Accuracy and Reliability of Combining a Smartphone and a Digital Angle Ruler Technique to Assist Acetabular Cup Placement: A Pelvic Model Study

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Objective: *To examine the accuracy and reliability of a method that used a smartphone and a digital angle ruler for improving the acetabular cup placement in a pelvic model.*

Materials and Methods: *An experimental study was conducted in a plastic pelvic model. During the cup placement at the target of radiographic inclination (RI) 40º and anteversion (RA) 15º verified by the Orthopilot navigation system, 3 orthopedic surgeons simultaneously assessed the cup orientation by a smartphone application for the anteversion and a digital angle ruler for the inclination. The surgeon-measured angles were calculated into the RI and RA values by Murray's equation; and then used to compare with the target angle by the navigation system.*

Results: *The mean RI and RA angles from the 3 surgeons were 40.08º ± 2.15º and 11.01º ± 0.35º, respectively. The mean differences between the RI and RA angles from the navigation system and those calculated from the combined devices were 0.80º ± 2.15º (-3.10º to 5.3º) and -3.98º ± 0.35º (-4.60º to -3.30º), respectively. Both intra-tester and inter-tester reliabilities were good to excellent in the assessment of the cup RI and RA.*

Conclusion: *Use of smartphone application combined with a digital angle ruler could provide a high accuracy of acetabular cup positioning, especially for the inclination angle.*

Keywords: *Accuracy, Reliability, Smartphone, Digital angle ruler, Acetabular cup placement*

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Introduction

Mal-positioning of the prosthesis after total hip arthroplasty (THA) can lead to an increased risk of postoperative complications, such as prosthetic impingement, dislocation, restricted range of motion, polyethylene wear, and loosening[1-3]. Hence, the initial prosthesis positioning with accuracy and reproducibility is crucial to prevent these complications and achieve the long-term survival of implants. Moreover, desirable cup positioning cannot always be achieved by the conventional technique using the mechanical alignment guides. To address this, computer navigation has been introduced in orthopedics with many studies showing improved accuracy of implant placement[4-8]. The Orthopilot imageless navigation system (Aesculap, Tuttlingen, Germany) has been used for the improvement of acetabular cup orientation during THA in the author's institute since 2014. There have been some drawbacks that limit its wide utilization, such as the costs, increased operative time, need for more space in the operating room and potential complications from the insertion of tracker pins.

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According to a study by Peter et al[9], the use of a relevant smartphone application could offer some potential benefits in acetabular cup positioning. Similarly, Kurosaka et al[10] demonstrated, in a cadaveric experiment that by utilizing an iPhone/iPad technique, it was possible to achieve an acceptable performance in determining cup alignment in THA regardless of the surgeon's expertise. Nevertheless, the mentioned studies[9, 10] were performed in the lateral decubitus position, which differed from the author's preferred position and approach. Another potential disadvantage was the difficulty to simultaneously measure both the inclination and anteversion. It was highly challenging in the real clinical practice to observe the measurement results from the two different devices (i.e., the iPhone and iPad) while the surgeons were adjusting the cup alignment with the cup holder. Likewise, both inter-tester and intra-tester reliabilities were relatively low in the assessment of acetabular cup anteversion.

With the increasing accessibility to smartphones and other gadgets in the medical field, particularly in orthopedic surgery[11, 12], the authors developed a new technique that combined the use of a smartphone and a digital angle ruler in assisting the placement of acetabular cup. The purpose of this study was to examine the accuracy and reliability of this technique in comparison to the corresponding measurements obtained from the Orthopilot navigation system in a pelvic model.

The hypothesis of this study was that the combined use of a smartphone and a digital angle ruler could provide acceptable accuracy and good to excellent reliability in assisting the placement of acetabular cup in a pelvic model.

Materials and Methods

Two free smartphone applications; Smart Protractor by ExaMobile S.A. and The Best Level by Netigen Kluzowicz sp.j, were downloaded onto the smartphone (iPhone 6S) from the Apple Application Store. Both applications utilized the smartphone's built-in accelerometer to detect motion and showed the angles in which the smartphone had been moved.

Fig.1 The pelvic model was positioned and fixed firmly in the supine position on a flat table. The Orthopilot imageless navigation system was located on the opposite side.

