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Original Research

# Does Artificial Intelligence Outperform Humans Using Fluoroscopic-Assisted Computer Navigation for Total Hip Arthroplasty?

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A B S T R A C T

*Background:* Successful total hip arthroplasty (THA) relies on the correct implant position. THA accuracy can be improved with the use of intraoperative fluoroscopic-assisted computer navigation. Artificial intelligence (AI) software may enhance fluoroscopic navigation; however, the accuracy of the AI compared to human-controlled software in assessing acetabular component position and leg length discrepancy (LLD) has not been studied.

*Methods:* We analyzed 420 consecutive primary THAs performed by a single surgeon using fluoroscopic-assisted computer navigation software. The first cohort of 211 patients required inputs from a human technician (manual), while the second cohort of 209 patients used an automated version of the software controlled by AI. The intraoperative acetabular component placement (inclination and anteversion) and LLD were recorded and compared to the 2-week postoperative standing anterior-posterior pelvis radiograph.

*Results:* Ninety-four percent (199/211) of cups in the manual cohort and 95% (198/209) of cups in the AI cohort were within the Lewinnek “safe-zone” ($P = 1.0$). In the manual cohort, 69% (146/211) of THAs had a final LLD within ±2 mm of the intraoperatively navigated LLD (ie, $\Delta$LLD $\leq$2 mm). In the AI cohort, 66% (137/209) of THAs had a final LLD within ±2 mm of the intraoperatively navigated LLD ($P = .47$). Ninety-nine percent (209/211) of hips in the manual cohort and 98% (205/209) of hips in the AI cohort had a final LLD within ±5 mm of the intraoperatively navigated LLD ($P = .45$).

*Conclusions:* Both AI and human-controlled versions of the same navigation platform were similarly accurate for navigating cup position within the Lewinnek “safe zone” and LLD accuracy.



## Introduction

Total hip arthroplasty (THA) is regarded as one of the most successful surgeries of the 20$^{th}$ century [1], with some authors reporting 25-year implant survivorship as high as 95% [2,3]. This clinical success reflects continued improvements in implant design, patient optimization, and surgical techniques. Crucial to the long-term success of THA is accurate placement of the components, thereby reducing the risks of complications such as dislocation, leg length discrepancy (LLD), and aseptic loosening [4,5]. Notably, THA has become more accurate with the use of enabling technologies such as fluoroscopy, computer navigation, and robotics [6-8], which help to decrease component malposition and mitigate the risk of dislocation [9,10].

The use of intraoperative fluoroscopy has become increasingly frequent during THA as the direct anterior (DA) approach continues to gain popularity [11-13]. Fluoroscopic imaging is relatively easy to perform in the supine position and allows intraoperative qualitative assessment of cup position and leg length by the surgeon. Recently, computer navigation software has been introduced that allows quantitative assessment of acetabular cup position and leg lengths on fluoroscopic images [14,15]. Early versions of this software allow intraoperative calculation of cup inclination, cup anteversion, and LLD but require inputs from a human technician to

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register anatomic landmarks. Most recently, artificial intelligence (AI) software has been developed that analyzes the fluoroscopic images and immediately calculates cup position in real time during the surgery, without the need for human radiographic registration [14,16]. However, to date, we are not familiar with any study that investigates the accuracy of this AI software in comparison with the human-controlled software using the same navigation platform.

We therefore designed the present comparative study, asking the following research questions regarding fluoroscopic-assisted computer navigation for THA: 1) Is AI more accurate than human-controlled software for assessing cup inclination and anteversion? 2) Is AI more accurate than human-controlled software for assessing LLD? We hypothesized that there would be no difference between the intraoperative accuracy of AI vs human-controlled software compared to postoperative films. To our knowledge, this is the first report of the clinical use of AI-enabled fluoroscopic-assisted computer navigation for THA.

