cup orientation, which is crucial in preventing postoperative luxation.[4] While the optimal cup position has been defined by BioMedtrix (Whippany, New Jersey, United States) as an ALO of 45 degrees and version angle between 15 and 25 degrees,[10,11] this is a rather subjective assessment and in some dogs these angles may be imprecise and contribute to hip luxation. Therefore, objective, patient-specific measurement of native acetabular geometry may allow the surgeon to improve cup positioning and reduce the overall risk for luxation.

In this study, the measurements of acetabular geometry on 3D models showed good repeatability with a low intra- and inter-observer variability, and this allowed us to accept our first hypothesis. Similar findings were noted by Leasure and colleagues[18] who confirmed the low variability in measurements of ALO and version angle when CT images were used to measure acetabular cup position in dogs. Another human study, by Park and colleagues, demonstrated that 3D measurements are reliable for evaluating acetabular orientation and more consistent measurements were obtained using 3D bone models.[19] Similarly, Sariali and colleagues reported that the use of CT scans for THR preoperative planning results in greater accuracy than two-dimensional preoperative planning,[20] a finding that has since been also supported by results from other published studies.[21–24]

The results for ALO and version angle were similar to these obtained in a focused study of 13 Labrador Retrievers by Wu and

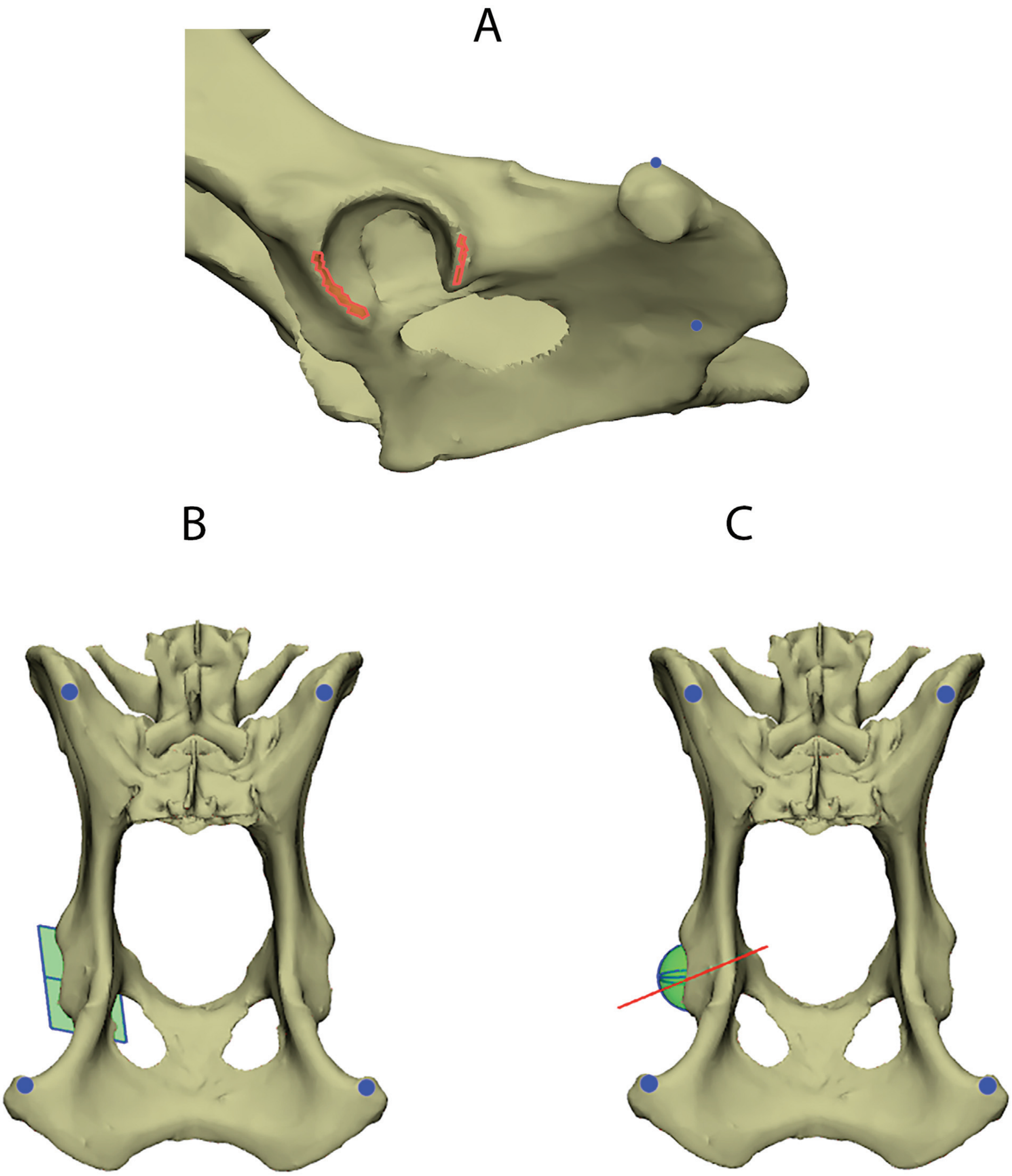

Fig. 3 Acetabular orientation was assessed by first marking triangles along the cranial and caudal aspects of the ventral acetabulum (A) and then establishing a best-fit plane to these voxels (B). The acetabular orientation plane was defined as a plane that was perpendicular to both the ventral acetabular plane and the dorsal pelvic plane, and that passed through the centre point of the acetabulum (C).

colleagues.[25] Additionally, measurements of left and right acetabula were not significantly different in our study, which corroborates the findings from Wu's study. In the current study the mean ALO was 42.6 degrees for the left acetabulum and 43.1 degrees for the right acetabulum, compared with mean ALO of 40.5 degrees in the earlier publication. Our mean version angles for the right and left acetabula were 27.51 and 26.85 degrees respectively, which was similar to the 27.7 degrees reported by Wu and colleagues.[25] However, the recommended angles for the position of acetabular cup in commercial THR system are slightly different – higher for ALO and lower for version angle.[10,26] Therefore, our second hypothesis was also supported. It has been reported that too high an ALO increases the risk of hip luxation, so it is recommended to insert an acetabular component at lower angle, since it may prevent luxation.[4] Some acetabula in our study, however, demonstrated more than 10 degrees difference between the angles measured using this workflow

