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Original Research

# Automated Web Tool Measurement of Total Hip Arthroplasty Acetabular Component Inclination and Anteversion Angles

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ABSTRACT

*Background:* Periprosthetic hip dislocation after total hip arthroplasty is a devastating postoperative complication. It is often associated with suboptimal orientation of the acetabular component, characterized by the acetabular abduction and anteversion angles obtained from anteroposterior pelvic radiographs. We introduce a novel automated web tool to streamline the subjective and lengthy process of this manual measurement and compare it to manual human measurements.
*Methods:* One board-certified orthopaedic surgeon used the web tool to make automatic measurements of anteroposterior radiographs of 97 patients who underwent unilateral hip arthroplasty. Manual and web tool measurements included abduction angle and calculated anteversion angle by Liaw's method. Differences between manual and web tool measurements were compared with a paired *t*-test and Bland-Altman analysis.
*Results:* There were no statistically significant differences between the average of manual measurements as compared to the web tool measurement in abduction angle ($43.29 \pm 7.05$ vs $43.00 + 6.22$, $P = .85$), anteversion angle ($20.43 \pm 7.62$ vs $20.82 \pm 7.37$, $P = .52$), and ratio of the minor axis of the acetabular cup circumference in the AP radiograph to the total length of the acetabular head ($0.42 \pm 0.15$ vs $0.44 \pm 0.15$, $P = .18$). The mean difference of average for abduction angle, anteversion angle, and ratio between the short axis of the transverse ellipse to the total length of the acetabular cup were −0.28, 0.39, and 0.02, respectively. Bland-Altman analysis for all 3 measurements displayed negligible systemic bias with random scattering.
*Conclusions:* Automated measurements obtained with a novel web tool are in strong agreement with the manually obtained ground truth measurements. The web tool helps to eliminate interobserver differences that arise with manual annotation. The web tool has the potential to streamline acetabular measurements with enhanced accuracy.


## Introduction

Total hip arthroplasty (THA) is a common surgical procedure used to provide pain relief and restore hip function in patients with debilitating end-stage osteoarthritis [1,2]. Despite high success rates, hip dislocation is a common complication, occurring in 0.2%-1.7% of cases and resulting in significant patient morbidity with lower patient satisfaction [3]. Treatment can involve external maneuvers, closed reduction, or open reduction [4]. While the cause of THA dislocation is multifactorial, the proper orientation of the acetabular component is paramount in preventing dislocation after THA [5]. Although acetabular orientation can be defined by terms such as inclination, anteversion, coverage, tilt, opening, and flexion, it is most commonly defined with the angles of inclination and anteversion [6,7].

These 2 angles can be defined radiographically, anatomically, or by direct observation during an operation. The radiographical angle of inclination is determined from anteroposterior (AP) radiographs

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and defined as the angle between the longitudinal axis and the acetabular axis projected onto the coronal plane; the radiographical angle of anteversion is the angle between the acetabular axis and the coronal plane. Although the angles can be converted between definitions using published nomograms, this proposed study requires only the radiographical definition [8].

Currently, physicians must manually compute these angles with the Widmer Protractor Method or by Liaw's anteversion angle formula, a complex trigonometric formula [9]. These methods can be discrepant and time-consuming due to the subjective nature of annotating landmarks. The need for an automated, error-free, and accessible acetabular component angle calculator for use in the intraoperative setting is evident. This study hypothesizes that a web tool may be used to produce measurements of acetabular inclination and anteversion angles that are statistically indistinguishable from manual measurements performed by orthopaedic surgeons.

The aims of this study were to develop a web tool to automatically measure acetabular component angles on intraoperative pelvic radiographs and evaluate the accuracy and reliability of the web tool compared to manual measurements performed by trained orthopaedic surgeons. The annotations collected from this tool can subsequently be used to segment radiographs and train a deep learning model to automate measurement of acetabular and inclination angles and inform safe zone classification.