## Material and methods

### *Study design*

The present investigation was a retrospective comparative study of a prospectively collected series of patients undergoing DA THA in the supine position on a traction table using fluoroscopic-assisted computer navigation at an urban, high-volume orthopedic specialty hospital. We obtained approval for the study from the institutional review board prior to its undertaking. We included consecutive patients undergoing unilateral primary DA THA by a single fellowship-trained arthroplasty surgeon using the same implant system (PINNACLE acetabular component and ACTIS femoral component, DePuy Synthes, Warsaw, IN) between February 2022 and August 2023. We excluded patients undergoing nonelective, conversion, or revision THA. We additionally excluded patients who did not return for a follow-up radiograph ($n = 4$), had indeterminate landmarks on radiographs ($n = 5$), started >5 millimeters (mm) long on the operative side due to contralateral pathology ($n = 3$), were lengthened purposefully due to contralateral hip osteoarthritis (knowing that we would be performing THA on the other side in the future) ($n = 5$), and started >10 mm short on the operative side ($n = 3$). We started with 229 patients and excluded the 20 noted above to have a final cohort of 209.

All surgeries were performed using one of 2 versions of the same navigation software platform (OrthoGrid Systems, Inc., Salt Lake City, UT). The first cohort underwent surgery between February 2022 and December 2022 using a "manual" version of the software, which requires input from a human technician to identify radiographic landmarks. The second cohort underwent surgery between January 2023 and August 2023 using AI software in which radiographic landmarks were automatically identified without human input. The AI identifies the cup position and fits an ellipse along the outer rim in the anterior-posterior (AP) image, which is then used by the software to calculate the anteversion and inclination. For the LLD, the AI identifies the teardrops and the most prominent portion of the lesser teardrop. This created 2 consecutive subgroups of patients (manual and AI) for comparison.

Application of our inclusion/exclusion criteria yielded a total of 209 THAs in the AI group, which were then retrospectively compared to our previously presented cohort of 211 THAs in the manual group [14]. This yielded a total study population of 420 THAs. Patient demographic variables were obtained for the final study population (Table 1). All patients received a standing AP radiograph in the office at the 2-week postoperative visit.

**Table 1**
Perioperative demographic variables.

| | Manual navigation N = 211 THAs | Artificial intelligence navigation N = 209 THAs | *P* |
|---|---|---|---|
| Age (mean) | 63 y (range 29-86) | 66 y (range 13-96) | .005 |
| Body mass index (mean) | 27.2 kg/m$^2$ (range 17.8-36.9) | 26.9 kg/m$^2$ (range 17.7-35.7) | .33 |
| Gender | | | |
| Male | 103 | 83 | .06 |
| Female | 108 | 126 | |
| Diagnosis (osteoarthritis vs other) | | | .6 |
| Osteoarthritis (OA) | 198 | 193 | |
| Avascular necrosis | 11 | 12 | |
| Post-traumatic arthritis | 1 | 3 | |
| Developmental dysplasia of hip | 1 | 0 | |
| Pseudoachondroplasia | 0 | 1 | |
| Laterality | | | .92 |
| Left | 105 | 102 | |
| Right | 108 | 107 | |

### *Description of navigation technique*

Unilateral THA was performed using a standard DA approach in the supine position on a traction table [17]. For acetabular preparation, an AP fluoroscopic view of the pelvis was obtained, adjusting the angle of the fluoroscopic beam to achieve obturator foramen that were equal in shape and size to the preoperative standing AP pelvis. We attempted to reproduce the pubic symphysis-sacrococcygeal distance on fluoroscopy to adjust for pelvic tilt, as described by Ranier et al [18,19]. The same fluoroscopy machine was used with a 31-cm rectangular detector without correction (OEC Elite CFD, GE HealthCare, Chicago, IL).

After reaming, the cup was impacted, aiming for the Lewinnek "safe zone" (LSZ) target inclination and anteversion of $40 \pm 10^\circ$ and $15 \pm 10^\circ$, respectively [4]. Anteversion adjustments were made to place the anterior edge of the cup countersunk under the anterior acetabular wall to avoid psoas impingement and account for spinopelvic tilt using the target guidelines previously published by Frandsen et al [20].

