The Use of Combining a Smartphone and a Digital Angle Ruler Technique to Assist Acetabular Cup Placement: A Clinical Study

Charoenwat Uthaicharatratsame, MD, Suppawut Pruetiworanan, MD, Pracha Suebpongsiri, MD

Department of Orthopedic Surgery, Nopparat Rajathanee Hospital, Bangkok, Thailand

Purpose: *To evaluate the percentage of acetabular cups that were correctly placed within the Lewinnek safe zone and the accuracy of the combined use of a smartphone and a digital angle ruler technique in assisting the placement of the acetabular cup by comparing the intraoperative values of acetabular cup inclination and anteversion to postoperative radiographic and CT scan measurements.*

Materials and Methods: *This prospective observational study included 23 hips upon which were performed primary total hip arthroplasty through a lateral transgluteal approach in supine position. The combined use of a smartphone and a digital angle ruler technique was used for the reamers and cup positioning during acetabular reaming steps and final cup implantation. Postoperatively, a multislice CT scan was obtained at one month or later for cup anteversion measurement including a standard plain film of both hips in true anteroposterior position for cup inclination evaluation compared to the intraoperative values by using a paired t-test with a 0.05 level of significance.*

Results: *The mean radiographic inclination (RI) angle from the digital angle ruler was 42.1º (SD 2.4). The mean RI angle from the postoperative radiographic measurement was 42.2º (SD 5.3). The mean paired difference was 0.39° (SD 4.8), this difference was not significant ($p = 0.97$). The mean radiographic anteversion (RA) angle from the smartphone was 7.4º (SD 3.1).The mean RA from the postoperative CT scan was 11.9º (SD 5.9). The mean paired difference was 4.52° (SD 4.3), this difference was significant ($p< 0.05$). The percentage of cup placements in the Lewinnek safe zone was 82.61%.*

Conclusion: *The use of smartphone application combined with a digital angle ruler could provide an acceptable percentage of cup placements within the Lewennek safe zone and the inclination measurements were more accurate than the anteversion measurements.*

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

The Thai Journal of Orthopaedic Surgery: 44 No.1-2: 34-41
Received: *February 22, 2019* ***Revised:*** *March 16, 2020* ***Accepted:*** *April 6, 2020*
Full text. e journal: *http://www.rcost.or.th, http://thailand.digitaljournals.org/index.php/JRCOST*

Introduction

Malpositioning 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 (ROM), 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. Lewinnek et al(4) had defined a "safe zone" for the acetabular component placement which postulated that would decrease the incidence of prosthetic dislocation. The safe zone widely accepted by various authors is abduction or inclination (IC) of 40º ± 10º and anteversion (AV) of 15º ± 10º. These goals have been the most widely used targets for several decades although there is controversy in the literature regarding the ideal orientation.

Correspondence to: Uthaicharatratsame C, Department of Orthopedic Surgery, Nopparat Rajathanee Hospital, Bangkok, Thailand
E-mail: Charoenwat@hotmail.com

Conventional techniques rely on the mechanical alignment guides or the surgeon's experiences to estimate the cup orientation in relation to the patient's position on the operating table. The percentage of acceptably placed cups in the Lewinnek safe zone varies from 25.7% to 70.5% reported in the literature. Callanan et al(5) reported the percent of optimally positioned acetabular cups in 1,823 hips and demonstrated that 1,144 (63%) cups were within the abduction range, 1,441 (79%) were within the anteversion range and 917 (50%) were within the both range of both. However, Digioia et al(6) demonstrated that 78% of cups by using freehand technique were placed outside the safe zone. To address this, the concept of computer navigation has been introduced in orthopedics with many studies showing improved implant placement accuracy(7-11). Computer navigation can increase the percentage of cup placement in the safe zone up to 81%(12). Despite of its strong points, there were some major drawbacks with the navigation system that hindered its popularity i.e. 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.

