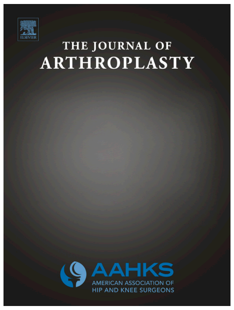
Journal Pre-proof



Validation of a Novel Method of Measuring Cup Orientation using BiPlanar Simultaneous Radiographic Images

Dan Sun, MD, William S. Murphy, MD MBA, Andrew Amundson, BA, Patrick Lane, AB, Jens Kowal, PhD, Stephen B. Murphy, MD

PII: S0883-5403(23)00357-1

DOI: https://doi.org/10.1016/j.arth.2023.04.011

Reference: YARTH 59974

To appear in: *The Journal of Arthroplasty*

Received Date: 7 December 2022

Revised Date: 5 April 2023

Accepted Date: 8 April 2023

Please cite this article as: Sun D, Murphy WS, Amundson A, Lane P, Kowal J, Murphy SB, Validation of a Novel Method of Measuring Cup Orientation using BiPlanar Simultaneous Radiographic Images, *The Journal of Arthroplasty* (2023), doi: https://doi.org/10.1016/j.arth.2023.04.011.

Validation of a Novel Method of Measuring Cup Orientation using BiPlanar Simultaneous Radiographic Images

Dan Sun MD[1], William S Murphy MD MBA[2], Andrew Amundson BA[3], Patrick Lane AB[3], Jens Kowal PhD[4], Stephen B. Murphy MD[5]

[1]Tufts Medical Center, Boston MA USA
[2]Washington University in St. Louis, St. Louis MO USA
[3]Surgical Planning Associates, Boston MA USA
[4]University of Bern, Bern Switzerland
[5]New England Baptist Hospital, Boston MA USA

Corresponding Author:
Stephen B. Murphy MD
125 Parker Hill Ave Suite 545, Boston, MA 02120
stephenbmurphymd@gmail.com

Key words: Arthroplasty, Acetabular cup, Postoperative measurement, Biplanar Radiographs

Abstract word count: 220

Manuscript word count: 1650

Validation of a Novel Method of Measuring Cup Orientation using BiPlanar Simultaneous Radiographic Images

Key words: Arthroplasty, Acetabular cup, Postoperative measurement, Biplanar Radiographs

Abstract word count: 220

Manuscript word count: 1608

Background:

Accurate acetabular component positioning is paramount to the success of total hip arthroplasty. Two-dimensional imaging alone remains a popular tool for implant position assessment despite known limitations. We investigated the accuracy of a novel method for assessing acetabular component position based upon orthogonal simultaneous biplanar Xray images.

Methods:

There were forty consecutive patients who had a pre-existing total hip arthroplasty (THA) on the contralateral side who underwent both computed tomography (CT) and simultaneous orthogonal biplanar radiographic scans for pre-operative planning of THA. The operative inclination (OI) and operative anteversion (OA) of the acetabular cup were calculated by a new measurement method using the biplanar simultaneous scans. Those measurements were compared to measurement of the cup orientation on CT. The measurements were made by two independent observers. Interobserver correlation coefficients were calculated between the two observers to measure reliability.

Results:

The mean error in OA measurement of the acetabular cup between simultaneous orthogonal biplanar radiographic and CT imaging was 0.5° (Standard Deviation (SD): 1.9°, minimum -4.0°, maximum 5.0°), the mean error in OI was 0.0° (SD: 1.7°, minimum -5.0°, maximum 4.0°). The average absolute error was 1.5° for OA, and 1.2° for OI. Interobserver correlation coefficient was 0.83 for OA and 0.93 for OI.

Conclusion:

The novel method of measuring cup orientation using simultaneous biplanar radiographic scans utilized in this study was accurate and reproducible between observers compared to CT measurements.