The pelvic model in this study was positioned and fixed firmly in the supine position on a flat table. A triangular-shaped plastic corriboard was placed on the bilateral anterosuperior iliac spines (ASISs) and the superior border of the pubic symphysis to represent the anterior pelvic plane (APP) (Fig.1). The table and the APP were adjusted to zero degree of tilting in all directions by using the Best Level application (Figs. 2).The APP was considered to be parallel to the floor and the influence of pelvic tilting could be discarded (Fig. 3). The inclination and anteversion angles of interest were measured in the following steps.

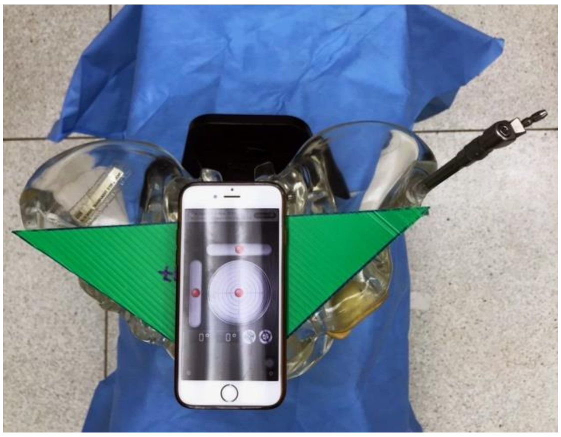

Fig.2 The pelvic model was positioned in the anterior pelvic plane by adjusting to zero degree of tilting in all directions, verified by using the Best Level application.

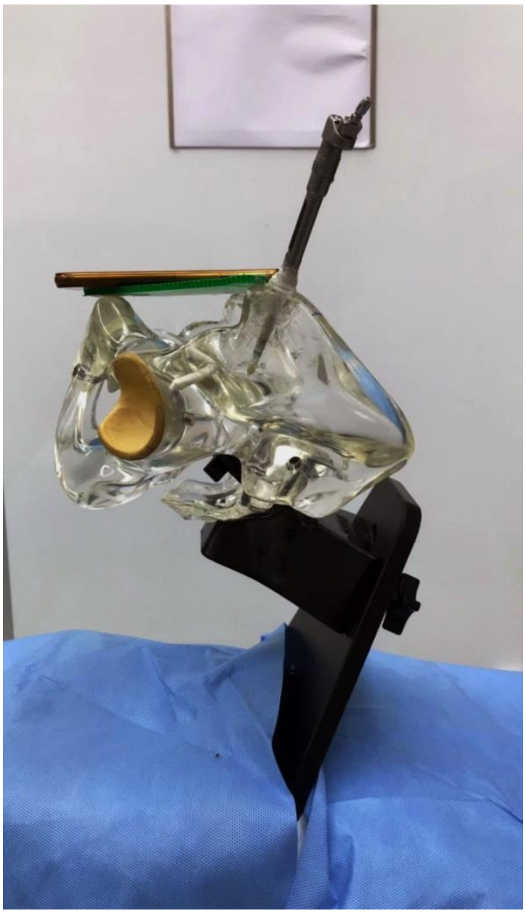

Fig.3 The anterior pelvic plane was parallel to the floor.

Step 1: Assessment of cup placement using the navigation system

The bilateral ASISs and the upper margin of the pubic symphysis of the pelvic model were registered as the anatomical landmarks to the Hip suite: THA Plus with cup only workflow of the Orthopilot imageless navigation system to create the reference plane for analysis. The radiographic inclination (RI) and anterversion (RA) angles obtained from the navigation system were measured in relation to this reference plane. A 50-mm diameter trial cup was inserted to the acetabulum of this pelvic model.

Step 2: Cup placement using the combined smartphone and digital angle ruler technique

The operative inclination (OI) of the acetabular cup was measured by using a 300-mm digital angle ruler (Shahe com, ltd. China), whereas the Smart Protractor application from the smartphone measured the operative anteversion (OA). Initially, both arms of the ruler were aligned with the base of the triangular-shaped plastic corriboard that connecting the bilateral ASISs and calibrated the angle at 0º. One arm of the ruler was then realigned to be parallel with the handle of the cup holder (Fig. 4). The measured angle was subtracted from 90° to represent the OI angle. At the same time, the smartphone was placed on top the cup holder to measure the OA angle (Fig. 5).