As the cup was impacted, inclination and anteversion measurements were calculated using fluoroscopic-assisted computer navigation software. The manual cohort required a technician to register anatomic landmarks (inferior border of the teardrops) and fit an ellipse to the rim of the cup prior to the software calculating cup measurements. The technician's points were verified by the surgeon and adjusted as needed for accuracy. The AI cohort obtained landmark registration automatically without human input, and the anteversion/inclination angles were immediately calculated. Importantly, while the software recommends measuring acetabular angles with the cup centered in the middle of the radiographic beam, we instead obtained these measurements with the cup positioned at the edge of the fluoroscopic image (Fig. 1). This technique is preferred by the senior author to visualize the entire pelvis during cup impaction, despite this being known to subject the cup to parallax distortion [21].

After preparation of the femur, the trial hip was reduced, and an additional AP pelvis fluoroscopic image was obtained. External rotation of the hips was performed as needed to ensure the symmetry of the lesser trochanters (Fig. 2). Image calibration was performed in both cohorts by entering the known acetabular cup size. The manual cohort required a technician to then register anatomic landmarks for LLD calculation; we used 1)


**Figure 1.** Intraoperative AP pelvis fluoroscopic image of the artificial intelligence-operated navigation system measuring the acetabular cup inclination and anteversion.

bilateral inferior borders of the teardrops and 2) bilateral superior borders of the lesser trochanters. The software then calculated the LLD. For the AI cohort, landmarks were automatically recognized by the AI software, and the LLD was immediately calculated. The preoperative goal for each hip was to achieve LLD within ±2 mm; however, intraoperative LLDs of as much as ±5 mm were allowed if the surgeon deemed this necessary for either clinical stability or to accommodate the patient's preoperative perception of leg length.

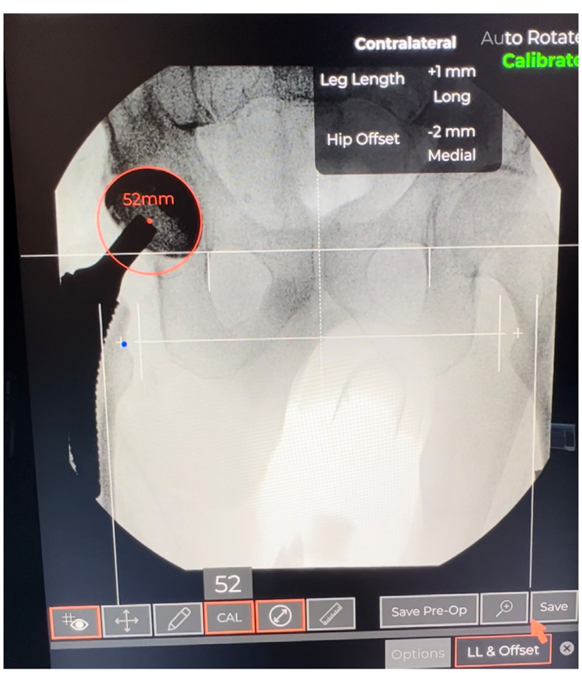


**Figure 2.** Intraoperative AP pelvis fluoroscopic image of the artificial intelligence-operated navigation system marking the teardrops and lesser trochanters to measure leg length and offset compared to the contralateral leg.

### *Study outcomes, sample size calculation, and data analysis*

Primary outcomes in the current investigation included: 1) final cup inclination and anteversion; and 2) final LLD, as measured at the 2-week postoperative visit on a standing AP pelvis radiograph. Postoperative measurements were calculated using our institutional imaging software (Merge OrthoPACS, IBM, Armonk, NY) by an investigator who was blinded to the intraoperative navigation measurements. The leg lengths were measured using the teardrop and superior border of the lesser trochanter. The cup inclination was the angle between a parallel line to the floor and the superior and inferior borders of the cup. The cup anteversion was measured with the OrthoPACS ellipse tool [19]. These postoperative measurements were compared to the intraoperative measurements for both the manual and AI cohorts to determine the accuracy of the navigation software.

