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Original Research

Correlation of Acetabular Cup Placement Angles Between an Artificial Intelligence-Powered System Using a Smartphone and Human Measurements

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A R T I C L E I N F O

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Background: An automated measurement system for the placement angles of acetabular cup in total hip arthroplasty prostheses was developed utilizing artificial intelligence (AI) algorithms. The AI-powered system enables immediate measurement by capturing an anteroposterior pelvic X-ray through a smartphone camera.
Methods: While developing the AI-powered measurement system, we trained AI utilizing 100 labeled anteroposterior pelvic X-rays to recognize the hip joint and 483 labeled anteroposterior pelvic X-rays to identify anatomical landmarks and the acetabular cup. To validate the AI-powered system, we measured the acetabular cup placement angles of 126 unlabeled post-total hip arthroplasty anteroposterior pelvic X-rays with both the AI-powered system and conventional measurement methods and assessed the correlation between the 2 methods.
Results: The Pearson's correlation coefficients for the acetabular cup placement angles measured using the AI-powered system and conventional method were 0.88 (95% confidence interval, 0.84-0.92, $P < .001$) in inclination angle and 0.76 (95% confidence interval, 0.67-0.83, $P < .001$) in anteversion angle, respectively.
Conclusions: Both inclination and anteversion angles measured using the AI-powered system showed a strong correlation with angles obtained through conventional methods.

Introduction

The placement angles of the acetabular cup play a significant role in determining the outcomes of total hip arthroplasty (THA) [1]. Most commonly, inclination and anteversion angles of the acetabular cup are measured using an anteroposterior pelvic X-ray [2-4]. Since accurately measuring these angles through X-ray is crucial for evaluating the surgery, there has been high anticipation for the development of quick and precise measurement methods.

Rapid object detection has become achievable with artificial intelligence (AI), and there is a rising trend in studies employing this technology for detecting objects in X-ray images [5-7]. We have created a system powered by AI that streamlines the measurement of cup inclination and anteversion angles by capturing X-ray images using a smartphone camera (Fig. 1). Our system (Hip Scouter) can be freely downloaded onto any smartphone, and there are no maintenance costs. The objective of this study is to verify the hypothesis that the measured values of the acetabular cup placement angles obtained through our AI-powered system correlate with those obtained through traditional measurement methods.

Material and methods

We performed this study following institutional review board approval.

Development of the AI-powered measurement system for acetabular cup placement angles

We developed a THA prosthesis recognition and measurement system based on the You Only Look Once version 5 (YOLOv5) object detector. YOLO is an AI algorithm designed for computer vision

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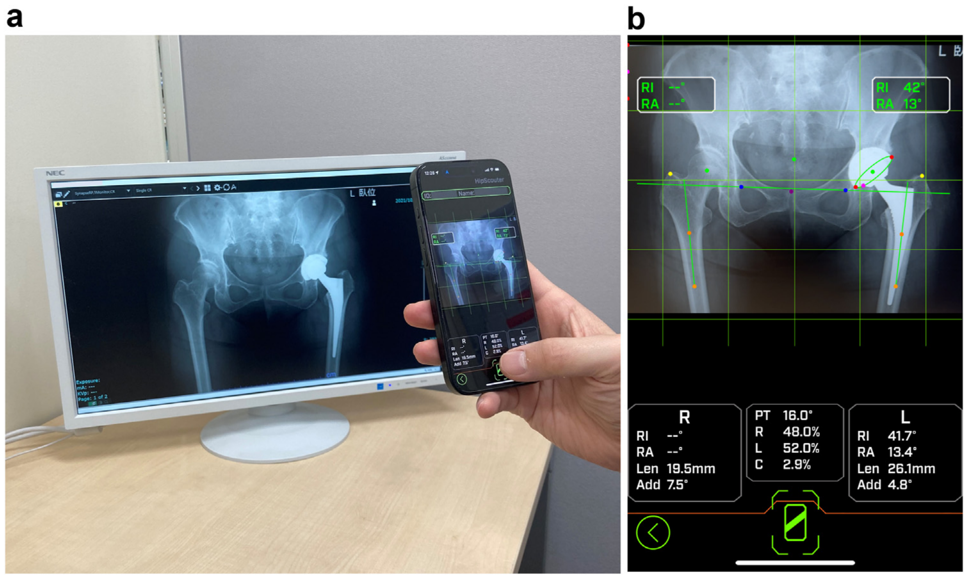

Figure 1. AI-powered system for the immediate measurement of acetabular cup placement angles by capturing X-ray with a smartphone camera. (a) The inclination and anteversion angles of the acetabular cup of THA are measured by capturing postoperative pelvic X-ray images using a smartphone camera. (b) Screenshot image of figure 1a.

tasks [8]. Our AI-powered system can automatically measure the placement angles of the acetabular cup by capturing a post-THA anteroposterior pelvic X-ray through a smartphone camera.