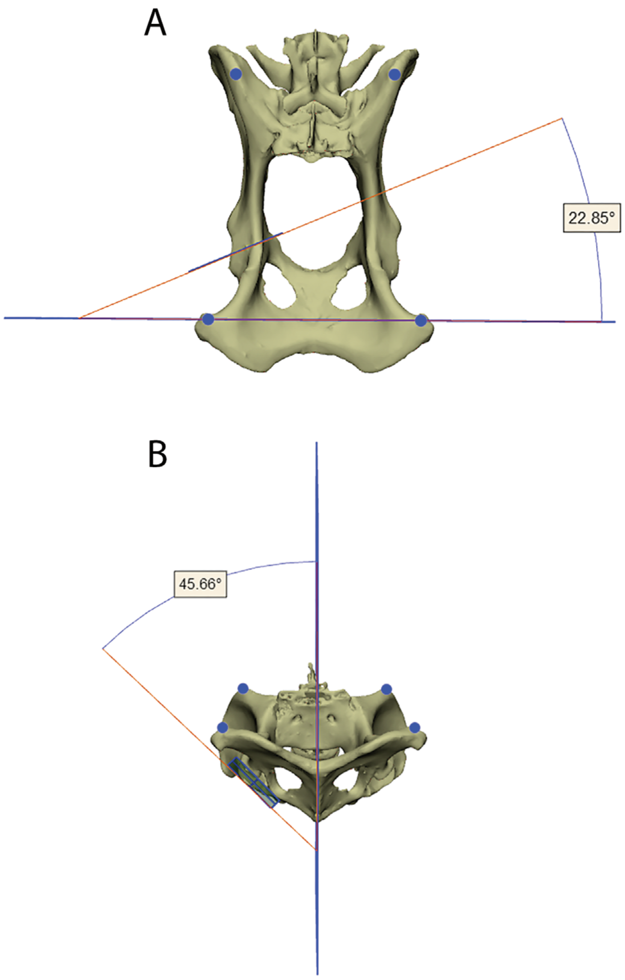

Fig. 4 The version angle was measured between the acetabular orientation plane and the transverse plane (A). The angle of lateral opening was calculated by measuring the angle formed between the best fit plane to the ventral acetabulum and the median plane (B), then subtracting this from 90 degrees.

(ALO and version angle) and those recommended by manufacturers. These findings highlight the potential for angular mismatch between the native acetabulum in dogs and the manufacturer's recommendations for acetabular cup placement. This discrepancy needs to be considered when positioning the acetabular component.

Different values between manufacturer's recommendation and those reported from the current study may reflect our previous reliance on radiography rather than CT for measurement of acetabular geometry and cup positioning. When using CT data and 3D reconstructed pelvic models for measurement of acetabular cup position, pelvic rotation and tilt are controlled by the operator,[27] while radiography does not account for the pelvic tilt and rotation. This may increase variability between measurements.[28] For this reason, ideal positioning of the patient for radiographs is critical to being able to obtain accurate angles and to avoid discrepancies in measurements.

Our study population consisted of 27 dogs of 18 different breeds, as compared with the study of 13 dogs from a single breed (Labrador Retrievers) by Wu and colleagues.[25] The breed variability corresponds better with the real-life situation in which a variety of pure- and cross-bred dogs are presented for THR. Although this larger and more heterogenous sample of breeds improves the clinical relevance of the data, a much larger study is needed to make definitive recommendations regarding the true extent of variation in ALO and version angles in dogs. Notwithstanding the limitation of sample size, this study demonstrates that although the mean values for acetabular alignment were generally consistent with clinical THR guidelines, some dogs in this study had more extreme values, and there was a wide range of angles across different breeds. Using a standard set of recommended angles across all breeds of dogs may lead to incorrect cup placement and an increased risk of postoperative complications such as luxation.

The measurements reported in this study were based on the use of just four anatomical landmarks – the cranial dorsal iliac spines and the ischial tuberosities, bilaterally. We selected these specific landmarks because they are widely distributed across the four corners of the 'pelvic box' and are palpable through the skin intraoperatively, providing a realistic option for intraoperative surgical navigation. Similar observations were made by Leasure and colleagues.[18]

Studies from human medicine suggest that there are some differences in hip morphometry between ethnic groups.[29] In a veterinary setting, breed-related differences have also been described among large-breed dogs. For example, St. Bernards and Bernese Mountain dogs have relatively deep acetabula as compared with Labrador Retrievers and Boxers. In contrast, Labrador Retrievers and Boxers had shallow and relatively open acetabula.[30] A similar comparison between two small-breed dogs, the Shih Tzu and the Maltese, showed that the Shih Tzu acetabulum was deeper and wider than that of the Maltese.[31] Such variety in acetabular morphometry between breeds may have an impact on acetabular measurements and surgical planning for THR, so further investigations are needed to verify it.

In humans, differences have been demonstrated between male and female hip joints. It has been reported that females have relatively greater acetabular depth, increased acetabular version and smaller femoral heads,[32,33] while femoral offset is greater in males.[33] Interestingly, despite these anatomical differences, the same THR implant systems are used successfully in both sexes.[34] Less is known about sex-related difference in acetabular geometry in dogs. In small-breed dogs, sex was identified as a variable that impacted acetabular width and depth, but acetabular index measurements were similar in the two sexes, suggesting that their acetabula are shaped similarly.[31] Currently, it is unclear whether sex-related variation in canine acetabular morphometry is sufficient to impact recommendations for optimum component positioning in THR.