Background

Accurate placement and orientation of implants is essential to the success of total hip arthroplasty (THA). Correctly positioning the cup within the acetabulum is necessary to minimize the risk of joint dislocation, component wear, and limited range of motion and impingement [1,2]. In 1978, Lewinneck et al. proposed the often quoted goal of safe zone for acetabular component positioning of 40 ± 10 degrees of inclination and 15 ± 10 degrees of anteversion, which was determined by reviewing the inclination and anteversion of dislocating hips compared to non-dislocating hips[3]. Subsequent efforts to identify more robust targets for cup placement have been undertaken with larger data sets and patient specific factors such as pelvic tilt and rotation, but there remains no universal consensus on a safe zone.[4–11] Much of the difficulty in defining the concept of a safe zone comes from the limited ability to measure acetabular component positioning both intraoperatively and postoperatively. Snijders et. al. performed a systematic review of studies of acetabular cup orientation and dislocation, and identified a universal lack of uniformity in assessment of cup orientation. This was found to be due to inconsistent definitions of angles, reference planes, and measurement methodology or repeatability[4].

Three-dimensional (3D) imaging such as computed tomography (CT) allows for direct measurement of the angle of the cup and is considered the gold standard for evaluation of cup placement. Due to cost, time, and exposure to radiation, these scans are not routinely performed for postoperative acetabular component measurement, and traditionally angulation of the cup is measured on an antero-posterior (AP) Xray. Due to variation in patient positioning, distance and individual pelvic orientation relative to the X ray source and plate, this has been shown to be inaccurate[12], with one study demonstrating recorded errors in measurement of up to 30 degrees in anteversion using plain radiographs alone.[13] To address this need for accurate measurement, multiple methodologies to correct for pelvic rotation Xray offset have been developed, including synchronized Xrays and 2D/3D matching algorithms.[12,14,15] A recent review by Zhao et al. of these methodologies compared recent efforts in postoperative radiographic assessment, and determined that the 2D/3D matching algorithms show the most promise with regards to accuracy of assessment[15], however, these accurate methods still require that 3D imaging is obtained prior to or after the surgery.

We propose a novel methodology based on orthogonal simultaneous biplanar scans to measure acetabular component positioning without the need for 3D imaging. Through use of two simultaneous orthogonal scans at a known distance, the three-dimensional position of objects can be determined. We then compared measurements from this methodology with ground truth 3D imaging from a postoperative CT scan.

Material and methods

A novel methodology for measurement of the acetabular cup was developed based on biplanar simultaneous imaging. The accuracy of this method was tested by comparing measurements from the biplanar simultaneous imaging measurement method to measurements made on CT imaging with the CT measurements treated as the gold standard. There were forty patients who had an existing THA undergoing preoperative CT and biplanar scan evaluation for contralateral surgery chosen for this study.

CT measurement: For measurement of cup orientation using CT, 3D surface models of the pelvis were created. The anterior pelvic plane (APP) was defined by selecting landmarks on the two anterior superior iliac spines and the most anterior point of the pubic symphysis (Figure 1). Then using a hip arthroplasty preoperative planning module (HipInsight System v1.4.3, Surgical Planning Associates, Boston, Massachusetts USA*)*, a 3D computer aided design (CAD) file of an artificial acetabular cup was positioned to match the position of the existing cup to determine its orientation (Figure 2). The operative inclination (OI) and operative anteversion (OA) of the acetabular cup as defined by Murray[16] were calculated using the relative position of the acetabular cup and APP. This measurement from the scan was used as the ground truth of OI and OA for the acetabular component.

Simultaneous biplanar radiographic measurement: The simultaneous biplanar radiographic scans were acquired using the EOS Imaging System (*ATEC, Carlsbad, California, USA*), designed to take simultaneous AP and lateral orthogonal radiographic scans in a functional standing position[17]. In the system, standing AP and lateral orthogonal simultaneous radiographic scans are taken and positioned in the iso center of the EOS coordinate system according to Groisser[18]. An anterior pelvic plane was then constructed for each patient by selecting and back-projecting the anterior superior iliac spines (ASIS) and pubic symphysis landmarks defined on both images. A cup center was also defined on both images. Next, the center of a 3D CAD model of the specific size implant was placed at the center defined on the biplanar scans. The position, operative inclination, and operative anteversion could be adjusted by the user (Figure 3). Using the fan-beam projection model from the EOS images, all vertices defining the cup model were projected on the biplanar images as semi-transparent dots. This approach simulates different absorptions depending on the amount of material that an X-ray beam would have to pass through, and the cup center position of the 3D cup model was aligned to maximize the fit between cup shadow shown in both images and the projected overlays from the 3D cup model (Figure 4). Once the position and orientation of the 3D CAD file produced projected overlays that reproduced the appearance of the cup on the images, the cup orientation could be determined according to Murray's definitions of operative anteversion and operative inclination.

