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Surgical Technique

Intraoperative Fluoroscopy Versus Navigation to Determine Cup Anteversion in Direct Anterior Total Hip Replacement: A Technical Trick for Obtaining "True" Anteversion

Filippo Romanelli, DO, Ian S. Hong, MD, Jibran A. Khan, DO, Andrew Porter, MD, Jaclyn M. Jankowski, DO, Frank A. Liporace, MD, Richard S. Yoon, MD*

Division of Orthopaedic Trauma & Adult Reconstruction, Department of Orthopaedic Surgery, Cooperman Barnabas Medical Center/Jersey City Medical Center – RWJBarnabas Health, Livingston/Jersey City, NJ, USA

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A B S T R A C T

During acetabular cup positioning, intraoperative measurements of cup anteversion were taken using both fluoroscopy and navigation system. With the C-arm introduced at 40°, an anteroposterior view of the pelvis is taken. The C-arm is then centered over the hip, showing an anteverted cup with an approximate inclination of 40°. The axial C-arm is tilted away until the cup opening is visualized as a straight line, indicating that the beam of the fluoroscopy is aligned with the cup's anteversion. The tilt angle on the C-arm and anteversion reading on the navigation workstation were recorded. The high degree of agreement between fluoroscopic and navigation measurement of acetabular cup anteversion supports the use of fluoroscopy in settings with limited access to navigation systems in direct anterior total hip arthroplasty.

Introduction

Accurate implantation of the acetabular cup component during total hip arthroplasty (THA) with respect to cup inclination and anteversion is critical, as it significantly impacts postoperative outcomes by reducing the risk of impingement, hip dislocation, accelerated wear of polyethylene, postoperative pain, aseptic loosening, and mechanical failure. [1-4] Literature has shown that optimal cup positioning may have prevented up to 51% of revision THAs. [5] Historically, Lewinnek et al.'s landmark paper described a "safe zone" of 5°-25° of anteversion and 30°-50° of abduction or inclination, which continues to be a benchmark for surgeons. [3]

Various traditional methods, including equipment guides with predetermined angles, free-hand positioning, and the use of anatomic landmarks, are available for determining acetabular cup position intraoperatively. [6] However, these techniques have shown inconsistency in achieving a cup position within the previously described safe zone, with only 50%-86% of cups placed within the target range. [7]

Another variable that introduces additional complexity and has been a topic of interest in recent studies involves spinopelvic mobility and its impact on pelvic positioning. [8] These studies have concluded that individuals with abnormal spinopelvic mobility can lead to functionally abnormal pelvic positions that are not easily predictable from routine anteroposterior (AP) preoperative radiographs. [9] Consequently, despite placing the acetabular cup within the "safe zone," the abnormal spinopelvic mobility may cause the patient to dislocate postoperatively. Furthermore, an important established concept regarding the need for increased precision in the placement of accurate cup positioning was conveyed in Babisch et al.'s study exploring the relationship of pelvic tilt and acetabular cup position. [10] The authors found that a 1° change in pelvic tilt was correlated with a 0.8° change in cup version and a 0.3° change in cup inclination, which introduced the importance of considering the patient's individual pelvic anatomy when positioning the cup.

Computer-assisted navigation systems have revolutionized THA surgery in the past decade by providing real-time feedback and precise measurements of cup position intraoperatively. [11-13] However, despite their reported benefits, these new technologies

* Corresponding author. Director, Orthopaedic Trauma & Complex Adult Reconstruction Fellowship, Director, Orthopaedic Research, 377 Jersey Ave, Suite 550, Jersey City, NJ 07302, USA. Tel.: +1 201 716 5850.