Previous authors have compared the use of fluoroscopic-assisted computer navigation to standard fluoroscopy for assessing LLD, where the primary outcome of interest was the difference between the mean planned and actual LLD. Categorizing this difference into 6 categories (up to 1 mm, 1-2 mm, 2-3 mm, 3-4 mm, 4-5 mm, and >5 mm), the authors performed a sample size calculation and determined that a minimum sample of 100 patients (50 per group) was required to achieve a power of 0.8 [15]. We further performed a sample size/power calculation (assuming $\alpha = 0.05$ and power $= 0.8$) and determined the total sample size required to be 376 subjects (188 in each group) to determine a clinically significant 5% difference between manual and AI groups for ΔLLD within ±5 mm. We subsequently enrolled >200 patients in each group, for a total of 420 study patients.

All data were entered, stored, and analyzed using Microsoft Excel (Microsoft Corporation, Redmond, WA) and GraphPad QuickCalcs (GraphPad Software, San Diego, CA). Sample size was determined using the Universität Wien Sample Size Calculator Version 1.06 [22]. Continuous variables were analyzed with the Student's *t*-test, while categorical variables were analyzed with the Fisher's exact test. In all cases, statistical significance was set at $P = .05$.

## Results

### *Acetabular component position*

Ninety-four percent (199/211) of cups in the manual cohort and 95% (198/209) of cups in the AI cohort were implanted within the LSZ at postoperative evaluation ($P = 1.0$) (Fig. 3). In the manual cohort, 81% (171/211) of cups had a final inclination within ±5° of the intraoperative navigated inclination, compared to 80% (167/209) of cups in the AI cohort ($P = .81$). For manual navigation, final cup inclination averaged 43° (SD ± 3.2°), which was 3 degrees more vertical compared to the 40° (SD ± 2.7°) measured intraoperatively ($P < .001$). With AI navigation, final cup inclination also averaged 43° (SD ± 3.0°), again 3 degrees more vertical compared to the 40° (SD ± 3.2°) measured intraoperatively ($P < .001$).

In the manual cohort, 91% (191/211) of cups had a final anteversion within ±5° of the intraoperative navigated anteversion, compared to 92% (192/209) in the AI cohort ($P = .73$). The manual cohort final cup anteversion averaged 19° (SD ± 3.8°), similar to the 19° (SD ± 3.4°) measured intraoperatively ($P = .17$). In the AI cohort, final cup anteversion averaged 21° (SD ± 3.2°), similar to the 21° (SD ± 3.3°) degrees measured intraoperatively ($P = .50$).

### *Leg length discrepancy*

For manual cohort hips, the mean ΔLLD (difference between the intraoperative and final postoperative LLD measurements) was 0.3