Data analyses: The CT measurement was completed once for each patient and used as the ground truth of operative inclination and operative. Two independent observers performed the biplanar Xray measurements. The measured values of OA and OI from the biplanar Xray measurement were compared with the ground truth value from the CT measurement. Interobserver correlation coefficients were also calculated between the two observers to measure reliability using the methodology described in Koo et al.[19]. Demographics of patients were reported in a summary table. This study was approved by the New England Baptist Hospital, Boston, Massachusetts, IRB, 2022-07.

Results

The mean error in operative anteversion measurement of the acetabular cup between the novel biplanar radiographic imaging technique and CT imaging was 0.5° (Standard Deviation (SD): 1.9°, minimum -4.0°, maximum 5.0°). The mean error in operative inclination measurement of the acetabular cup between the novel biplanar radiographic imaging technique and CT imaging was 0° (SD: 1.7°, minimum -5.0°, maximum 4.0°). The average absolute error was 1.5° for operative anteversion, and 1.2° for operative inclination.

The interobserver correlation coefficient was 0.83 for operative anteversion and 0.93 for operative inclination.

Discussion and Conclusion

Assessment of the acetabular component orientation postoperatively is essential to evaluating the impact of component positioning on outcomes and to evaluating the impact of new surgical techniques and technologies. Routine cup orientation measurement using 3D imaging methods such as CT scans is impractical and rarely clinically indicated. Thus, single intraoperative or postoperative radiographs are routinely used to measure cup angle, but are associated with major errors in measurement[13]. Although techniques have advanced in postoperative cup measurement, the most accurate of current techniques involve using a preoperative 3D scan to match with postoperative radiographs (2D/3D matching)[15]. Yet these methods also of limited practicality since not all patients undergo preoperative CT imaging. This study proposes a novel methodology using commercially available biplanar radiographic imaging (EOS) to perform these measurements without any preexisting 3D imaging, which would allow for measurement of the great number of patients who do not have a 3D study either pre or postoperatively.

This study demonstrated that the novel methodology is accurate, and without absolute individual measurement errors larger than 5 degrees from 40 patients. Furthermore, the measurements are reproducible among observers. The average absolute error of less than 2 degrees, and the maximum absolute error of 5 degrees is well within the tolerance of published safe zones for acetabular component positioning. Thus, this methodology may be useful in measuring clinically meaningful results from total hip arthroplasty in patients who do not have 3D imaging. This methodology may be useful in evaluating acetabular component placement of novel surgical approaches or technologies, or may be employed in routine postoperative monitoring of THA patients to identify those at greater risk of complications due to component positioning. This method is currently limited to postoperative monitoring due to the biplanar radiographic technology, however, future applications may include intraoperative measurement, or preoperative planning to determine optimal acetabular component positioning prior to surgery.

This study was limited by a relatively small sample size of 40 patients. Additionally, the authors performing measurements noted a 'learning curve' of making the measurements, feeling more facile with placement of the cup and landmarks as the study progressed, indicating that reliability of measurements may improve over time. The CT scan measurement was chosen as the ground truth due to precision of measurement with 3D imaging, however, interobserver differences in measurement of acetabular component positioning have been reported, with one study showing an average difference of version measurement of 1.57 degrees, and 95% limit of agreement of 3.1 degrees.[20] This additional source of error may increase the reported error found in this study. Additionally, further research on cost effectiveness of this method should be undertaken prior to widespread use of this methodology, particularly if biplanar imaging may be used instead of CT for acetabular component-related complications. Future research may validate this methodology with larger datasets and more observers across institutions.

The novel method proposed in this study was accurate and reproducible between observers for measuring acetabular component positioning on biplanar Xray compared to CT measurements. This method may be used to generate accurate assessment of acetabular component positioning when patients have not undergone 3D imaging.