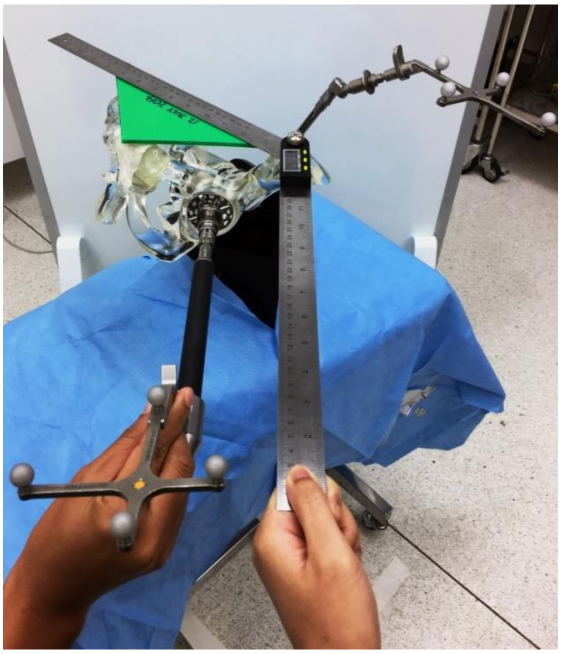

Fig. 4 To measure the operative inclination, one arm of the digital angle ruler was aligned with the base of the triangular-shaped plastic corriboard that represented the line connecting both anterior superior iliac spines, while the other arm was realigned with the cup holder.

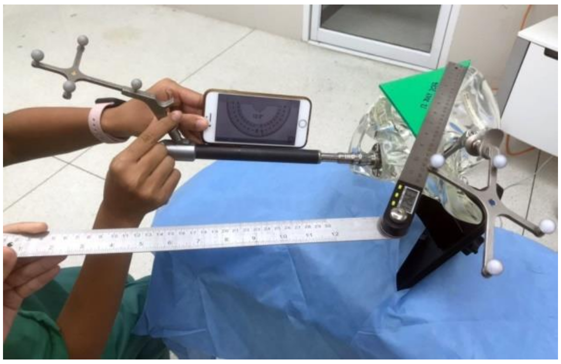

Fig.5 A smartphone with the Smart Protractor application was used for operative anteversion measurement by placing the phone on top the cup holder.

Step 3: Comparison of the combined smartphone and digital angle ruler technique, and the navigation assessment results

During each cup placement using the navigation system, cup orientation was assessed simultaneously by using the combined smartphone and digital angle ruler technique. The target angles from Orthopilot were set at 40º for RI and 15º for RA. The angles were measured by 3 orthopedic surgeons with different experiences in navigated hip replacement. The first surgeon (Dr1, CU) was senior staff with more experience in navigated THAs. The second surgeon (Dr2, TA) was junior staff with some experience in navigated THAs and the third surgeon (Dr3, SS), another senior staff, but with less experience in navigated THAs. Each surgeon performed the measurement twice a day in ten different days. Each attempt of the measurement in the same day would be separated at least three to four hours gap to minimize muscle memory and bias. The average value of each measurement for both OI and OA were used for data analysis. Therefore, ten sets of alignment data were collected by each surgeon.

Definition of acetabular orientation

The Orthopilot navigation system computed the acetabular orientation by RI and RA angles in relation to the APP. Thus, the OI angle from the digital angle ruler and the OA from the smartphone must be converted to RI and RA angles by using a formula proposed by Murray [13] before its comparison as follow.

$$RI = \arctan(\tan[OI] / \cos[OA])$$

$$RA = \arcsin(\sin[OA] \times \cos[OI])$$

Statistical analysis

Statistical analysis was performed by using SPSS version 20.0 software (SPSS Inc, Chicago, Illinois). The mean and standard deviation (SD) of all measurements were calculated and analyzed. Paired t-test was calculated to compare the difference in inclination and anteversion angles among the three surgeons. A *p*-value less than 0.05 was considered statistically significant. The intra-tester and inter-tester reliabilities were assessed with intraclass correlation coefficients (ICCs). The authors used the two-way random effects model with absolute agreement type for the ICC calculation.

Results

The target orientation of the acetabular cup measured from the navigation system was set at RI 40º and RA 15º. The mean RI angles measured by Dr1, Dr2, and Dr3 were 40.82º ± 2.51º, 40.63º ± 1.96º and 40.97 º± 2.03º, respectively. The mean RA angles measured by Dr1, Dr2, and Dr3 were 10.98º ± 0.37º, 11.0º ±.40º and 11.04º ± 0.29º, respectively. The mean calculated RI and RA angles of all three surgeons were 40.80º ± 2.15º and 11.01º ± 0.35º, respectively. There was no significant difference in both RI and RA among the three surgeons (Table 1).