The primary limitation of this study is that all the dogs included in this study had normal hip joints without visible signs of pathology. Therefore, the results may vary in dogs with dysplastic hip joints. We used visual (subjective) estimates of anatomical landmarks, the identification of which

Table 1 Angles of lateral opening (ALO) and version angles, means and standard deviation (SD) for left and right hips of 27 dogs. *p*-Values for ALO and version angle are based on paired Student's *t*-test. Left-right symmetry is defined by symmetry index (see text for formula)

Dog	Angle of lateral opening			Version angle		
	Left (degree)	Right (degree)	Symmetry index (%)	Left (degree)	Right (degree)	Symmetry index (%)
1	39.9	44.7	11.3	28.1	25.6	9.3
2	42.1	45.5	7.8	26.1	24.7	5.5
3	34.9	32.7	6.5	38.7	39.9	3.1
4	46.0	45.2	1.8	26.8	25.8	3.8
5	43.6	47.1	7.7	26.3	19.8	28.2
6	45.3	41.1	9.7	28.2	29.5	4.5
7	49.7	51.5	3.6	22.6	18.4	20.5
8	41.9	43.0	2.6	25.8	28.8	11.0
9	36.2	41.1	12.7	35.8	31.8	11.8
10	43.5	43.2	0.7	23.8	24.9	4.5
11	44.5	43.1	3.2	29.5	12.6	80.3
12	48.6	47.6	2.1	20.7	20.1	2.9
13	48.1	47.5	1.3	23.4	24.1	2.9
14	41.7	36.4	13.6	29.4	34.8	16.8
15	47.3	43.6	8.1	25.1	25.8	2.8
16	44.6	40.6	9.4	28.5	33.1	14.9
17	42.4	44.6	5.1	30.0	29.8	0.7
18	42.2	42.2	0.0	23.5	24.7	5.0
19	39.8	42.9	7.5	26.6	26.6	0.0
20	47.4	42.8	10.2	28.1	28.8	2.5
21	36.4	37.9	4.0	32.5	33.7	3.6
22	43.4	47.2	8.4	29.3	24.5	17.8
23	37.9	45.4	18.0	15.0	19.5	26.1
24	40.8	42.1	3.1	29.5	28.4	3.8
25	38.7	37.1	4.2	31.5	32.0	1.6
26	36.2	43.5	18.3	34.1	31.6	7.6
27	47.3	45.4	4.1	23.7	25.4	6.9
Mean	42.6	43.1	6.8	27.5	26.9	11.1
SD	4.2	3.9	4.9	4.8	5.8	15.8
p-Value	0.43			0.44		

will undoubtedly be subject to some intrinsic error. Nevertheless, based on our results, the method of defining planes and angles measurement appears feasible and repeatable. Further work is needed to compare the outcome of acetabular component placement in dogs with normal hips and dogs with hip disease. A much larger sample size will be needed to establish reliable reference ranges and to allow for breed-to-breed comparisons of these measurements.

Conclusions

Measurements of the ALO and version angle on 3D *in-silico* models of the canine pelvis are feasible and repeatable. These data may be used to better define the optimal placement of the acetabular component in THR surgery, leading to a reduced risk of postoperative complications such as hip luxation. Patient-specific morphometric data and the ability to obtain accurate and reproducible measurements also establish the possibility of combining *in-silico* planning with intra-operative surgical navigation, further improving the surgeon's ability to ensure correct placement of the acetabular components in dogs undergoing THR surgery.