E-mail address: yoonrich@gmail.com

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are not without drawbacks, which can include factors such as being cost-prohibitive, additional operative time due to set-up, potential for technical issues or computer malfunctions, and limited accessibility in certain hospitals. Therefore, the purpose of this two-part study is to: first, introduce a proof-of-concept method of accurately obtaining an anatomically correct cup anteversion via C-arm fluoroscopy; and second, compare the efficacy of intraoperative fluoroscopy to the Intellijoint HIP mini-optical navigation system (Intellijoint Surgical, Inc., Kitchener, Ontario, Canada) in accurately determining acetabular cup anteversion in direct anterior (DA) THA.

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Proof-of-concept: intraoperative technique via anatomic pelvic model

This study utilizes a detailed intraoperative fluoroscopy technique for determining acetabular cup position in DA THA. Prior to implementing this technique intraoperatively, the authors ran a pilot test utilizing an anatomic pelvic model predrilled with Kirschner wires to easily visualize the XYZ axis to facilitate accurate measurements of the cup position using any of the XYZ axis of the pelvis as a frame of reference (Fig. 1). Prior to making any measurements, a “zero” was defined and established by aligning the anterior pelvic plane with the coronal plane of the pelvic model, which was parallel to the floor and aligned with the Z-axis of the pelvis (Fig. 2).

Using a goniometer, the acetabular cup position was adjusted on the X-axis and measured from the Z-axis (coronal plane) to be at 40° of inclination and 20° of anteversion by rotating the cup on the Z-axis and measured from the X-axis (axial plane) (Fig. 3).

Proof-of-concept: C-arm fluoroscope setup utilizing anatomic pelvic model

Next, a C-arm fluoroscope was meticulously introduced at an angle equivalent to the 40° cup inclination angle, which matches the inclination plane (Fig. 4). By opening and rotating the C-arm 90 degrees, a fluoroscopic image provides confirmation that the x-ray beam is in complete alignment with the inclination plane with the superior most aspect of the cup overlapping the inferior most aspect of the cup (Fig. 5). The C-arm beam is returned to the AP position, and the axial arm of the fluoroscopy is then opened to tilt the C-arm cephalad to the desired 20° of anteversion obtaining a precise view with the cup opening overlapped, corresponding to the anteversion plane (Fig. 6).

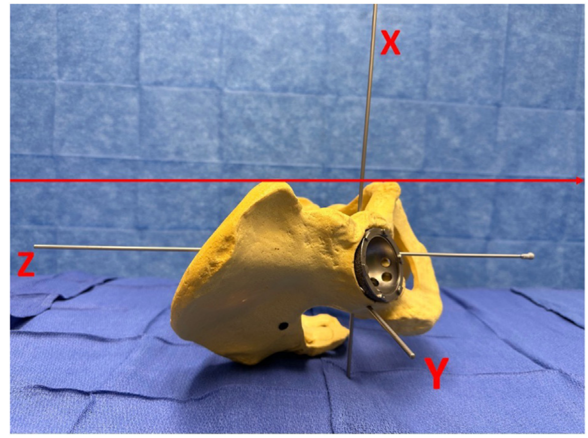

Figure 2. Defining “zero” by aligning the anterior pelvic plane (red line) with the coronal plane of the pelvic model, which can be easily visualized using the Z-axis.

Application of proof-of-concept: intraoperatively

Following institutional review board approval (WCG Institutional Review Board; Study#: 1177009), written informed consent was obtained from six consecutive patients prior to undergoing primary DA THA. All surgeries were performed at one institution by one fellowship-trained surgeon between July 2021 and August 2021. All patients underwent DA THA with intraoperative assistance of fluoroscopy and the Intellijoint HIP mini-optical navigation system (Intellijoint Surgical, Inc., Kitchener, Ontario, Canada) to determine acetabular cup anteversion. For registration of the navigation system, the supine coronal plane was used as previously described by Parvizi et al. [14]