The absolute discrepancy among the two techniques calculated from the data of all three surgeons for the RI was 0.80º ± 2.15º (-3.10º to 5.3º) and RA was -3.98º ± 0.35º (-4.60º to -3.30º). The discrepancy within 3º was found in 24 of 30 (80%) measurements for RI but 0% for RA. However, when the acceptable discrepancy values were extended to 5º or less, all 30 measurements for RA (100%) were within this range.

With regards to the intra-tester reliability, the ICCs of the RI angle were 0.996 for Dr1, 0.839 for Dr2, and 0.774 for Dr3, while the ICCs of the RA angle were 0.913 for Dr1, 0.905 for Dr2, and 0.897 for Dr3. The inter-tester reliability indicated an ICC of 0.949 (95% CI 0.894 – 0.978) for RI and 0.933 (95% CI 0.859 – 0.971) for RA.

Table 1 The calculated RI and RA from the OI and OA that had been measured by the combined smartphone and digital angle ruler technique, comparing between 3 surgeons at the same target of RI 40º and RA 15º from computer navigation.

	Radiographic inclination (º) mean±SD	***P*-value**	**Radiographic anteversion (º) mean±SD**	***P*-value**
Dr1	40.82 ± 2.51	0.465	10.98 ± 0.37	0.708
Dr2	40.63 ± 1.96		11.00 ± 0.40	
Dr1	40.82 ± 2.51	0.606	10.98 ± 0.37	0.186
Dr3	40.97 ± 2.03		11.04 ± 0.29	
Dr2	40.63 ± 1.96	0.124	11.00 ± 0.40	0.423
Dr3	40.97 ± 2.03		11.04 ± 0.29	

Discussion

The navigation system has been shown to be effective in achieving more consistent acetabular cup alignment in comparison conventional procedures using the mechanically guided instruments(14-16). In a study by Fukunishi et al(14), the authors examined the accuracy of an image-free navigation system in determining prosthetic alignment in reference to the results of CT evaluation and showed that the mean differences between the intraoperative navigation and postoperative CT measurement values were 1.2º for inclination and 2.3º for anteversion, which represented a good agreement. However, there were some major drawbacks with the navigation system that hindered its popularity such as the higher costs, longer operative time, the need for more space in the operating room, a longer learning curve, and possible complications from insertion of the tracker pins.

Currently, smartphones and associated applications have become widely available and easily accessible. Smartphone applications can provide real-time measurements by using the built-in accelerometer functions. In 2012, Peter et al(9) reported the intraoperative use of smartphone technology in THAs for improving of the accuracy of acetabular cup placement. All implanted cups could be placed within the Lewinnek safe zone. In 2016, Kurosaka et al(10) studied the accuracy and reliability of acetabular cup placement using an iPhone/ iPad system compared with the reference values obtained from the image-free navigation system in a cadaveric experiment. They showed that the system could achieve an acceptable performance in THA regardless of the surgeon's expertise. However, the assessment for anteversion has been found to be less favorable due to difficulty in determining the reference plane of 0°anteversion in lateral decubitus position that was dependent on the alignment of the pelvis and back. Moreover, the difficulty in assessing both inclination and anteversion with two different devices (iPhone and iPad) simultaneously while adjusting the cup holder should be expected. These findings were quite different from those found in the technique reported herein.

There have been some studies on the accuracy of smartphone in assisting acetabular cup positioning. Kurosaka et al[10] demonstrated that the mean absolute discrepancy of 2.1º for inclination and 1.6º for anteversion compared with the navigation results. Sukapan H [18] demonstrated that combining of smartphone and alignment guide could significantly reduce error of RI from1.3º-2.5º to 0.1º-0.6º and RA from 9.4º-10.7º to7.4º-9.9º. The analytical results of the present study showed an acceptable accuracy of the combined smartphone and digital angle ruler technique, with a mean discrepancy of less than 1° for RI and less than 4° for RA as compared to the navigation system. There was a substantial error in the anteversion measurement according to the authors' technique. This error could theoretically be corrected by adding 3º-5º for OA from the smartphone during the real operation in order to achieve the target angles within the Lewinnek safe zone.