Authors' Contribution

All authors contributed equally in conception, study design, or acquisition of data, as well as analysis and

Table 2 Intra-observer variability was calculated from 3 repeat measurements of 6 hemipelvis specimens. All data are expressed in degrees

	Trial 1	Trial 1	Trial 3	CV, %
ALO				
Hemipelvis 1 (left)	37.62	39.99	39.01	3.06
Hemipelvis 2 (left)	43.82	40.31	45.26	5.90
Hemipelvis 3 (right)	45.62	45.78	44.03	2.14
Hemipelvis 4 (right)	42.13	44.3	43.54	2.54
Hemipelvis 5 (left)	46.88	47.95	45.72	2.38
Hemipelvis 6 (right)	47.93	44.01	47.03	4.43
			Mean CV, %	3.48
Version angle				
Hemipelvis 1 (left)	27.81	25.1	26.43	5.12
Hemipelvis 2 (left)	21.62	23.93	20.67	7.60
Hemipelvis 3 (right)	26.51	26.86	27.11	1.12
Hemipelvis 4 (right)	31.4	30.54	28.28	5.36
Hemipelvis 5 (left)	26.11	23	27.49	9.01
Hemipelvis 6 (right)	29.09	27.46	28.88	3.11
			Mean CV, %	5.22

Abbreviations: ALO, angles of lateral opening; CV, coefficient of variation.

interpretation of data and approved the version to be published.

Conflict of Interest
M.J.A. and C.Z. are directors of Veterinary Surgical Innovation Ltd.

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References

1 Olmstead ML. Canine cemented total hip replacements: state of the art. J Small Anim Pract 1995;36(09):395–399
2 Bergh MS, Gilley RS, Shofer FS, Kapatkin AS. Complications and radiographic findings following cemented total hip replacement: a retrospective evaluation of 97 dogs. Vet Comp Orthop Traumatol 2006;19(03):172–179
3 Olmstead ML, Hohn RB, Turner TM. A five-year study of 221 total hip replacements in the dog. J Am Vet Med Assoc 1983;183(02):191–194
4 Dyce J, Wisner ER, Wang Q, Olmstead ML. Evaluation of risk factors for luxation after total hip replacement in dogs. Vet Surg 2000;29(06):524–532
5 Paul HA, Bargar WL. Histologic changes in the dog acetabulum following total hip replacement with current cementing techniques. J Arthroplasty 1987;2(01):71–76
6 Nelson LL, Dyce J, Shott S. Risk factors for ventral luxation in canine total hip replacement. Vet Surg 2007;36(07):644–653
7 Olmstead ML. Total hip replacement. Vet Clin North Am Small Anim Pract 1987;17(04):943–955
8 Vezzoni L, Vezzoni A, Boudrieau RJ. Long-term outcome of Zürich cementless total hip arthroplasty in 439 cases. Vet Surg 2015;44(08):921–929
9 Hayes GM, Ramirez J, Langley Hobbs SJ. Does the degree of preoperative subluxation or soft tissue tension affect the incidence of postoperative luxation in dogs after total hip replacement? Vet Surg 2011;40(01):6–13
10 Dyce J, Wisner ER, Schrader SC, Wang Q, Olmstead ML. Radiographic evaluation of acetabular component position in dogs. Vet Surg 2001;30(01):28–39
11 Schulz KS. Application of arthroplasty principles to canine cemented total hip replacement. Vet Surg 2000;29(06):578–593
12 Lu M, Zhou Y-X, Du H, Zhang J, Liu J. Reliability and validity of measuring acetabular component orientation by plain anteroposterior radiographs. Clin Orthop Relat Res 2013;471(09):2987–2994