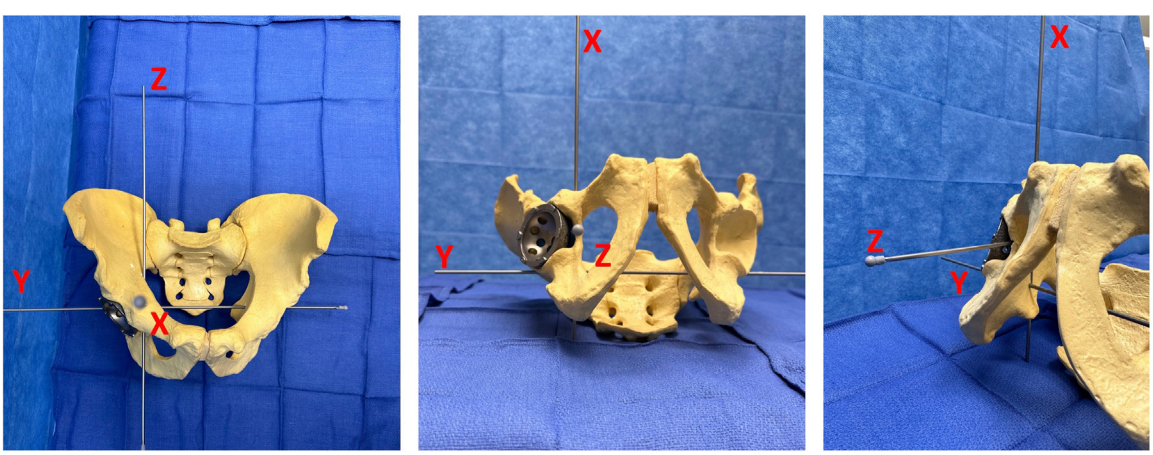

Figure 1. Using an anatomic pelvic model to first establish the XYZ axis to facilitate appropriate measurement of the cup position using the XYZ axis of the pelvis as a frame of reference.

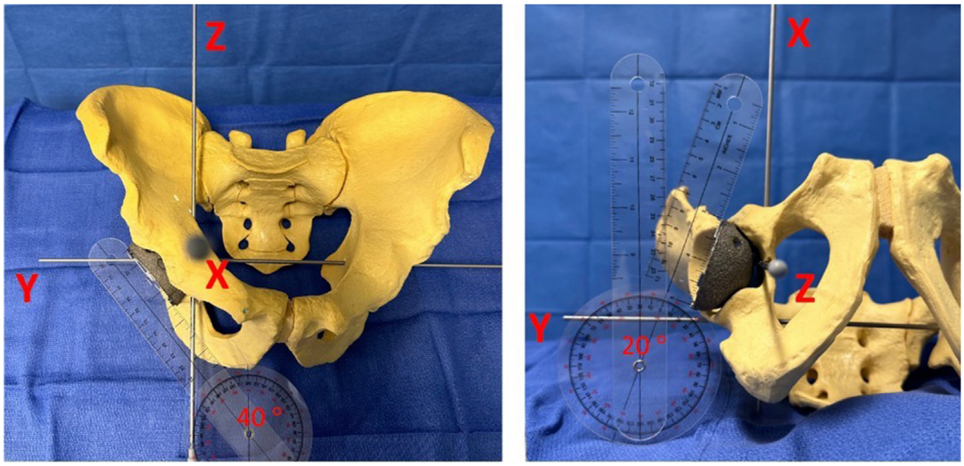

Figure 3. Using a goniometer, the acetabular cup position was adjusted on the X-axis and measured from the Z-axis (coronal plane) to be at 40° of inclination and 20° of anteversion by rotating the cup on the Z-axis and measured from the X-axis (axial plane).

Operative technique

Patients were positioned supine on a standard radiolucent operating table with C-arm fluoroscopy machine positioned contralaterally to the operated hip. To minimize variability, the positioning of the table is confirmed to be parallel to the floor. For navigation registration, two self-tapping screws for the pelvic platform are inserted 2 fingerbreadths proximally from the anterior superior iliac spine on the contralateral side. The pelvic platform is inserted within the two screws, and the optical camera is then magnetically attached to the pelvic platform.