In the last few years, the use of smartphone has become more widespread along with an increasing variety of associated applications. Smartphone applications are simple, cheap, and quick to use and can provide objective and real-time measurements using the smartphone's built-in accelerometer, protractor, and level functions. The intraoperative uses of smartphone technology in THA for improving the accuracy of acetabular cup placement were reported in a plastic pelvic model, cadaveric and clinical studies[13-19]. A point to note was that the authors of the mentioned studies performed the operation or studies in the lateral decubitus position, which differs from our preferred position and approach. In a previous study, the current author (CU) examined the accuracy and reliability of the combined use of a smartphone and a digital angle ruler in assisting the placement of the acetabular cup in a plastic pelvic model study. The results showed that, within the in vitro condition, this technique could be used to assist acetabular cup positioning with acceptable accuracy and good to excellent reliability[20]. Therefore, the authors would like to implement this technique in actual clinical practice.

The purpose of the present study was to determine the percentage of acetabular cups that were correctly placed within the Lewinnek's "safe zone" and the accuracy of the combined use of a smartphone and a digital angle ruler technique in assisting the placement of the acetabular cup by comparing the intraoperative values of acetabular cup inclination and anteversion to postoperative data from radiographic and CT scan measurement.

The hypothesis of this study was that the combined use of a smartphone and a digital angle ruler could provide acceptable accuracy in assisting the placement of the acetabular cup in actual clinical practice.

Materials and Methods

The present study was approved by the Ethic Committee of Nopparat Rajathanee Hospital. Informed consent was obtained from all patients who participated. Between June 2019 and January 2020, patients required primary total hip arthroplasty (THA) were prospectively enrolled in the present single-center study. Exclusion criteria were patients with pelvic deformity, severe kyphoscoliosis that precluded supine position and patients who refused to participate in this study. All cases were underwent THA by a single surgeon (CU) in a standardized manner, using a cementless titanium spray coated spherical pressfit cup (Plasmafit®, Aesculap, Germany) and a cementless titanium non-anatomical straight stem (Excia®, Aesculap, Germany) , brought in by the lateral transgluteal approach in supine position on the simple operating table. For the patients who were younger than 65 year old with good bone quality, the author used a non-modular short femoral stems (Metha®, Aesculap, Germany) instead of straight stems. For the bearing surfaces of all THA used in this study, the author used metal femoral head articulated with highly cross-linked polyethylene liner without lip elevation.

At first, the author made a straight lateral skin incision and exposure of the hip joint including the opening of the anterior hip capsule. The surgical procedure continued with the anterior dislocation of the hip joint, the femoral head and neck was resected and removed. The acetabulum was exposed and labrum was completely excised. During reaming procedure, the position of the reamer was acquired by the author's technique. Initially, the author started the measurement of the operative inclination (OI) by placing both arms of a 300-mm digital angle ruler (Shahe com, ltd. China) which was strictly sterilized under the protocol of the operating room parallel onto the imaginary line connecting the bilateral anterior superior iliac spines (ASISs) and set the angle of ruler at zero degree. The author then moved one arm of the digital angle rule that coincided with operated hip horizontally and caudally. The angle that was read from screen was subtracted from 90° to represent the OI angle (Figure 1). To achieve the 40º target angle of radiographic inclination (RI), the OI angle set from the digital angle ruler should be 38º. The handle of the reamer was then moved parallel to this arm of the digital angle ruler. At the same time, the smartphone (iPhone 6S) with a Smart Protractor application (ExaMobile S.A.), free to downloaded from the Apple Application Store, was enclosed in a sterile clear plastic bag and placed along the handle of the reamer to measure the operative anteversion (OA) angle. The handle of the reamer was then moved vertically until the 13º of OA was shown in the application to achieve a10º target angle of RA (Figure 2). The author chose to lessen the RA to decrease the risk of anterior hip dislocation from the author's preferred approach. However, both OI and OA could be adjusted relying on the anatomy of the acetabulum of each patient.