[1] Patil S, Bergula A, Chen PC, Colwell Jr CW, D'Lima DD. Polyethylene wear and acetabular component orientation. JBJS 2003;85:56–63.

[2] Widmer K-H. Containment versus impingement: finding a compromise for cup placement in total hip arthroplasty. Int Orthop 2007;31:29–33.

[3] Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Jt Surg Am 1978;60:217–20.

[4] Snijders TE, Willemsen K, van Gaalen SM, Castelein RM, Weinans H, de Gast A. Lack of consensus on optimal acetabular cup orientation because of variation in assessment methods in total hip arthroplasty: a systematic review. HIP Int 2019;29:41–50. https://doi.org/10.1177/1120700018759306.

[5] Danoff JR, Bobman JT, Cunn G, Murtaugh T, Gorroochurn P, Geller JA, et al. Redefining the acetabular component safe zone for posterior approach total hip arthroplasty. J Arthroplasty 2016;31:506–11.

[6] Murphy WS, Yun HH, Hayden B, Kowal JH, Murphy SB. The Safe Zone Range for Cup Anteversion Is Narrower Than for Inclination in THA. Clin Orthop Relat Res 2018;476. https://doi.org/10.1007/s11999.0000000000000051.

[7] Yun H, Murphy WS, Ward DM, Zheng G, Hayden BL, Murphy SB. Effect of Pelvic Tilt and Rotation on Cup Orientation in Both Supine and Standing Positions. J Arthroplasty 2018;33. https://doi.org/10.1016/j.arth.2017.11.069.

[8] Fujishiro T, Hiranaka T, Hashimoto S, Hayashi S, Kurosaka M, Kanno T, et al. The effect of acetabular and femoral component version on dislocation in primary total hip arthroplasty. Int Orthop 2016;40:697–702.

[9] García-Rey E, García-Cimbrelo E. Abductor biomechanics clinically impact the total hip arthroplasty dislocation rate: a prospective long-term study. J Arthroplasty 2016;31:484–90.

[10] Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, Stöckl B. Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. J Bone Joint Surg Br 2005;87:762–9.

[11] Feng JE, Anoushiravani AA, Eftekhary N, Wiznia D, Schwarzkopf R, Vigdorchik JM.

Techniques for optimizing acetabular component positioning in total hip arthroplasty: defining a patient-specific functional safe zone. JBJS Rev 2019;7:e5.

[12] Zheng G, Zhang X, Steppacher SD, Murphy SB, Siebenrock KA, Tannast M. HipMatch: An object-oriented cross-platform program for accurate determination of cup orientation using 2D-3D registration of single standard X-ray radiograph and a CT volume. Comput Methods Programs Biomed 2009;95:236–48. https://doi.org/10.1016/j.cmpb.2009.02.009.

[13] 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;58:294–300.

[14] Yu W, Tannast M, Zheng G. Non-rigid free-form 2D–3D registration using a B-spline-based statistical deformation model. Pattern Recognit 2017;63:689–99. https://doi.org/10.1016/j.patcog.2016.09.036.

[15] Zhao J-X, Su X-Y, Zhao Z, Xiao R-X, Zhang L-C, Tang P-F. Radiographic assessment of the cup orientation after total hip arthroplasty: a literature review. Ann Transl Med 2020;8:130–130. https://doi.org/10.21037/atm.2019.12.150.

[16] Murray DW. The definition and measurement of acetabular orientation. J Bone Jt Surg - Ser B 1993;75:228–32. https://doi.org/10.1302/0301-620x.75b2.8444942.

[17] Melhem E, Assi A, El Rachkidi R, Ghanem I. EOS® biplanar X-ray imaging: concept, developments, benefits, and limitations. J Child Orthop 2016;10:1–14.

[18] Groisser B. Geometry of the EOS(R) Radiographic Scanner 2019.

[19] Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 2016;15:155–63.

[20] Saracco A, Grassi A, Romagnoli M, Camarda L, Logishetty K, Zaffagnini S, et al. Reduced-dose computed tomography is the most accurate method to measure ceramic hip resurfacing cup version. Eur J Radiol 2020;128. https://doi.org/10.1016/j.ejrad.2020.109040.