Measuring cup anteversion intraoperatively: fluoroscopy vs navigation

At this juncture, the navigation tracker is attached to the metal impactor, and the cup is placed and positioned in the appropriate targeted inclination and version of 40/20 prior to impaction. The C-arm is then introduced at a 40° angle to the long axis of the patient, and an AP view of the pelvis is taken, ensuring that the center of the sacrum is aligned with the pubic symphysis and the obturator foramen are symmetrical in size bilaterally. The C-arm is then centered over the operative hip, showing an anteverted cup with an approximate inclination of 40° (Fig. 7A). The C-arm is then tilted away from the operative side cephalad until the opening of the cup is no longer visualized and appears perfectly overlapping, indicating that the beam of the fluoroscopy is aligned with the cup anteversion (Fig. 7B). The tilt angle on the C-arm corresponding with the cup anteversion is recorded along with the anteversion reading on the navigation workstation, which is then compared. The cup is then impacted, followed by the insertion of a neutral liner, and the rest of the THA is performed in a standard fashion. Final AP fluoroscopic imaging is used to confirm femoral and acetabular component position, leg length, and offset.

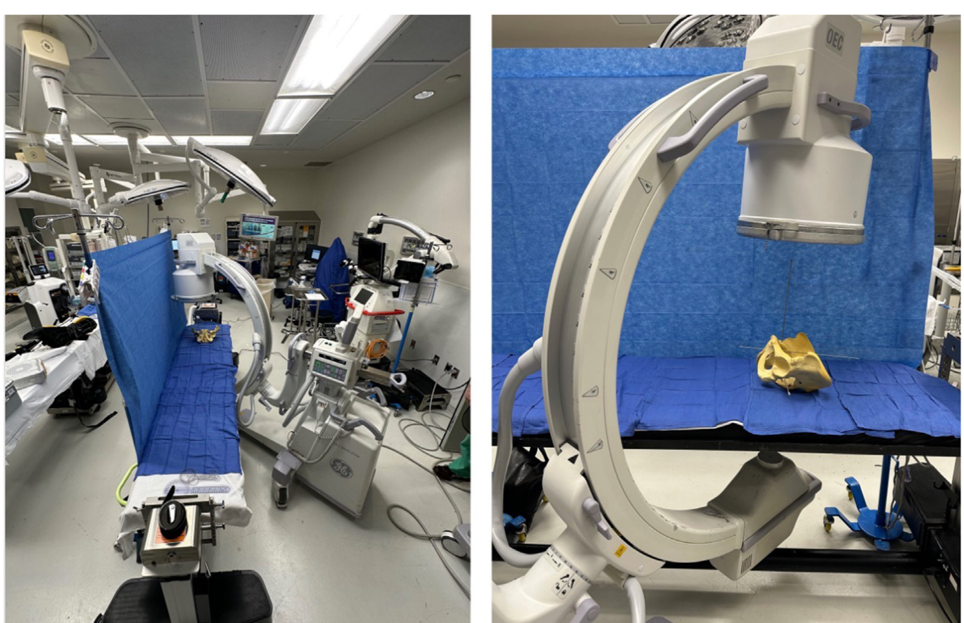

Figure 4. Introduction of C-arm fluoroscope angled at an angle equivalent to the 40° cup inclination angle, which matches the inclination plane.