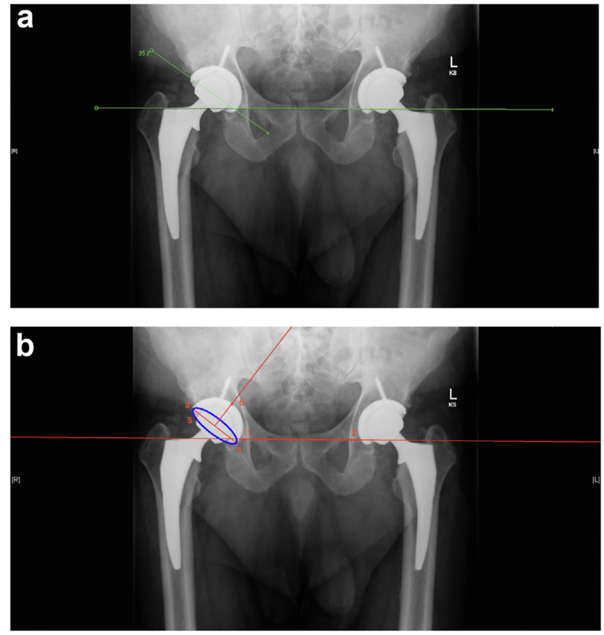


**Figure 1.** (a) Manual annotation on PACS and (b) web tool annotation of AP pelvic radiograph. Abbreviations: AP, anteroposterior; PACS, picture archiving and communication system.

## Material and methods

### *Data sources*

This retrospective study consists of a cohort of patients who underwent THA in an urban academic tertiary referral center between January 12, 2017 and December 18, 2017. Data were obtained from a retrospective THA database. From this database, 100 deidentified digital imaging and communication in medicine files of THA AP pelvic radiographs were randomly selected. All THAs were done in the posterior approach (manual). Three patients with bilateral total hip arthroplasty were excluded due to uncertainty in determining whether the manual measurements corresponded to the left or right side. None of the patients in the cohort sustained a dislocation.

A total of 97 AP pelvic radiographs were included in the study, each with 2 manual measurements and 1 web tool measurement. The cohort consisted of 52 (54%) women patients and 45 (47%) THA on the right side. Patients were aged 56 ± 10 years and had a body mass index of 32 ± 6. Indications for THA included fracture in 4 (4%) patients, avascular necrosis in 15 (15%) patients, and osteoarthritis in 75 (77%) patients.

Ground truth (manual) measurements of abduction angle, ratio of the minor axis of the acetabular cup circumference in the AP radiograph to the total length of the acetabular head (S/TL ratio), and Liaw's anteversion angle for this cohort were measured by 2 board-certified orthopaedic surgeons, as shown in Figure 1a. The age, body mass index, sex, laterality of THA, and indication for THA were extracted from the database.

### *Web tool development*

The web tool was developed using JavaScript with the React framework and Canvas library. The web tool requires the user to mark 6 points on the uploaded image:

(1 and 2) each end of the teardrop line, (3 and 4) each end of the horizontal diameter of the acetabular cup, (5) 1 point along the circumference of the acetabular cup, and (6) 1 point along the acetabular head, as displayed in Figure 1b.

Points 1-4 are used to determine the teardrop line and acetabular axis, for which the angle in between marks the acetabular angle. Points 3-4 also indicate the major axis of the ellipse around the circumference of the acetabular cup and point 5 is used to determine the equation for the ellipse. Point 6 is used to determine the equation for the ellipse around the top of the acetabular cup. The minor axis of the ellipse around the acetabular cup circumference is the short axis ("S"), while half of the major axis of the ellipse around the top of acetabular cup added to half of the minor axis of the ellipse around the acetabular cup circumference is the total length ("TL") used in the Liaw formula [10] to determine S/TL ratio and anteversion angle [9].

### *Radiograph annotation*

For each radiograph, 2 manual and 1 web tool measurement were obtained. Two trained orthopaedic surgeons performed the manual measurements. A third board-certified orthopaedic surgeon performed the web measurements. Measurements included abduction angle (°), Liaw's anteversion angle (°), and S/TL ratio.

### *Web tool evaluation*

The web tool was initially evaluated using simulated images of the acetabulum and femoral head from the THR Simulator, a freely available software program to generate simulated radiographs of hip prostheses [11]. Combinations of prosthesis with simulated anteversion angles ranging from 0° to 35° with 5° increments and simulated acetabular angles of either 35° or 40° were generated. The mean difference and standard deviation (SD) of each measurement were calculated.

### *Data analyses*

The mean differences of web tool and simulator measurements were compared to zero using a paired *t*-test. The mean and SD of both observer's manual measurements were calculated and compared to the mean and SD of web tool measurements using paired *t*-test, Bland-Altman analysis and plots, variation coefficient [12], and scatterplots with Lin's concordance correlation coefficient (CCC). A comparison was also performed between both observers' manual measurements.

Paired *t*-tests were performed in RStudio (version 2024.04.2 + 764) and $P < .05$ was considered statistically significant. Excel (version 2021) was used to perform Bland-Altman analysis, calculate variation coefficient and Lin's CCC, and construct Bland-Altman plots and scatterplots with trendlines.