Legend:

Figure 1: Defining the anterior pelvic Plane with landmarks defined on a three-dimensional (3D) surface model generated from computed tomography images.

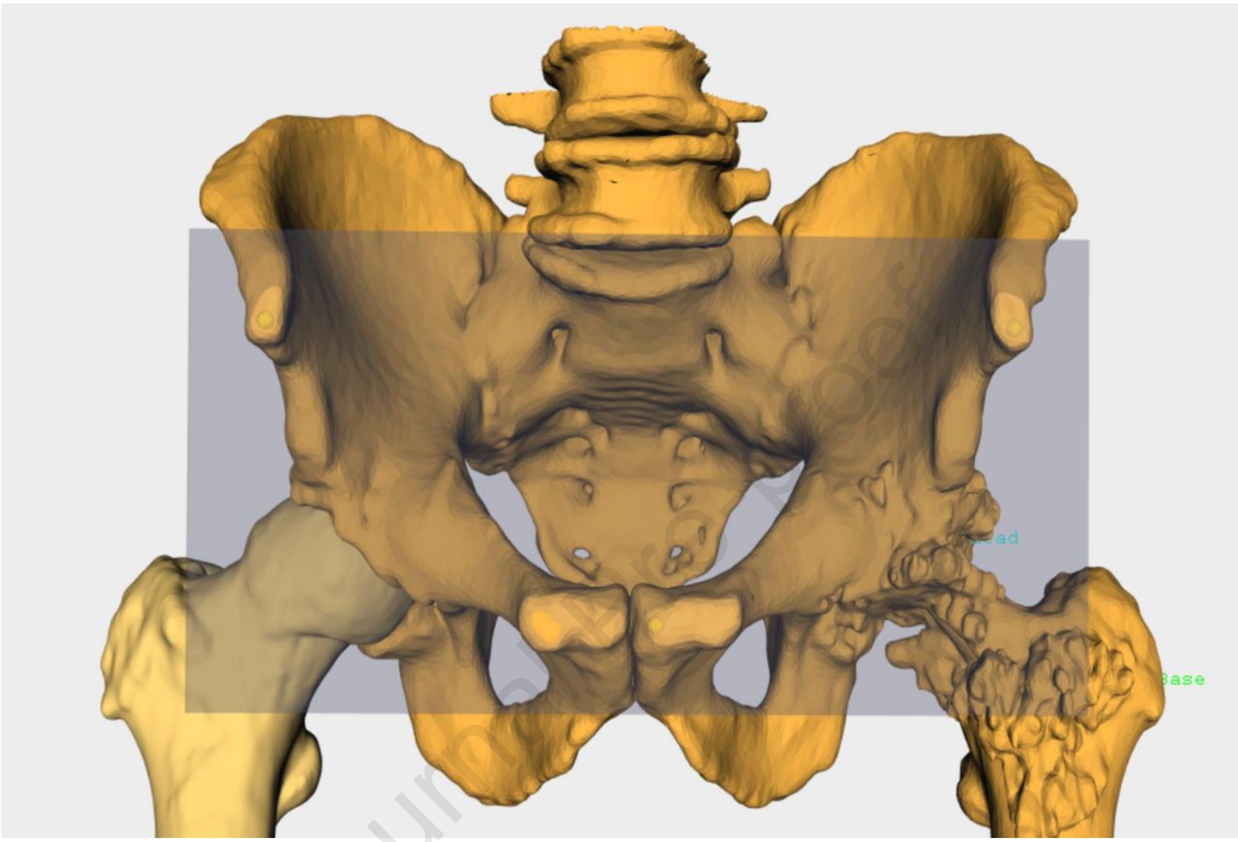


Figure 2: Measurement of acetabular component angles on multiplanar reconstructions from the computed tomography dataset.