After reaching the suitable reaming size, the spherical cup was implanted cementless to a safe press fit in the chosen OI and OA with the same technique. The data from the digital angle ruler and smartphone after the final cup implantation was recorded and used for later analysis. The femoral canal was prepared and the femoral stem was implanted with the conventional freehand technique. The operated hip was repositioned and a hip stability test was satisfactorily completed. The skin was closed layer by layer without reparation of the anterior hip capsule. Antibiotic prophylaxis was intravenous cefazolin before skin incision and at 6 hour intervals for 48 hours. Two doses of tranexamic acid (750-1,000 mg) were given intravenously if there wasn't any contraindicate to use, one before making skin incision and the other after finishing skin closure.

A pubic symphysis-centered pelvic anteroposterior radiograph was taken in the supine position postoperatively at one month or later for radiographic inclination (RI) which was measured between the inter-tear drop line and the long axis of the projected ellipse (Figure 3). In addition, a multislice computer tomographic (CT) scan was obtained at the same time for anatomical anteversion (AA) angle measurement. The AA angle was measured by identifying the largest cup diameter in the axial or transverse plane (Figure 4). All CT scan and radiographic measurements were performed by the co-authors: Dr1 (PS) and Dr2 (SP) who were not involved in the surgery and repeated 2 weeks later. The averages of four measurements were used for data analysis.

Fig. 1 To measure the operative inclination (OI), one arm of the digital angle ruler was aligned with the imaginary line connecting both anterior superior iliac spines, while the other arm was realigned with the cup holder.

(a)

(b)

Fig. 2 (a, b) A smartphone with the Smart Protractor application was used for operative anteversion (OA) measurement by placing the phone on top the cup holder.

Fig. 3 Measurement of the radiographic inclination (RI) of the acetabular cup from a pubic symphysis-centered pelvic anteroposterior radiograph.

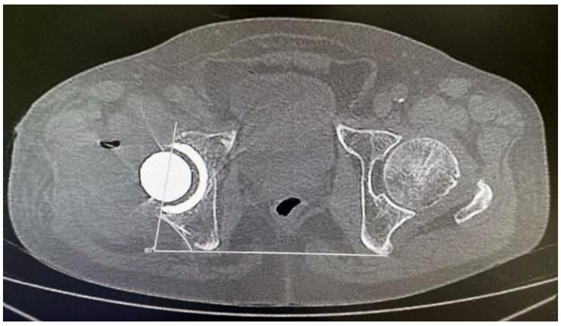

Fig. 4 Measurement of the anatomical anteversion (AA) of the acetabular cup from an axial view of CT scans both hips.

The inclination and anteversion angles of the cup measured by the author's proposed technique and from CT scan were distinctive from the definition or reference plane described by Murray[21]. In addition, Lewinnek et al[4] determined the safe zone of acetabular orientation by RI and RA angles in relation to the anterior pelvic plane (APP). Thus, the OI angle from the digital angle ruler and the OA from the smartphone including the AA angles from CT scan must be converted to RI and RA angles using a formula proposed by Murray[21] before its comparison which are as follows:

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

RA = arcsin (sin [OA] x cos [OI])

RA = arctan (tan [AA] x sin [RI])

Preoperative demographic data including patient's age, gender, body mass index (BMI) and diagnosis was recorded. The interesting outcomes were radiographic inclination (RI), radiographic anteversion (RA) and percentage of cup placement in the safe zone.

Statistical analysis

The inclination and anteversion angles measured from the author's proposed technique, pelvic anteroposterior radiographs and CT scans were compared together with *paired t*-test. A *p-value* less than 0.05 was considered statistically significant. The number of outliers was also recorded for each individual direction and as a whole. The intra-class correlation coefficients (ICCs) were calculated for intra-observer and inter-observer reliability. The author used the two-way random-effects model and absolute agreement for ICC calculation.