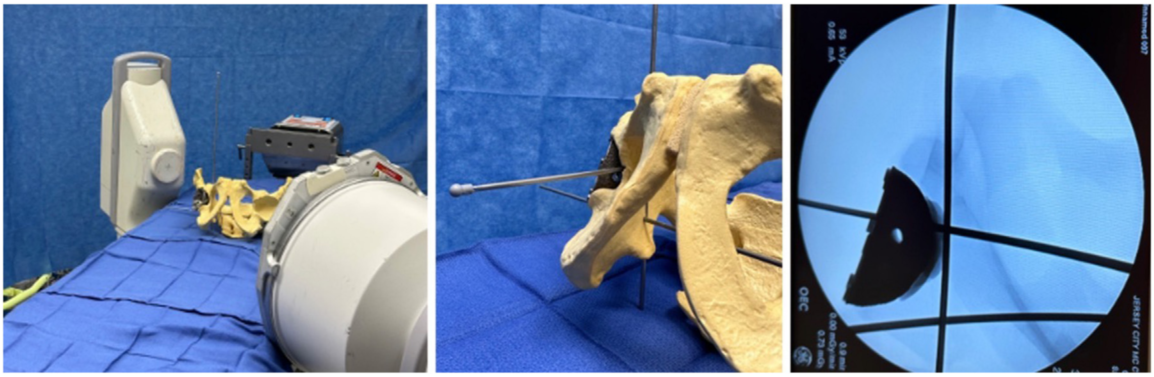

Figure 5. By rotating the C-arm 90 degrees, a fluoroscopic image provides confirmation that the x-ray beam is in complete alignment with the inclination plane with the superior most aspect of the cup overlapping the inferior most aspect of the cup.

Measurement of cup anteversion on cross-table lateral

Immediate postoperative AP and cross-table lateral radiographs of the hip are obtained as part of the standard postoperative protocol. Using the immediate postoperative cross-table lateral radiographs, 2 independent observers (F.R. and I.S.H.) measured and collected acetabular cup anteversion. The acetabular cup anteversion was measured as the angle between a line drawn perpendicular to the horizontal axis of the image and the line drawn along the straight line formed by the opening of the cup (Fig. 8).

Data analyses

The intraoperative C-arm, intraoperative navigation, and the postoperative cross-table lateral measurements of cup anteversion are described as a mean ± standard deviation. Comparison between the C-arm and navigation measurements were made using the Wilcoxon rank-sum test and the mean difference using the Bland-Atman plot. The Bland-Atman plot provides an analysis of the agreement of bias between 2 methods of measurement. The agreement of the 2 independent measurements on cross-table lateral was evaluated using a two-way mixed model intraclass correlation coefficient (ICC) on absolute agreement as a measure of inter-rater reliability. ICC values between 0.90-1.00 are considered very strong correlation, 0.70-0.89 strong correlation, 0.40-0.69 moderate correlation, and <0.39 poor correlation.

Results

The mean intraoperative C-arm measurements of cup anteversion were 20.8° ± 2.0°, compared to mean navigation of 21.3° ± 6.2° (*P*-value = .916). Mean difference (navigation − C-arm) was 0.5° ± 7.4° (95% confidence interval [CI]: −14.0° to 15.0°), and these values were used for the Bland-Atman plot. The Bland-Atman plot