### *Ethics statement*

This retrospective study using patient data was approved by the institutional review board (IRB #2019-10284) with a waiver of informed consent. All methods were performed in accordance with relevant guidelines and regulations pertaining to human subjects.

### *Data availability*

The data are available upon reasonable request made to the corresponding author.

## Results

There were no significant differences between simulated and web tool measurements for acetabular (mean difference 0.21 ± 0.15, $P = .22$) and anteversion (4.50 ± 3.10, $P = .05$) angles.

There were no statistically significant differences between the average of manual measurements as compared to the web tool measurement in abduction angle (43.29 ± 7.05 vs 43.00 + 6.22, $P = .85$), anteversion angle (20.43 ± 7.62 vs 20.82 ± 7.37, $P = .52$), and S/TL ratio (0.42 ± 0.15 vs 0.44 ± 0.15, $P = .18$), as shown in Table 1. The mean difference of average for abduction angle, anteversion angle, and S/TL ratio were −0.28, 0.39, and 0.02, respectively. 94 (97%) and 88 (91%) absolute differences in abduction and anteversion angle were < 10°, respectively, and 92 (95%) S/TL ratio measurements were < 0.3. Coefficients of variation for abduction angle (11%), anteversion angle (29%), and S/TL ratio (28%) were less than 30. The results of the Bland-Altman analysis for these comparisons are displayed in Figure 2. Lin's CCC was calculated for abduction angle (CCC = 0.528), anteversion angle (CCC = 0.372), and S/TL ratio (CCC = 0.394) for manual and web tool measurements. The scatterplots of these measurements are shown in Figure 3.

**Table 1**
Comparison of manual and web tool measurements of abduction angle, anteversion angle, and S/TL ratio.

| Measurement parameter or statistic | Abduction angle (°) | | Anteversion angle (°) | | S/TL ratio | |
|---|---|---|---|---|---|---|
| Manual measures | 43.29 ± 7.05 | | 20.43 ± 7.62 | | 0.42 ± 0.15 | |
| Automated measures | 43.00 ± 6.22 | | 20.82 ± 7.37 | | 0.44 ± 0.15 | |
| Mean difference of average | −0.28 | | 0.39 | | 0.02 | |
| 95% limits of agreement | (-12.94, 12.38) | | (-16.07, 16.84) | | (-0.31, 0.35) | |
| Percent of absolute differences below threshold | <10° 94 (96.91%) | <5° 81 (83.51%) | <10° 88 (90.72%) | <5° 68 (70.10%) | <0.3 92 (94.85%) | <0.1 66 (68.04%) |
| Variation coefficient | 10.59% | | 28.70% | | 27.94% | |

Data reported as mean ± SD or N (%).

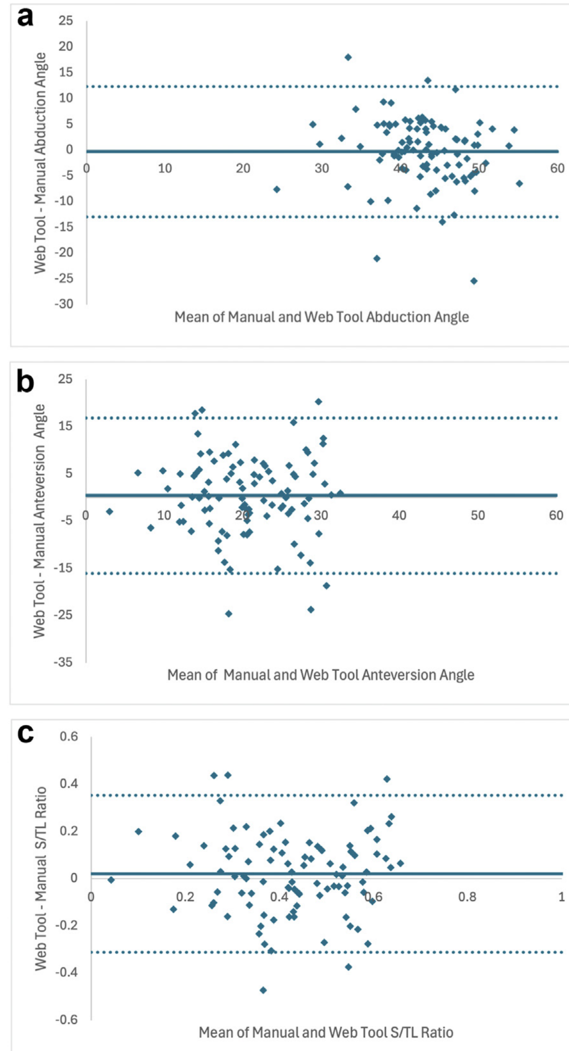


**Figure 2.** Bland-Altman plots of manual versus web tool measurements of (a) abduction angle, (b) inclination angle, and (c) S/TL ratio.