13 Shin WC, Lee SM, Lee KW, Cho HJ, Lee JS, Suh KT. The reliability and accuracy of measuring anteversion of the acetabular component on plain anteroposterior and lateral radiographs after total hip arthroplasty. Bone Joint J 2015;97-B(05):611–616
14 Trumpatori BJ, Mathews KG, Roe SR, Robertson ID. Radiographic anatomy of the canine coxofemoral joint using the dorsal acetabular rim (DAR) view. Vet Radiol Ultrasound 2003;44(05):526–532
15 Craiovan B, Weber M, Worlicek M, et al; Is It Valid and Verified for Daily Clinical Practice. Measuring acetabular cup orientation on antero-posterior radiographs of the hip after total hip arthroplasty with a vector arithmetic radiological method. Röfo Fortschr Geb Röntgenstr Neuen Bildgeb Verfahr 2016;188(06):574–581
16 Ocal MK, Kara ME, Turan E. Computed tomographic measurements of the hip morphology of 10 healthy German shepherd dogs. Vet Rec 2004;155(13):392–395
17 Jóźwiak M, Rychlik M, Musielak B, Chen BP, Idzior M, Grzegorzewski A. An accurate method of radiological assessment of acetabular volume and orientation in computed tomography spatial reconstruction. BMC Musculoskelet Disord 2015;16:42
18 Leasure JO, Peck JN, Villamil A, Fiore KL, Tano CA. Inter- and intra-observer variability of radiography and computed tomography for evaluation of Zurich cementless acetabular cup placement ex vivo. Vet Comp Orthop Traumatol 2016;29(06):507–514
19 Park J, Kim J-Y, Kim HD, et al. Analysis of acetabular orientation and femoral anteversion using images of three-dimensional reconstructed bone models. Int J CARS 2017;12(05):855–864
20 Sariali E, Mauprivez R, Khiami F, Pascal-Mousselard H, Catonné Y Accuracy of the preoperative planning for cementless total hip arthroplasty. A randomised comparison between three-dimensional computerised planning and conventional templating. Orthop Traumatol Surg Res 2012;98(02):151–158
21 Carter LW, Stovall DO, Young TR. Determination of accuracy of preoperative templating of noncemented femoral prostheses. J Arthroplasty 1995;10(04):507–513
22 Gamble P, de Beer J, Petruccelli D, Winemaker M. The accuracy of digital templating in uncemented total hip arthroplasty. J Arthroplasty 2010;25(04):529–532
23 Della Valle AG, Padgett DE, Salvati EA. Preoperative planning for primary total hip arthroplasty. J Am Acad Orthop Surg 2005;13(07):455–462
24 Knight JL, Atwater RD. Preoperative planning for total hip arthroplasty. Quantitating its utility and precision. J Arthroplasty 1992; 7(Suppl):403–409
25 Wu C-H, Lin C-C, Lu T-W, et al. Three-dimensional morphometry of native acetabulum in relation to design and implantation of canine total hip replacements. Biomed Eng Appl Basis Commun 2012;24:549–555
26 DeYoung DJ, Schiller RA. Radiographic criteria for evaluation of uncemented total hip replacement in dogs. Vet Surg 1992;21(02):88–98