Results

Twenty three primary THA (from 21 patients) were included in this study. The mean age was 61.8 years (SD 10.6) and 78.26 % of the cases were female. The main diagnosis was avascular necrosis of the femoral head (ONFH) (47.82%). The mean BMI was 24.7 kg/m^2 (SD 4.1) (Table 1). There were no acute postoperative complications such as dislocation, periprosthetic fracture or infection. The mean RI angle from the digital angle ruler was 42.1º (SD 2.4). The mean RI angle from the postoperative radiographic measurement was 42.2º (SD 5.3). The mean paired difference was 0.39° (SD 4.8), this difference was not significant (p = 0.97) (Table 2). The mean RA angle from the smartphone was 7.4º (SD 3.1). The mean RA from the postoperative CT scan was 11.9º (SD 5.9). The mean paired difference was 4.52° (SD 4.3), this difference was significant ($p < 0.05$) (Table 3). The percentage of cup placements in the Lewinnek safe zone was 82.61% (Figure 5). With regards to the intra-tester reliability, the ICCs of the RI angle were 0.996 for Dr1 (PS) and 0.995 for Dr2 (SP) while the ICCs of the RA angle were 0.999 for Dr1 and 0.997 for Dr2. The inter-tester reliability indicated an ICC of 0.998 (95% CI 0.996 – 0.999) for RI and 0.997 (95% CI 0.994 – 0.999) for RA.

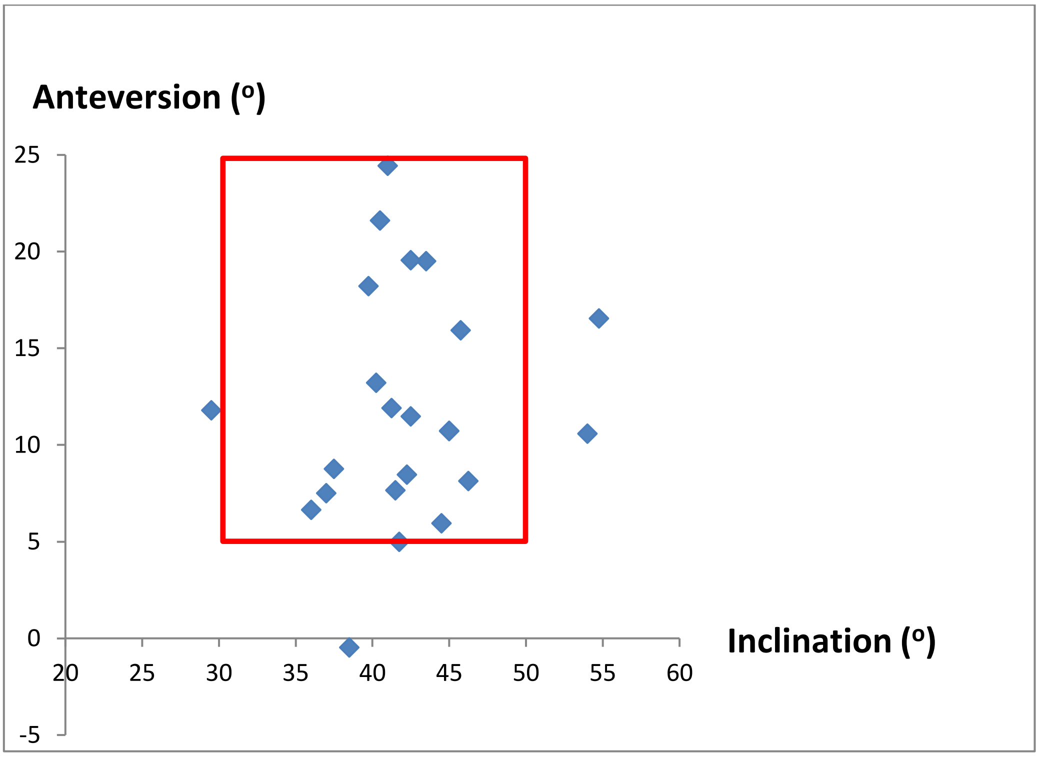

Fig. 5 Cup positions relative to the Lewinnek safe zone. Nineteen cases (82.61%) were within the safe zone.

Table 1 Demographic data of the combined use of a smartphone and digital angle ruler technique in assisting cup placement for total hip arthroplasty.