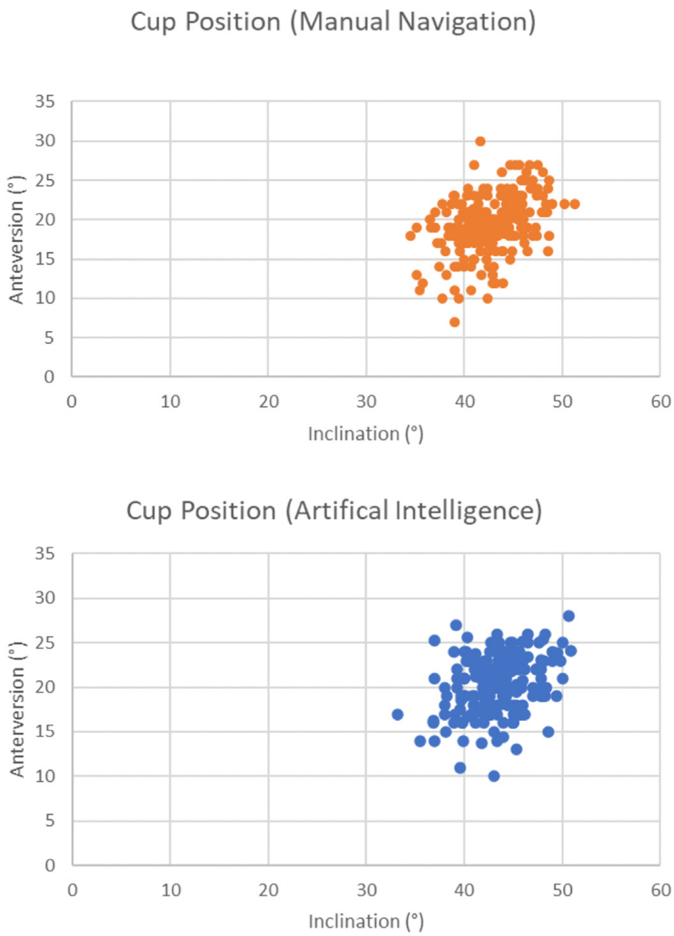


**Figure 3.** Comparison of postoperative acetabular cup inclination and anteversion measurements comparing the "manual" operated and the artificial intelligence operated systems.

mm (SD ± 2.1 mm), which was similar to the AI cohort ΔLLD of 0.5 mm (SD ± 2.2 mm), ($P = .25$). In the manual cohort, 69% (146/211) of patients had a final LLD within ±2 mm of the intraoperatively navigated LLD measurement (ie, ΔLLD ≤2 mm). In the AI cohort, 66% (137/209) of hips had a postoperative LLD within ±2 mm of the intraoperative navigated LLD measurement ($P = .47$). When considering a ΔLLD ≤5 mm, 99% (209/211) of hips in the manual cohort and 98% (205/209) of hips in the AI cohort were within ±5 mm of the intraoperative navigated measurements ($P = .45$) (Fig. 4).

## Discussion

This clinical study is the first to assess the accuracy of fluoroscopic-assisted computer navigation for THA using AI software. The results indicate that AI is comparable to the accuracy of human-controlled software in assessing cup position and LLD. On final postoperative films, 95% of cups in the AI cohort were found to be placed within the targeted LSZ. Additionally, 66% of patients had a final LLD within ±2 mm of the AI-navigated intraoperative LLD measurement, and 98% of hips were within ±5 mm. There were no clinical or statistical differences between the accuracy of the AI and manual software.

Multiple authors have previously demonstrated that computer navigation improves the accuracy of acetabular component position compared to conventional THA [19,23-27]. Nishihara et al. recently compared non-navigated THA using fluoroscopy to computed tomography (CT)-based navigation for determining acetabular component placement using a DA approach. The authors reported that cup anteversion within 10° of the target when using navigation was 100% (72/72), compared to 74% (53/72) with the freehand technique. Similarly, cup inclination within 10° of target when using navigation was 100% (72/72), compared to 75% (54/72) of non-navigated cups [27]. Fluoroscopy has also been shown to improve the accuracy of acetabular cup placement [28,29]. Comparing standard fluoroscopy to CT-based robotic-assisted THAs, a single-surgeon series showed that 85% of cups in the fluoroscopic group and 87% of cups in the robotic group were placed within the LSZ [30]. A recent prospective cohort study of 249 patients evaluated non-navigated, computer-assisted, and robotic-assisted THA to assess the accuracy of acetabular component placement in relation to the preoperative plan. Both computer-navigated and robotic THA were more accurate than non-navigated THA; however, robotic THA was shown to be the most accurate with final inclination 1 ± 1° and anteversion 1 ± 2° compared to the preoperative target [31].

Our data in the present study are consistent with the current navigated THA literature in that we report 95% of acetabular components placed within the targeted LSZ using fluoroscopic-assisted computer navigation with AI software. Interestingly, with both the manual and AI versions, we found cups approximately 3 degrees more vertical on postoperative films compared to what was measured intraoperatively. However, we believe this is likely explained by parallax distortion of the fluoroscopic beam. Although the navigation software recommends analyzing the cup position while centered in the fluoroscopic image, the senior author instead prefers to impact the cup while visualizing the entire pelvis. This technique notably requires the cup to be at the edge of the fluoroscopic image, where the parallax effect is greatest, and has been shown to underestimate inclination by up to 5 degrees [19].