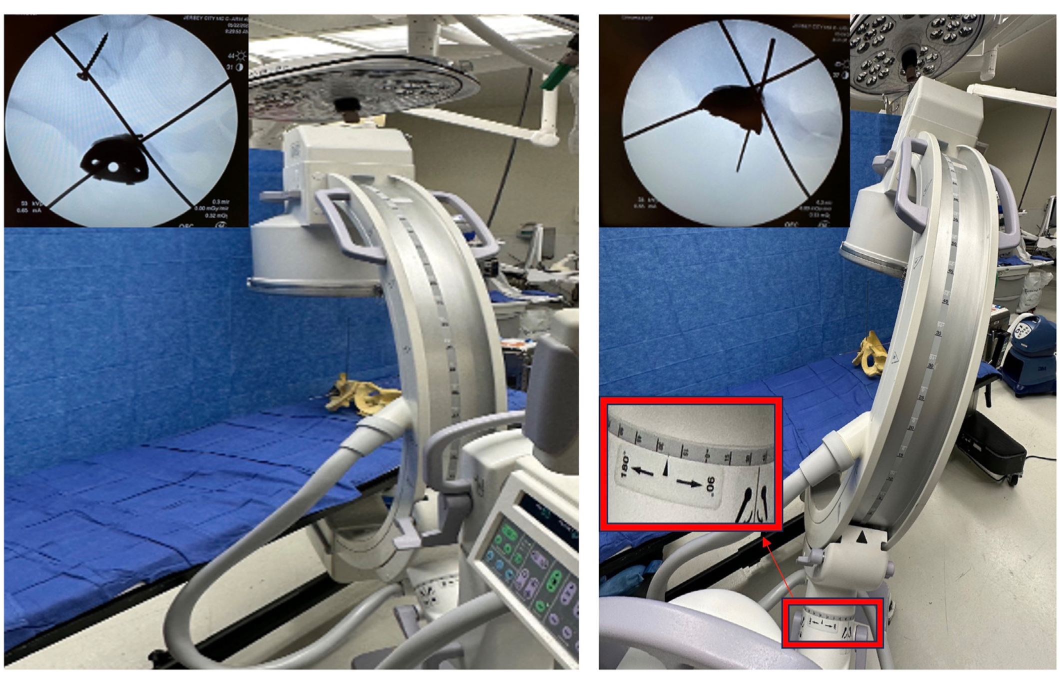

Figure 6. Fluoroscopic image corresponding with the position of the C-arm is shown. After opening the axial arm and tilting 20° cephalad, a precise fluoroscopic view in perfect alignment with cup anteversion plane is visualized.

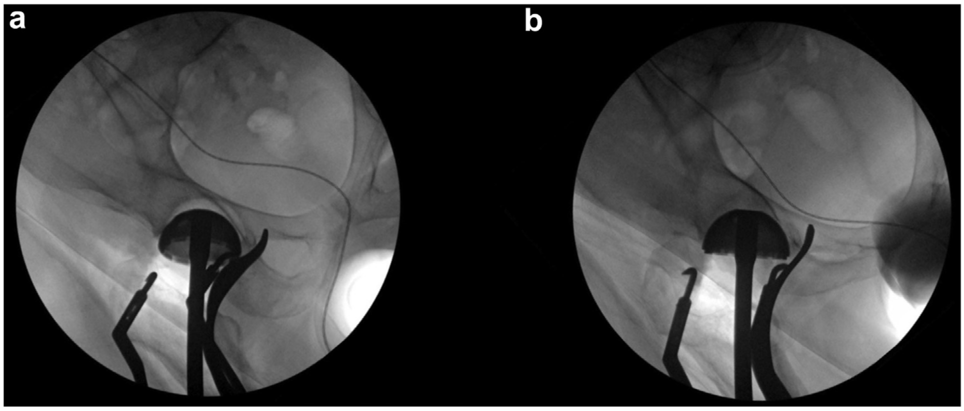

Figure 7. (a) Anteroposterior fluoroscopy image centered over the operative hip showing an anteverted cup with an approximate inclination of 40°. (b) Fluoroscopy image with C-arm tilted cephalad until the opening of the cup is visualized as a straight line; the tilt angle corresponds to the anteversion of the cup measured intraoperatively using fluoroscopy.

is shown in Figure 9 demonstrating 6/6 (100%) of measurements plotted within the statistical limits of acceptability represented by the 95% CI. The mean cross-table lateral measurements of cup anteversion were 26.1° ± 3.8°; the ICC showed a very strong correlation of 0.974 (95% CI: 0.811-0.996).

Discussion

The aim of this study was two-fold: 1. to demonstrate a proof-of-concept of accurately obtaining a “true anatomic” cup anteversion using C-arm fluoroscopy; 2. to compare the efficacy and noninferiority of intraoperative fluoroscopy with computer-assisted navigation in measuring acetabular cup anteversion during DA THA. The results of this study showed a high degree of agreement between the 2 methods, with mean intraoperative C-arm measurements closely aligning with those obtained from the navigation system. These findings suggest that surgeons without access to computer-assisted navigation can effectively utilize C-arm fluoroscopy, which is easily accessible intraoperatively, to reliably and accurately determine cup anteversion, providing a practice alternative to more advanced navigation systems.