This study had some limitations. This was an *in vitro* condition in which the pelvic model had a normal pelvic anatomy without any anatomical deviances. The effects of pelvic obliquity or tilting were not included in the study. Moreover, the good to excellent reliability for the assessment of cup inclination and anteversion found in this study might be impacted by the surgeon's expertise in navigation-assisted THA. However, this technique might be useful for surgeons with varying skillsets or those who preferred to perform THAs in the supine position. This pilot study can lead to further clinical study to validate its accuracy in the real clinical practice.

Conclusion

The combination of a relevant smartphone application and digital angle ruler technique could assist the acetabular cup positioning with acceptable accuracy, especially for the inclination angle. This technique is considerably less invasive, less time-consuming, and less costly than other sophisticated technology approaches, such as the computer navigation.

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Potential conflicts of interest

None

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การศึกษาถึงความถูกต้องและความน่าเชื่อถือในการใช้สมาร์ทโฟน ร่วมกับ ไม้บรรทัดวัดมุมแบบดิจิทัล เพื่อช่วยในการตั้งเบ้าข้อสะโพกเทียม : การศึกษาบนแบบจำลองกระดูกเชิงกราน

เจริญวัฒน์ อุทัยจรัสรัศมี, พบ, สมบูรณ์ สหจารุพัฒน์, พบ, ธีรภัทร อดุลยธรรม, พบ

วัตถุประสงค์: เพื่อศึกษาถึงความถูกต้องและความน่าเชื่อถือของวิธีการใช้ สมาร์ทโฟนร่วมกับไม้บรรทัดวัดมุมแบบดิจิทัล เพื่อช่วยปรับปรุงการตั้งเบ้าข้อสะโพกเทียม โดยเป็นการศึกษาบนแบบจำลองกระดูกเชิงกราน

วัสดุและวิธีการ: การทดลองนี้ทำบนแบบจำลองกระดูกเชิงกรานพลาสติก โดยที่จะตั้งเบ้าข้อสะโพกเทียมไว้คงที่ที่มุม Radiographic inclination 40 องศาและ Radiographic anteversion 15 องศา โดยอาศัยเครื่องคอมพิวเตอร์นำวิถี ในขณะเดียวกันก็จะให้ศัลยแพทย์ออร์โธปิดิกส์ 3 ท่านทำการทดลองโดยใช้ไม้บรรทัดวัดมุมแบบดิจิทัลและสมาร์ทโฟน เพื่ออ่านค่าของมุม inclination และ anteversion ของเบ้าสะโพกเทียมที่ตั้งเอาไว้แล้ว และค่าของมุมที่วัดได้จากการทดลองจะต้องได้รับการปรับให้เป็นค่าของมุม radiographic inclination และ anteversion ตามสมการที่ Murray และคณะได้ทำการศึกษาเอาไว้ ก่อนที่จะนำข้อมูลดังกล่าวมาเปรียบเทียบกับข้อมูลที่ได้จากเครื่องคอมพิวเตอร์นำวิถี

ผลการศึกษา: ค่าเฉลี่ยของมุม Inclination และ Anteversion ที่วัดโดยวิธีที่ศึกษา คำนวณเฉลี่ยจากแพทย์ทั้ง 3 คนมีค่า 40.80 ± 2.15 องศา และ 11.01 ± 0.35 องศา และค่าความแตกต่างของมุม Inclination และ Anteversion เปรียบเทียบกับมุมที่วัดด้วยเครื่องคอมพิวเตอร์นำวิถี คำนวณเฉลี่ยจากแพทย์ทั้ง 3 คนมีค่า 0.80 ± 2.15 (-3.10 to 5.3) องศา และ -3.98 ± 0.35 (-4.6 to -3.30) องศาตามลำดับ ส่วนค่าความน่าเชื่อถือทั้ง Intra-tester และ Inter-tester reliabilities อยู่ในระดีบดีถึงดีมาก สำหรับการประเมินค่าของมุม Inclination และ Anteversion

สรุป: การใช้ไม้บรรทัดวัดมุมแบบดิจิทัลร่วมกับแอพพลิเคชั่นจากสมาร์ทโฟนเพื่อช่วยในการตั้งเบ้าข้อสะโพกเทียมบนแบบจำลองกระดูกเชิงกราน สามารถให้ค่าความถูกต้องในระดับที่สูงโดยเฉพาะการตั้งค่ามุม inclination ของเบ้าสะโพกเทียม