LLD has also extensively been studied in the THA literature, with multiple authors reporting that navigation improves accuracy and reduces outliers. Rajpaul and Rasool performed a collective review of 14 separate studies and concluded that the use of computer navigation is more accurate than non-navigated THA, comparing both anterior and posterior approaches as well as multiple methods of navigation [24]. A separate meta-analysis of 21 studies also showed that THAs performed with navigation had increased LLD accuracy compared to traditional non-navigated THAs [32]. Ellapparadja and colleagues evaluated a series of 152 patients using a posterior approach with an image-free computer navigation system, reporting LLD <6 mm in 95.7% of patients [7].

A prospective randomized controlled trial of 125 patients compared computer navigation to standard fluoroscopy performed through an anterolateral approach in the lateral decubitus position. The authors report that 98% (54/55) of navigated hips and 77% (47/61) of standard fluoroscopy hips were within ±5 mm LLD ($P < .001$) [33]. Martin et al. have evaluated the use of DA THA with standard fluoroscopy to guide component placement and reported more accurate postoperative LLD (1.6 mm) compared to non-navigated posterior THA (5.5 mm) ($P < .0001$) [28]. Using fluoroscopic-assisted computer navigation software, O'Leary and colleagues report LLD accuracy within ± 3 mm of the intended target in 66% of THAs, which was a statistical improvement over the LLD accuracy (40% within ± 3 mm of the intended target) using standard fluoroscopy ($P < .01$) [15]. Our data are consistent with the previous authors in that we report a high degree of LLD accuracy using fluoroscopic-assisted AI computer navigation; on final radiographs, 66% of THAs were within 2 mm of the AI-navigated intraoperative LLD, and 98% were within 5 mm.

There are multiple limitations to the present study. First, the retrospective design is subject to the inclusion bias inherent in any

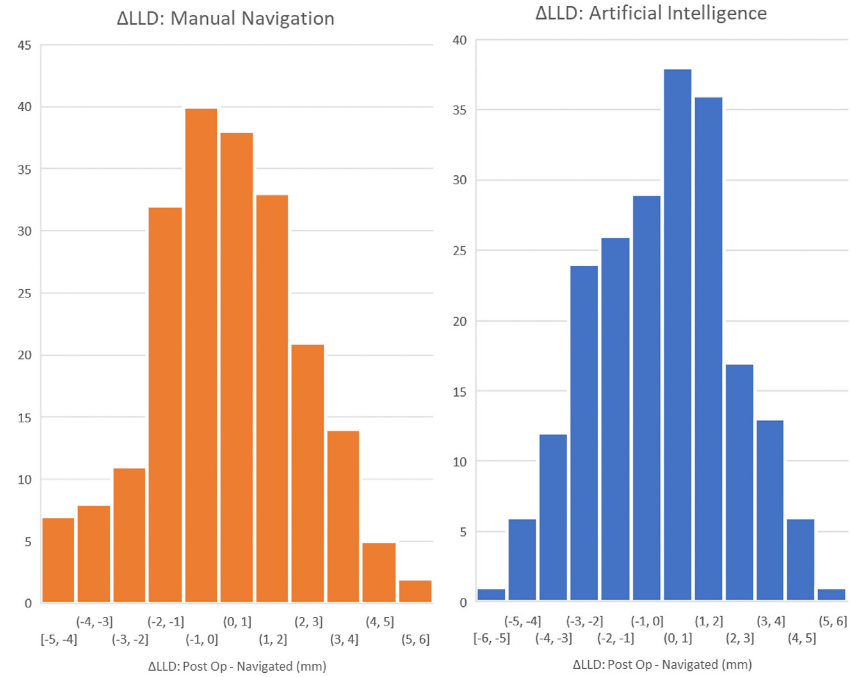


**Figure 4.** Comparison between the "manual" operated and the artificial intelligence operated systems difference (Δ) between the leg length discrepancy (LLD) measured on final postoperative films and the LLD measured intraoperatively by each cohort.