Comparison of the 2 observers' manual measurements showed no statistically significant difference in abduction angle (43.49 ± 6.71 vs 43.08 ± 8.10, $P = .39$), as shown in Table 2. However, both anteversion angle (20.74 ± 7.43 vs 20.11 ± 7.98, $P = .01$) and S/TL ratio (0.43 ± 0.15 vs 0.41 ± 0.17, $P < .01$) were higher in observer 1's measurements. The mean interobserver difference was 0.42, 0.63, and 0.02 for abduction angle, anteversion angle, and S/TL ratio, respectively. The coefficients of variation for abduction angle (7.72%), anteversion angle (8.38%), and S/TL ratio (8.25%) were all less than 10.

## Discussion

The manual method of measuring acetabular orientation through human annotation of AP radiographs is a lengthy and tedious process that relies on the annotator's skill and computation using trigonometric formulas such as the Widmer Protractor Method and Liaw's anteversion formula [8,9]. Accurate calculations are necessary for acetabular evaluation [5]. One study reported that the ellipse method for measuring acetabular and anteversion

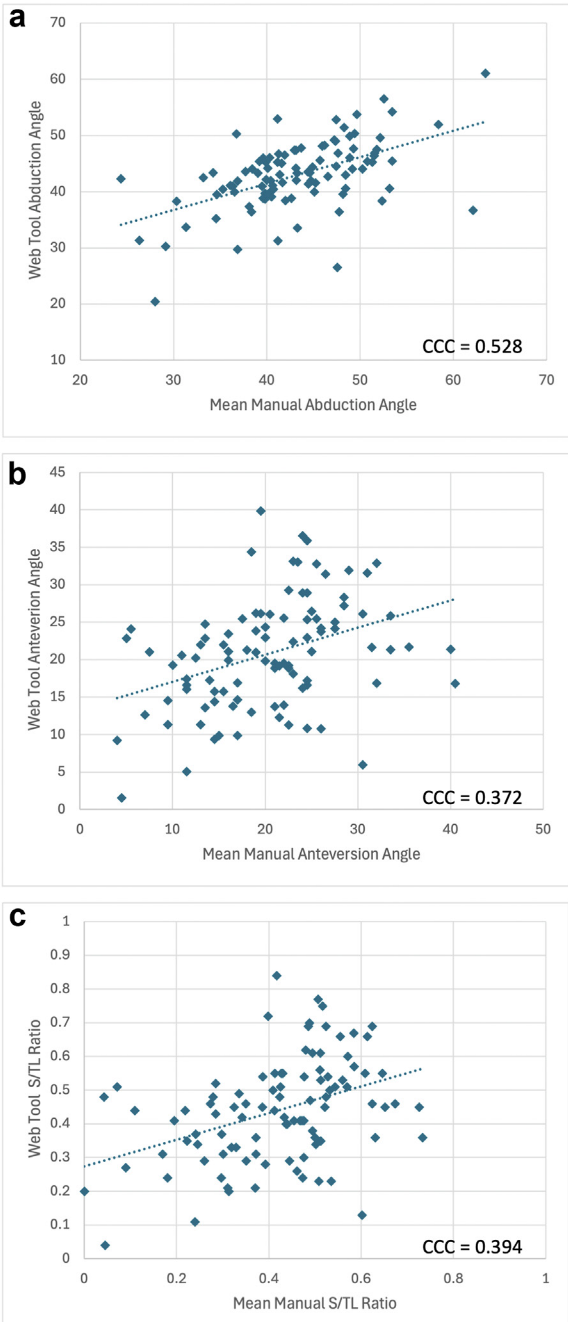


**Figure 3.** Scatterplots of mean and web tool measurements for (a) abduction angle, (b) anteversion angle, and (c) S/TL ratio. Lin's CCC is displayed on each plot. Abbreviation: CCC, concordance correlation coefficient.

angles may improve accuracy and precision compared to manual measurements; however, the technique remains protracted [10]. The present study involved elaborated upon the ellipse method to develop a web tool for simple and efficient measurement of acetabular and anteversion angles.