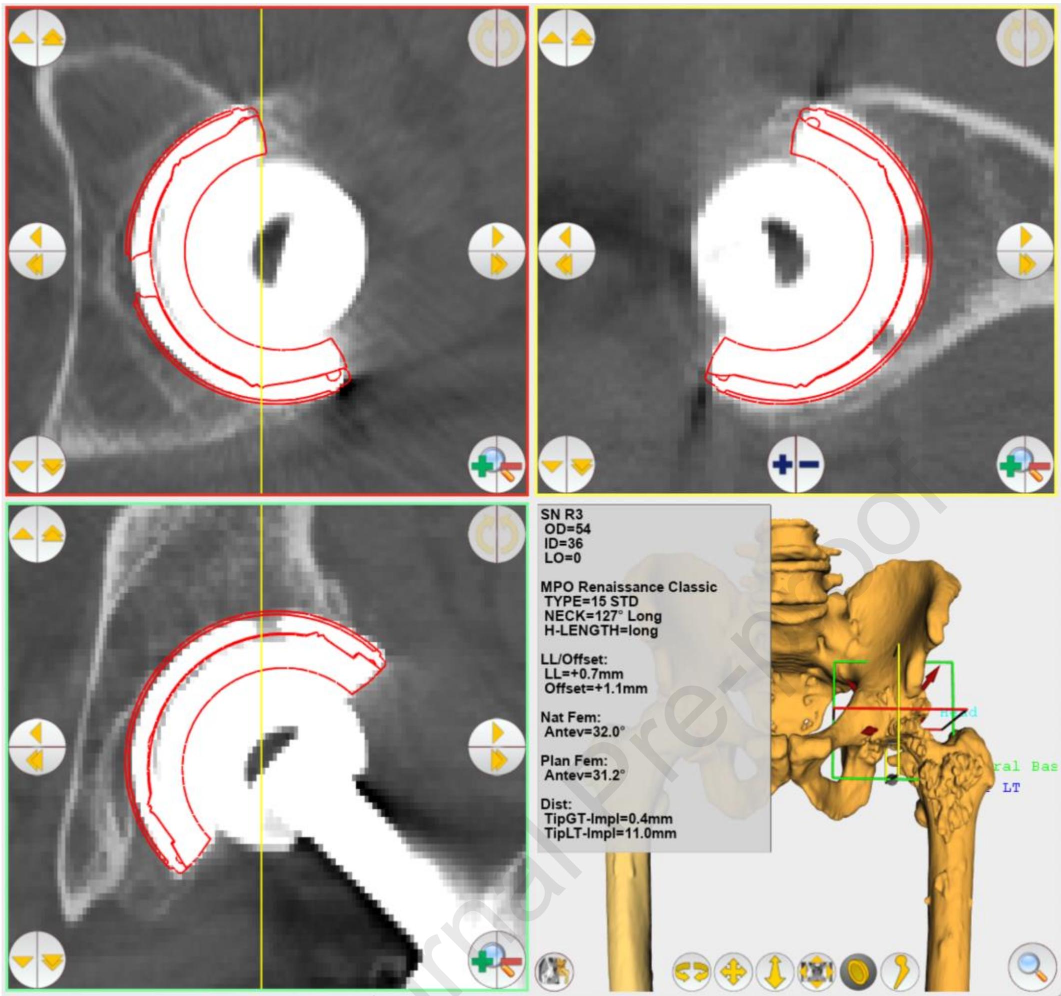
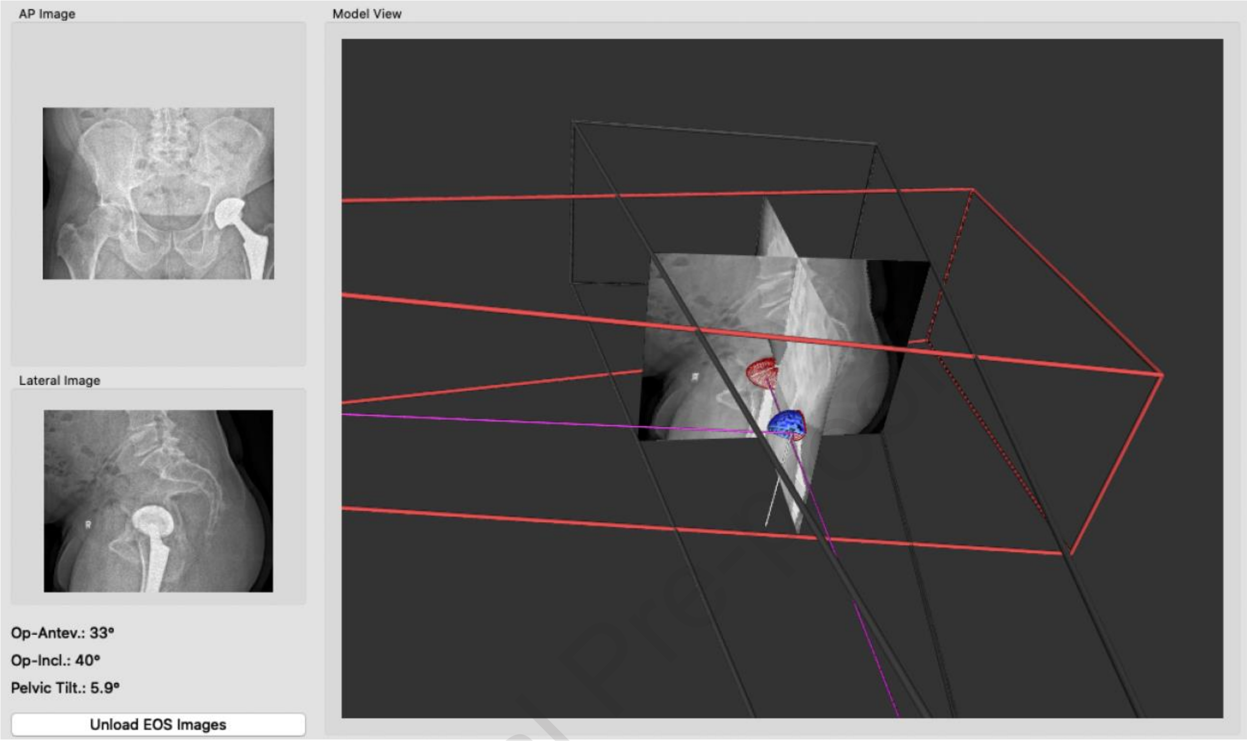
247 
SN R3
OD=54
ID=36
LO=0
MPO Renaissance Classic
TYPE=15 STD
NECK=127° Long
H-LENGTH=long
LL/Offset:
LL=+0.7mm
Offset=+1.1mm
Nat Fem:
Antev=32.0°
Plan Fem:
Antev=31.2°
Dist:
TipGT-Impl=0.4mm
TipLT-Impl=11.0mm
LT