27 Ghelman B, Kepler CK, Lyman S, Della Valle AG. CT outperforms radiography for determination of acetabular cup version after THA. Clin Orthop Relat Res 2009;467(09):2362–2370

28 Kalteis T, Handel M, Herold T, Perlick L, Paetzel C, Grifka J. Position of the acetabular cup – accuracy of radiographic calculation compared to CT-based measurement. Eur J Radiol 2006;58(02):294–300

29 Saikia KC, Bhuyan SK, Rongphar R. Anthropometric study of the hip joint in northeastern region population with computed tomography scan. Indian J Orthop 2008;42(03):260–266

30 Scartazzini R. A radiologic study of normal and dysplastic hip joints in six breeds of large dogs. Acta Radiol Suppl 1972;319:183–185

31 Kanthavichit K, Klaengkaew A, Thanaboonnipat C, Darawiroj D, Soontornvipart K, Choisunirachon N. Comparison of radiographic and computed tomographic acetabular index in small-breed dogs: a preliminary study using Maltese and Shih Tzu. J Vet Sci 2021;22(04):e58

32 Wang SC, Brede C, Lange D, et al. Gender differences in hip anatomy: possible implications for injury tolerance in frontal collisions. Annu Proc Assoc Adv Automot Med 2004; 48:287–301

33 Atkinson HD, Johal KS, Willis-Owen C, Zadow S, Oakeshott RD. Differences in hip morphology between the sexes in patients undergoing hip resurfacing. J Orthop Surg Res 2010;5:76

34 Kostamo T, Bourne RB, Whittaker JP, McCalden RW, MacDonald SJ. No difference in gender-specific hip replacement outcomes. Clin Orthop Relat Res 2009;467(01):135–140