Comparing the acetabular abduction and anteversion angle between manual and automated web tool measurement in 97 AP radiographs demonstrated (1) there is no statistically significant difference between manual and automated measurements; (2) a negligible level of systemic bias between manual and automated measurements by Bland-Altman analysis; and (3) the coefficients of

**Table 2**
Comparison of 2 observer's manual measurements of abduction angle, anteversion angle, and S/TL ratio.

| Measurement parameter or statistic | Abduction angle (°) | | Anteversion angle (°) | | S/TL ratio | |
|---|---|---|---|---|---|---|
| Observer 1 manual | 43.49 ± 6.71 | | 20.74 ± 7.43 | | 0.43 ± 0.15 | |
| Observer 2 manual | 43.08 ± 8.10 | | 20.11 ± 7.98 | | 0.41 ± 0.17 | |
| *P* value | 0.386 | | 0.012 | | 0.001 | |
| Mean difference of average | 0.42 | | 0.63 | | 0.02 | |
| 95% limits of agreement | (-8.84, 9.68) | | (-4.12, 5.37) | | (-0.08, 0.11) | |
| Percent of absolute differences below threshold | <10° 96 (98.97%) | <5° 93 (95.88%) | <10° 96 (98.97%) | <5° 89 (91.75%) | <0.3 97 (100.00%) | <0.1 91 (93.81%) |
| Variation coefficient | 7.72% | | 8.38% | | 8.25% | |

Data reported as mean ± SD or N (%). *P* value is obtained from paired *t*-test between observer 1 and observer 2.

variation for each measurement are less than 30%, indicating acceptable but moderate variability.

Despite their training, the 2 manual annotators in this study had statistically significant differences in their measured S/TL ratio and calculated acetabular anteversion angle. Although there were statistically significant differences, they were within the margins of error and were not of clinical importance.

Conversely, there was no statistically significant difference between automatic web tool measurements and the average of the manual measurements. Each Bland-Altman plot, for acetabular abduction angle, anteversion angle, and S/TL ratio, had minimal systemic bias (bias ~0) and random scatter without any funneling, indicating no bias toward certain measurement magnitudes. Approximately 90%-95% of angle calculations were with 10° of each other and about 95% of S/TL ratios were within 0.3 of each other, further indicating strong agreement between manual and automatic data. One other study [13] also compared automatic versus manual measurement of the anteversion angle in 80 radiographs using a deep learning tool and reported the mean difference to be 1.27°. Our study reported an even smaller mean difference of 0.39° despite a larger sample size. Thus, the web tool improves upon current methods of anteversion angle measurement.

No studies have evaluated automatic calculation of the 3 measurements presented in this article: acetabular abduction angle, anteversion angle, and S/TL ratio. Nevertheless, it is evident that the web tool presented in this study is accurate as compared to manual human annotations. With these preliminary results, there now exists a groundwork to warrant further data collection with this web tool over a larger and more diverse sample. Moreover, an artificial intelligence model may be applied to the dataset to enable automatic collection of the 3 measurements without requiring any human annotation. As of now, only 1 research group has developed a deep learning tool to calculate just the inclination and anteversion angles on postoperative radiographs [13,14]. The current web tool allows for the measurement of acetabular component angles in the intraoperative setting, and in the future adapted to be compatible with hand-held devices and digital imaging and communication in medicine viewers to streamline the angle acquisition process.

The main limitation of this study is the small sample size. Additionally, while the web tool is not difficult to use, it does require proper training to ensure automatic measurement is accurate and precise. Moreover, manual annotations, especially for anteversion, are subject to inaccuracies. To better validate the accuracy of the web tool, future comparisons with more precise methods, such as computed tomography–based measurements, would be useful. Nonetheless, the results reported here indicate that the web tool works well.

## Conclusions

This study successfully validated an automated web tool for measuring the acetabular abduction and calculated anteversion angle. The web tool is more accurate than currently published automatic tools and helps to eliminate interobserver differences that arise with manual annotation. This novel web tool has the power to streamline evaluation of the acetabular component.

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## Conflicts of interest

Eli Kamara is in the Journal of Arthroplasty Editorial Board and is a committee member of American Association of Hip and Knee Surgeons and American Academy of Orthopedic Surgeons. All other authors declare no potential conflicts of interest.

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## CRediT authorship contribution statement

**Christine Yoon:** Writing – review & editing, Writing – original draft, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Anna Eligulashvili:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Zeynep Seref-Ferlengez:** Data curation. **Barlas Goker:** Writing – review & editing, Validation, Data curation. **Eli Kamara:** Writing – review & editing, Validation, Supervision, Data curation. **Edward Mardakhaev:** Validation, Supervision, Data curation.

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