The use of intraoperative fluoroscopy in DA THA is not novel, as previous studies have documented various techniques employed. [15-18] However, when critically evaluating some of the techniques described in the literature, there is an important limitation: many do not quantitatively measure the “true” anatomical anteversion of the acetabular cup relative to the pelvic anatomy. Meermans et al. highlighted the importance of distinguishing between “anatomic anteversion” and “operative anteversion” in THA. [19] The authors' mathematical analysis found that established fluoroscopic techniques measure operative anteversion rather than the “true” anatomic anteversion of the acetabular cup relative to the patient's pelvic anatomy. This study attempts to bridge this gap by introducing a novel technique that allows for precise measurement of true anatomic anteversion of the acetabular cup that is straightforward and easily replicable, enabling widespread application.

A recent meta-analysis by Sun et al., which compared fluoroscopy to nonfluoroscopic methods found no significant differences between surgeons using intraoperative fluoroscopy and those using alternative methods with regard to cup inclination, cup anteversion, or combined cup positioning that were within the “safe zone” or limb-length discrepancy. [20] This further supports the findings of this current study, which showed noninferiority of utilizing fluoroscopy when compared to computer-assisted navigation. Therefore, while fluoroscopy is an easily accessible and reliable tool, further studies with a higher sample size are needed to determine if this method is superior at replicating the optimal cup positioning and association with good postoperative outcomes.

As previously mentioned, the consideration of spinopelvic mobility adds another layer of complexity to preoperative planning. [8] Lazennec et al. explored this concept by demonstrating significant changes in sagittal spinopelvic translation from standing to

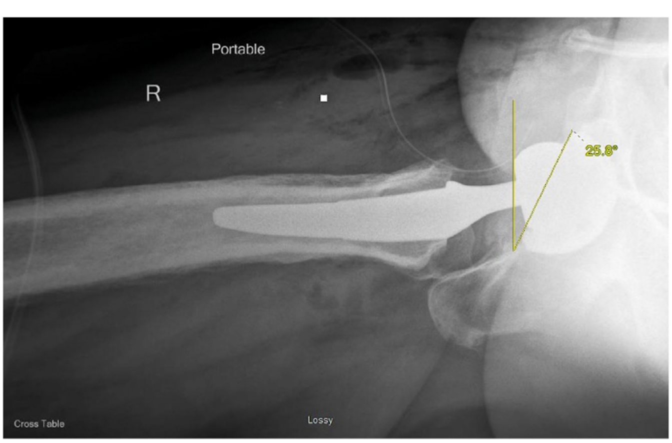

Figure 8. Measurement of cup anteversion utilizing cross-table lateral radiographs taken immediately postoperatively.

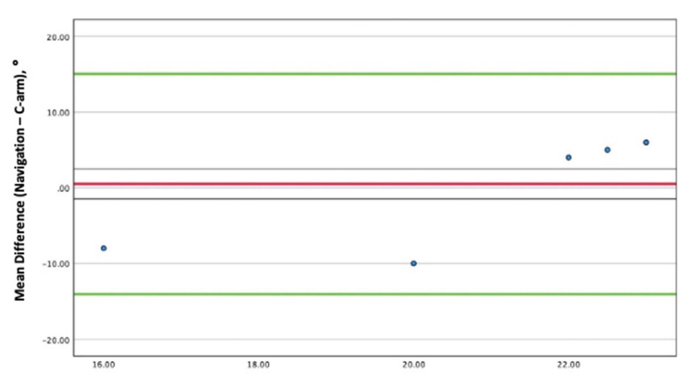

Figure 9. Bland-Atman plot comparing the acetabular cup anteversion measured intraoperatively using C-arm and navigation. Red line = mean difference of 0.5°; green line = upper and lower 95% confidence limits of −14.0° to 15.0°.

sitting in post-THA patients. [21] Even in patients where the acetabular cup position is within acceptable ranges, the influence of pelvic incidence on distinctive sagittal spinopelvic translation patterns is exhibited during functional movements such as standing and sitting. Therefore, despite hitting the acetabular cup "safe zone" described by Lewinnek et al., [3] additional factors must be taken into consideration, including the patient's spinopelvic mobility and pelvic anatomy.