Figure 3: Projection model of a 3D cup computer aided design file onto the biplanar simultaneous radiographic scans that replicates the appearance of the cup seen on the images.



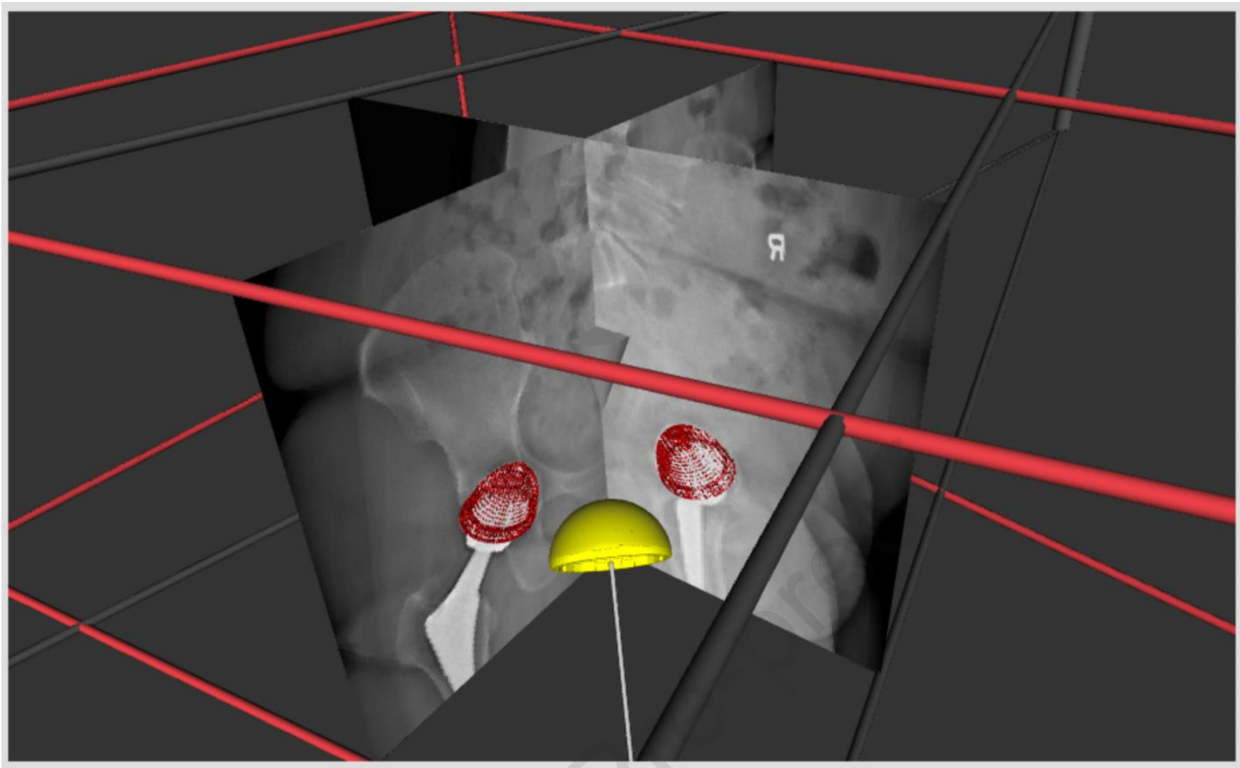


Figure 4: Projection of synthetic rays through a 3D cup computer aided design model onto the images with the cup positioned to replicate the position of the cup seen on the images.

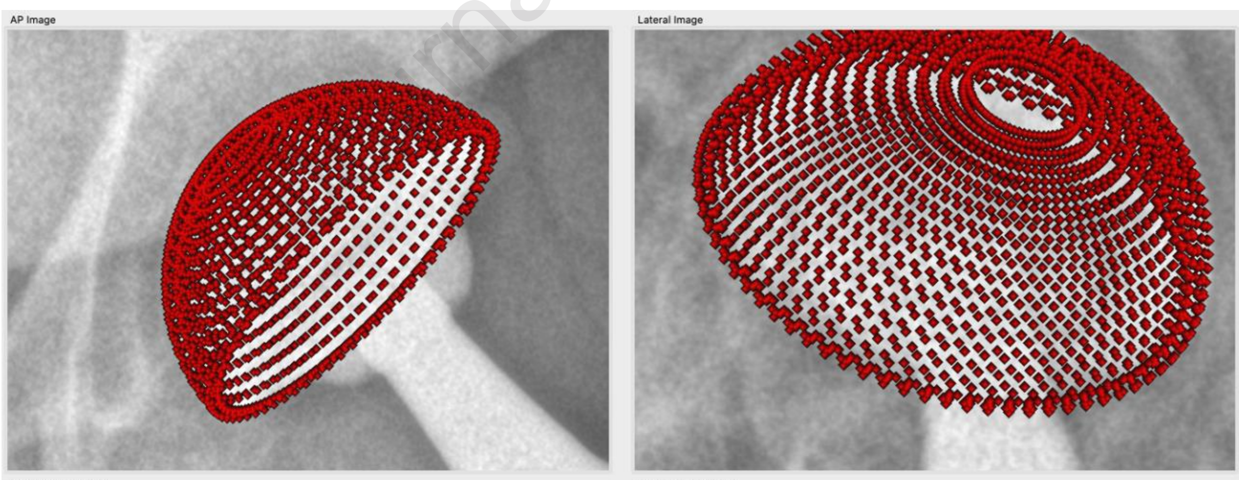


Table 1: Results and demographics

	Accuracy	*Degrees*
Operative anteversion	Mean error	0.5
	Standard deviation error	1.9
	Maximum error	5.0
	Minimum error	-4.0
	Mean absolute error	1.5
	Intraclass correlation coefficient	0.83
Operative inclination	Mean error	0.0
	Standard deviation error	1.7
	Maximum error	4.0
	Minimum error	-5.0
	Mean absolute error	1.2
	Intraclass correlation coefficient	0.93

Patient demographics	
N	40
Men	19
Women	21
Men (%)	48%
Women (%)	53%