As anteroposterior pelvic X-ray is used to measure the acetabular cup placement angles [2-4], it is crucial for the AI-powered measurement system to identify that the captured image corresponds to an anteroposterior pelvic X-ray. To achieve this recognition, we trained the system using 100 labeled anteroposterior pelvic X-rays (Fig. 2), which were extracted from those of patients attending the hip joint outpatient clinic. The anteroposterior pelvic X-rays were centered over the superior margin of the pubic symphysis. The target for the central X-ray beam was over the superior margin of the pubic symphysis. These X-rays encompassed patients who have and have not undergone THA and were taken in both supine and standing positions. Additionally, X-rays from other sites, like the lumbar spine and knee joints, were included as labeled data during the training process for enhanced accuracy. The application is designed to automatically crop only the hip joints, eliminating extraneous details when the photo is recognized as an anteroposterior pelvic X-ray. In simpler terms, irrelevant information in the photo, such as monitor icons or surrounding scenery, is automatically removed (Fig. 1B).

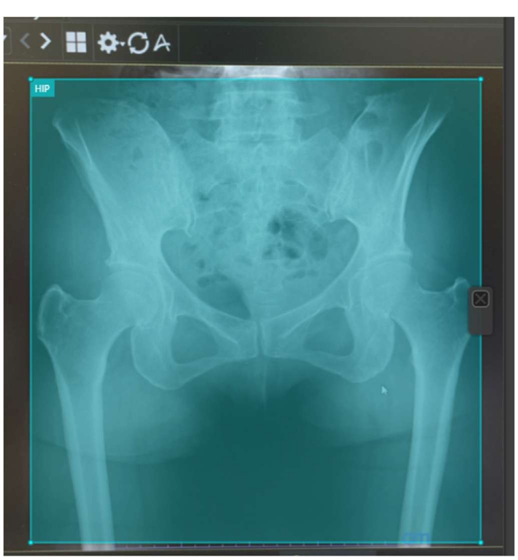

Figure 2. Supervised learning using labeled anteroposterior pelvic X-rays to teach AI that the images depicted in X-rays are pelvic X-rays. The AI was trained to automatically exclude parts other than the pelvis and crop only the pelvic region.

Subsequently, our system underwent training to identify crucial anatomical landmarks, utilizing 483 anteroposterior pelvic X-rays with provided labels (Fig. 3). These X-rays encompassed hips with various conditions, including healthy and arthritic hips, with and without THA prostheses, and were captured in both supine and standing positions. No adjustments were made for pelvic tilt during the pelvic X-rays, such as aligning the anterior pelvic plane of the patient parallel to the X-ray cassette. These labels contained positional details of bilateral tear drops and the acetabular cup margin, essential for determining acetabular cup placement angles. Through recognizing the positions of the teardrops and the acetabular cup's rim, our system autonomously computes inclination and anteversion angles. The calculation of placement angles follows the way reported by Liaw et al. [4]

Validation of the AI-powered measurement system for acetabular cup placement angles

To validate the effectiveness of our AI-powered measurement system, we examined the correlation between placement angles measured by our system and those determined by humans using conventional measurement methods as the gold standard. We measured 126 unlabeled post-THA pelvic X-rays taken with patients in supine position. All THAs were performed using a hemispherical acetabular cup. Among the 126 patients, diagnoses for THA were distributed as follows: 79 patients of secondary osteoarthritis resulting from developmental dysplasia of the hip (1 of whom had a history of the rotational acetabular osteotomy), 29 patients of primary osteoarthritis, 7 patients of femoral neck fractures, 6 patients of avascular necrosis of the femoral head, 4 patients of rapidly destructive coxarthrosis, and 1 patient of