retrospective study. We attempted to mitigate this potential bias by studying 2 consecutive series of patients and adhering to well-defined inclusion and exclusion criteria, and analysis of perioperative demographic variables demonstrated that the groups were comparable. A second limitation is the single-surgeon, single-implant study design. While this was done purposefully to prevent the introduction of additional confounding variables commonly seen in multisurgeon studies, there nonetheless exists the possibility that our results may not be as generalizable to other surgeons using different implants, surgical techniques, or radiographic techniques. A third limitation is that postoperative standing AP pelvis radiographs were chosen as the reference standard for evaluating the accuracy of both the AI and manual versions of the navigation software. While this was done purposefully to approximate what is routinely done in clinical practice, it is possible that other forms of radiography such as CT would have been more accurate for determining cup position or LLD. A fourth limitation is that in order to visualize the entire pelvis during acetabular preparation, all cups were impacted with the acetabulum positioned at the margin of the fluoroscopic beam rather than in the center of the image as recommended by the software manufacturer. While this was done purposefully to accommodate the senior author's preferred technique, this is known to introduce up to 5 degrees of error when measuring cup inclination due to the parallax effect [19].

Importantly, evaluation of the intraoperative and postoperative images is limited by the quality of visible radiographic landmarks; in fact, we excluded patients from the study who did not have identifiable landmarks for making intraoperative or postoperative measurements. The present navigation software uses the teardrop and the lesser trochanter as landmarks; thus, the image quality of the teardrop and lesser trochanter may affect the measurements, particularly for LLD. The teardrop has been traditionally thought to be the most accurate anatomic landmark in relation to the bony acetabulum [34]. However, a recent study has challenged this by utilizing deep learning to automate LLD measurements by identifying multiple different landmarks (teardrop, obturator foramen, ischial tuberosity, greater and lesser trochanters), and this showed variation in accuracy among these radiographic landmarks. The authors reported that the most accurate landmarks for determining LLD were the greater trochanter on the femur, and for the acetabulum were either the inferior aspect of the obturator foramen or the ischial tuberosity [35]. Thus, variations in image quality, as well as our use of the teardrop and lesser trochanter as landmarks, may potentially limit the reproducibility and accuracy of our results.

## Conclusions

Fluoroscopic-assisted computer navigation is a relatively new technology that may improve the accuracy of component placement during THA. In this first clinical report regarding the use of AI for navigating THA component position intraoperatively, we show that both the AI and human-controlled versions of the same navigation platform were similarly accurate for navigating cup position within the LSZ, and both techniques achieved similar postoperative LLD accuracy. Careful attention to fluoroscopic technique, radiographic landmarks, and the limitations of fluoroscopy, especially parallax distortion are critical concepts that surgeons should factor into their navigation methodology.

## Conflicts of interest

K. Kitziger received research support from Depuy-Synthes and Smith and Nephew and is an editorial board member of Orthopedics. P. Peters received royalties from Depuy-Synthes and a Johnson & Johnson company and received research support from Depuy-Synthes and Smith and Nephew. B. Waddell is a paid consultant for Smith and Nephew and OrthoAlign, received research support from Depuy-Synthes and Stryker, and is an editorial board member of Current Reviews in Musculoskeletal Medicine. B. P. Gladnick is a paid consultant for Depuy-Synthes and Enovis, has stock options in

OrthoGrid Systems, received research support from Depuy-Synthes and Smith and Nephew, is an editorial board member of the Journal of Arthroplasty, and is a committee member of AAHKS. All other authors declare no potential conflicts of interest.

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## CRediT authorship contribution statement

**Justin M. Cardenas:** Data curation, Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Dan Gordon:** Project administration, Writing – review & editing. **Bradford S. Waddell:** Conceptualization, Investigation, Writing – review & editing. **Kurt J. Kitziger:** Conceptualization, Investigation, Writing – review & editing. **Paul C. Peters:** Conceptualization, Investigation, Writing – review & editing. **Brian P. Gladnick:** Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Writing – review & editing, Conceptualization, Data curation.

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