Limitations

While this study provides a novel approach of utilizing intraoperative C-arm fluoroscopy during DA THA to accurately obtain cup anteversion, there are certain limitations that must be addressed. The study only included a relatively small sample size of 6 patients, mainly due to the time constraints incurred due to utilizing 2 different methods of measuring cup anteversion simultaneously. Patients with extreme spinopelvic mobility (stiff or hypermobile pelvic motions incurred during sitting and standing) were not accounted for. Furthermore, all surgeries were performed by a single, fellowship-trained surgeon at one academic institution with experience in DA THA. A critical consideration is the technique's fundamental assumption that the anterior pelvic plane aligns perfectly with the horizontal plane (such as the operating table, floor, or coronal plane), an assumption that is also made when defining the coronal plane with the Intellijoint system. Thus, the accuracy of this novel technique may be diminished in patients with considerable pelvic tilt, failing to account for variations in pelvic tilt. Furthermore, the patient's body habitus may preclude the easy manipulation of the fluoroscopic C-arm, particularly when opening the axial arm and tilting cephalad to obtain anteversion measurements; therefore, this novel technical trick may not be applicable to all patients. Thus, this demographic consideration is an important aspect to highlight, which may reduce the study's general applicability to a broader patient population.

Summary

The high degree of agreement between fluoroscopic and computer-assisted navigation measurement of acetabular cup anteversion supports the efficacy and practicality of using C-arm fluoroscopy in settings with limited access to navigation systems in DA THA. While the findings are promising, additional research with larger sample sizes and inclusion of diverse patient demographic with varying spinopelvic mobility are needed. However, this technical trick effectively addresses the crucial gap in existing technical guides with a novel approach to accurately measure "true" anatomic cup anteversion during DA THA.

Conflicts of interest

F. A. Liporace receives royalties from Biomet, DePuy, A Johnson & Johnson Company, Stryker, and Synthes; is a speaker and paid consultant for Biomet and Synthes; is an unpaid consultant for AO; receives research support from Biomet, DePuy, and A Johnson & Johnson Company; and is a board/committee member of AAOS and the Orthopaedic Trauma Association. I. S. Hong is a paid consultant for LifeNet Health and receives research support from Irrimax Corporation and LifeNet Health. R. S. Yoon receives royalties from Arthrex Inc., Springer, and Stryker; is a paid consultant for Arthrex Inc., DePuy, A Johnson & Johnson Company, LifeNet Health, MiCare Health, OrthoGrid, ORTHOXEL, SI-Bone, Stryker, Synthes, and Use-Lab; has stock options in ORintelligence and WNT Scientific; receives research support from AO Foundation, AO Innovation Translation Center, Bicomposites, Biomet, COTA, DePuy, A Johnson and Johnson Company, Irrimax, LifeNet Health, OMEGA, Organogenesis, Pacira, SI-Bone, Smith & Nephew, and Synthes; receives other financial/material support from Springer; and is a board/committee member of American Association of Hip and Knee Surgeons, Foundation for Orthopedic Trauma, Foundation for Physician Advancement, and Orthopaedic Trauma Association. All other authors declare no potential conflicts of interest.

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CRediT authorship contribution statement

Filippo Romanelli: Conceptualization, Data curation, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Ian S. Hong:** Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jibran A. Khan:** Investigation, Validation, Visualization, Writing – original draft. **Andrew Porter:** Investigation, Supervision, Validation, Writing – original draft. **Jaclyn M. Jankowski:** Investigation, Methodology, Project administration, Supervision, Validation, Writing – review & editing. **Frank A. Liporace:** Conceptualization, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – review & editing. **Richard S. Yoon:** Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing.

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