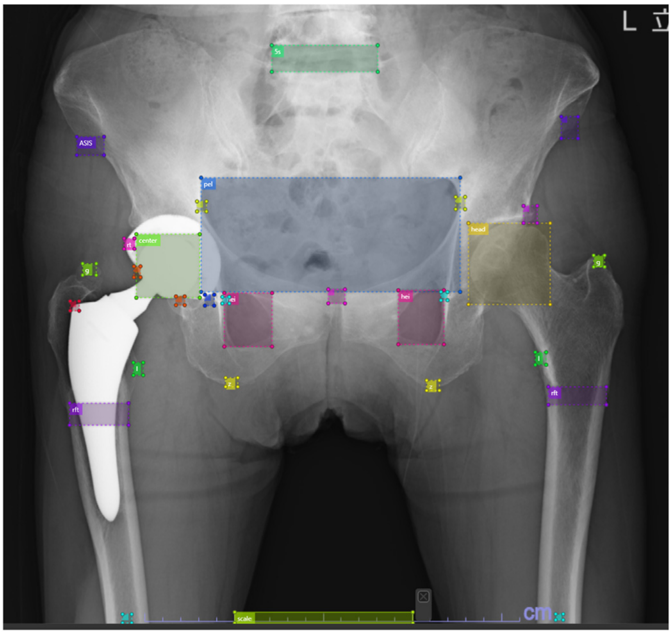

Figure 3. Supervised learning using labeled anteroposterior pelvic X-rays to identify anatomical landmarks and THA prosthesis. The AI was trained using X-rays labeled by humans to automatically detect the essential landmarks necessary for measurement.

rheumatoid arthritis. Twelve of the 126 patients had a THA prosthesis in the contralateral hip at the time of X-ray imaging.

Each pelvic X-ray was independently measured by 2 assessors using both conventional measurement methods and those measured using our AI-powered system. We used computer software (Two-Dimensional Template; Kyocera) to measure inclination and anteversion angles as traditional measurements [9]. First, we anonymized patient names in the hospital's Picture Archiving and Communication System and exported post-THA pelvic X-rays as JPEG data on a CD-R. After transferring this data to a computer with the measurement application, we manually drew a teardrop line by positioning the cursor on the bilateral teardrops on the computer screen and adjusting an ellipse to the rim of the acetabular cup. When utilizing our AI-powered system to measure acetabular cup angles, we captured X-rays from the electronic medical record screen using a smartphone camera (Fig. 1).

Statistical analysis

For validation of the AI-powered measurement system, we used the Pearson's correlation test to assess the correlations between the acetabular cup placement angles measured using our automated THA prosthesis measurement system and those measured using conventional computer software. The Pearson's correlation coefficients were interpreted as follows: <0.1, negligible correlation; 0.1-0.39, weak correlation; 0.4-0.69, moderate correlation; 0.7-0.89, strong correlation; and >0.9, very strong correlation [10]. Additionally, we computed the absolute values of differences between the measurements obtained from the AI-powered system and those from human assessment.

To test interobserver reliability, the intraclass correlation coefficients (ICCs) of postoperative measurements of the cup inclination and anteversion angles using X-rays were calculated for 2 assessors. Furthermore, we evaluated the absolute values of the differences between the measurements obtained by the 2 assessors.

All statistical analyses were performed with R software version 4.2.2. (The R Foundation for Statistical Computing, Vienna, Austria).

Results

The Pearson's correlation coefficients for the acetabular cup placement angles measured using conventional computer software as the gold standard and the acetabular cup placement angles measured using our AI-powered system were 0.88 (95% confidence interval [CI], 0.84-0.92, $P < .001$) in inclination angle and 0.76 (95% CI, 0.67-0.83, $P < .001$) in anteversion angle, respectively (Figs. 4 and 5). The mean absolute values of differences between AI-powered system and human measurements were 1.5 ± 1.2 degree (95% CI, 1.3-1.7) in inclination and 2.9 ± 1.8 degree (95% CI, 2.6-3.2) in anteversion, respectively.

ICCs between the 2 assessors for measurement of acetabular cup placement angles using our AI-powered system were 0.91 (95% CI, 0.88-0.94) in inclination and 0.82 (95% CI, 0.75-0.87) in anteversion, respectively. The mean absolute values of differences between 2 assessors were 1.4 ± 1.0 degree (95% CI, 1.2-1.6) in inclination and 2.6 ± 1.9 degree (95% CI, 2.3-3.0) in anteversion, respectively.

Discussion

We have developed an AI-powered system that allows for the immediate measurement of cup placement angles by capturing postoperative X-ray images with a smartphone camera. Both inclination and anteversion angles measured using our system showed a strong correlation with angles obtained through conventional methods (0.88 and 0.76, respectively).

The use of AI in healthcare is rapidly progressing, with numerous studies reporting its application in THA [11]. AI-powered systems in THA have frequently focused on predicting surgical outcomes [12]. In recent years, there have been a growing number of studies incorporating AI-based image recognition technology into the field of THA [6,7]. The early reports of AI-based image recognition technology in THA were studies that used a mechanism similar to accurately distinguishing between dogs and cats through

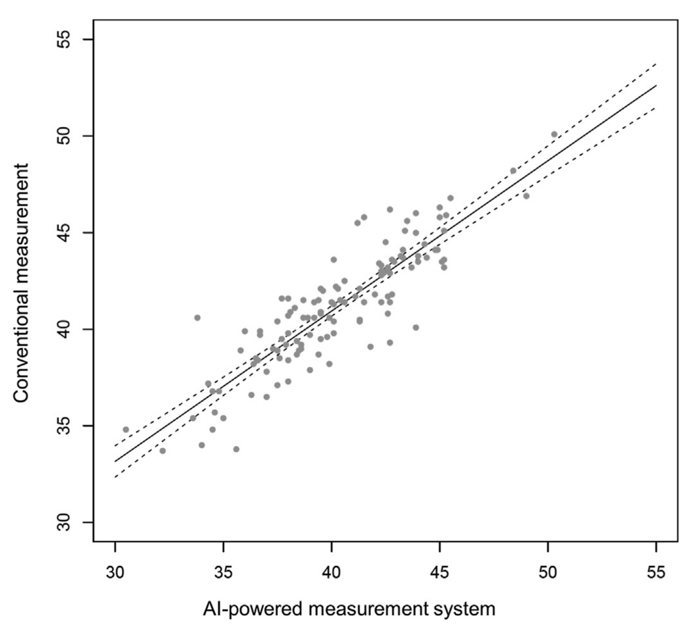

Figure 4. Correlation of inclination angles between the AI-powered measurement system and conventional method. The Pearson's correlation coefficient was 0.88 (95% CI, 0.84-0.92, $P < .001$).

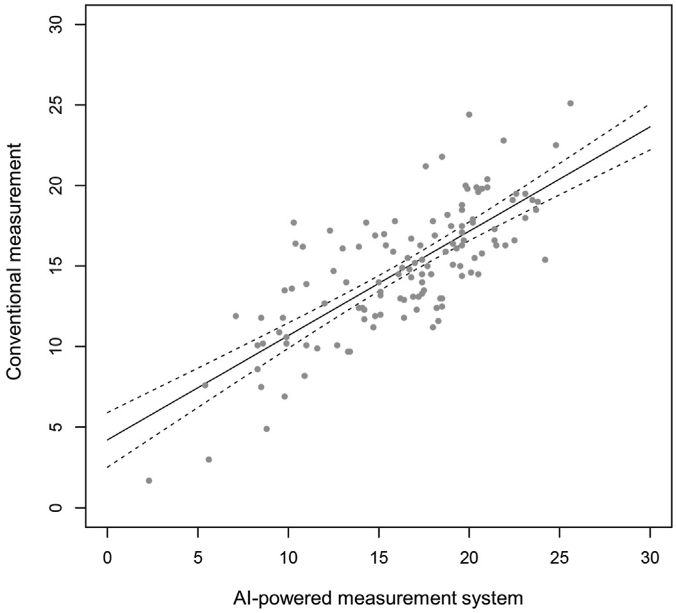

Figure 5. Correlation of anteversion angles between the AI-powered measurement system and conventional method. The Pearson's correlation coefficient was 0.76 (95% CI, 0.67-0.83, $P < .001$).

deep learning to identify the femoral stems employed in THA [6]. More recently, AI algorithms including YOLO can identify specific regions, such as the dog's eye, in X-ray images by training on distinctive features [7]. In this study, teardrops and the acetabular cup are representative of such features. Through the application of this technology, we have successfully developed a system that allows measurements with just a smartphone camera. To the best of our knowledge, this system is the first to enable the measurement of cup placement angles solely through capturing an X-ray image with a smartphone camera.

This study focused on the correlation of the measurement values derived from our AI-powered system and those obtained from human measurements. Hence, it is impossible to ascertain whether human measurement or the AI-powered system is more accurate due to the study design. Other AI-powered systems have been developed to either correct pelvic tilt or discern whether the acetabular cup is in anteversion or retroversion solely from anteroposterior pelvic X-rays [7]. These systems hold the potential to offer more precise measurements than human assessment and to replace the conventional method.

The anteversion angle exhibited a higher degree of discrepancy compared to the inclination angle in both the Pearson's correlation coefficients between AI-powered system measurements and human measurements, as well as in the ICCs between 2 assessors. This disparity may be associated with inherent challenges in measuring anteversion. Inclination angle is measured by connecting distinct points: the upper and lower edges of the cup. In contrast, anteversion angle is calculated by fitting an ellipse to the rim of the acetabulum. The shorter distances involved in the diameter of the ellipse, particularly in the short axis, make it more susceptible to errors.

We must note some limitations. First, this study was conducted at the institution where the developer of the system has been affiliated. However, the developer was not involved in the X-ray measurements in this study. Nevertheless, for further validation, it is advisable to include a larger number of assessors in the verification process. Second, all THAs were performed using a hemispherical acetabular cup. While the hemispherical shape has been the most commonly used, our measurement results may not apply to cups with different shapes.

Conclusions

The measured values of the acetabular cup placement angles obtained through our AI-powered system showed a strong correlation with those obtained through traditional measurement methods.

Conflicts of interest

S. Tsukada certifies receipt of personal payments during the study period in an amount of less than USD 10,000 from Zimmer-Biomet Japan and Stryker Japanan and is an editorial board member of the Journal of Orthopaedic Science. All other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2024.101439.

CRediT authorship contribution statement

Sachiyuki Tsukada: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hiroyuki Ogawa:** Writing – original draft, Conceptualization. **Masayoshi Saito:** Writing – original draft. **Naoyuki Hirasawa:** Writing – original draft, Supervision.

References

[1] Widmer KH, Zurfluh B. Compliant positioning of total hip components for optimal range of motion. J Orthop Res 2004;22:815–21.
[2] Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 1978;60:217–20.
[3] Widmer KH. A simplified method to determine acetabular cup anteversion from plain radiographs. J Arthroplasty 2004;19:387–90.
[4] Liaw CK, Yang RS, Hou SM, Wu TY, Fuh CS. Measurement of the acetabular cup anteversion on simulated radiographs. J Arthroplasty 2009;24:468–74.
[5] Karnuta JM, Shaikh HJF, Murphy MP, Brown NM, Pearle AD, Nawabi DH, et al. Artificial intelligence for automated implant identification in knee arthroplasty: a multicenter external validation study exceeding 3.5 million plain radiographs. J Arthroplasty 2023;38:2004–8.
[6] Murphy M, Killen C, Burnham R, Sarvari F, Wu K, Brown N. Artificial intelligence accurately identifies total hip arthroplasty implants: a tool for revision surgery. Hip Int 2022;32:766–70.
[7] Murphy MP, Killen CJ, Winfrey SR, Schmitt DR, Hopkinson WJ, Wu K, et al. Artificial intelligence autonomously measures cup orientation, corrects for pelvis orientation, and identifies retroversion from antero-posterior pelvis radiographs. J Arthroplasty 2023;38(Suppl 2):S319–23.
[8] Diwan T, Anirudh G, Tembhurne JV. Object detection using YOLO: challenges, architectural successors, datasets and applications. Multimed Tools Appl 2023;82:9243–75.
[9] Tsukada S, Ogawa H, Hirasawa N, Nishino M, Aoyama H, Kurosaka K. Augmented reality- vs accelerometer-based portable navigation system to improve the accuracy of acetabular cup placement during total hip arthroplasty in the lateral decubitus position. J Arthroplasty 2022;37:488–94.
[10] Schober P, Boer C, Schwarte LA. Correlation coefficients: appropriate use and interpretation. Anesth Analg 2018;126:1763–8.
[11] Myers TG, Ramkumar PN, Ricciardi BF, Urish KL, Kipper J, Ketonis C. Artificial intelligence and orthopaedics: an introduction for clinicians. J Bone Joint Surg Am 2020;102:830–40.
[12] Lopez CD, Gazgalis A, Boddapati V, Shah RP, Cooper HJ, Geller JA. Artificial learning and machine learning decision guidance applications in total hip and knee arthroplasty: a systematic review. Arthroplast Today 2021;11:103–12.