Characteristics	Total (n= 23)
Gender, n (%)	
Male	5 (21.74%)
Female	18 (78.26%)
Age (years)	
Mean (SD)	61.8 (10.6)
Range	45-78
BMI (kg/m2)	
Mean (SD)	24.7 (4.1)
Range	16.43-31.62
Diagnosis, n (%)	
AVN	11 (47.82%)
Osteoarthritis	9 (39.13%)
Aseptic loosening post bipolar hemiarthroplasty	2 (8.69%)
Rheumatoid arthritis	1 (4.34%)

BMI = body mass index; AVN = avascular necrosis; SD = standard deviation

Table 2 Comparison of radiographic inclination angle between intraoperative digital angle ruler and postoperative radiographic measurement.

	Digital angle ruler value Mean (SD) Range	Radiographic measurement Mean (SD) Range	Paired difference Mean (SD)	*p*-value
Radiographic inclination angle	42.1º (2.4) 37.7º - 48.4º	42.2º (5.3) 29.5º - 55.0º	0.39º (4.8)	0.97

SD = standard deviation

Table 3 Comparison of radiographic anteversion angle between intraoperative smartphone and postoperative CT scan.

	Smartphone value Mean (SD) Range	CT value Mean (SD) Range	Paired difference Mean (SD)	*p*-value
Radiographic anteversion angle	7.4º (3.1) 0.56º - 13.06º	11.9º (5.9) -0.62º - 24.6º	4.52º (4.3)	<0.05

CT = computed topography; SD = standard deviation

Discussion

Nowadays, smartphones and associated applications have become widely available and easily accessible. Smartphone applications can provide real-time measurements by using their built-in accelerometer functions. In 2012, Peter et al[13] 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[14] 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 the 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 concerned. Pongkunakorn et al[19] studied the use of smartphone to improve acetabular component positioning in THA and showed that using the computerized function of smartphone could improve the precision of cup positioning and that most cups (90.2%) were placed within a narrow margin inside the Lewinnek safe zone. However, their technique had some complexity that needed a learning curve for fluoroscopic control and instrument installation. Furthermore, the authors of the aforementioned studies performed the operation or studies in the lateral decubitus position, which differed from our preferred position and approach.

To address these problems, the authors developed an easy and feasible technique that use a smartphone with a particular application for measuring cup anteversion and a digital angle ruler for measuring cup inclination simultaneously during cup reaming and placement for the hip operated in supine position. The author implemented the technique that has been already proven the accuracy and reliability in a pelvic model into the real clinical practice in this study. Consistent with our results, we found that the mean RI angle from the digital angle ruler was 42.1º (SD 2.4). The mean RI angle from the postoperative radiographic measurement was 42.2º (SD 5.3). The mean paired difference was 0.39° (SD 4.8), this difference was not significant ($p = 0.97$). The mean RA angle from the smartphone was 7.4º (SD 3.1). The mean RA from the postoperative CT scan was 11.9º (SD 5.9). The mean paired difference was 4.52° (SD 4.3), this difference was significant ($p < 0.05$) but considered to be clinically irrelevant.

The difference of inclination measurements was less than the difference of anteversion measurement in the present study. This could be explained from conversion of the OI and OA angles of the cup measured by the author's proposed technique and AA from CT scan to RI and RA angles using a formula proposed by Murray(21). From the mentioned study demonstrated by nomograms and show that conversion of the inclination angle was less different than conversion of the anteversion angle. However, most of the cases (82.61%) were placed within the Lewennek safe zone which was better than using the conventional techniques relied on the mechanical alignment guides or the surgeon's experiences that demonstrated the percentage of acceptably placed cups in the Lewinnek safe zone varies from 25.7% to 70.5% reported in the literature.

There were several limitations of this study. First, the sample size was small which might have impaired the quality of the analytic assessment and the fact that this was a prospective observational study which didn't have any comparable results with other techniques such as conventional or computer assisted technique. Second, this technique could measure only cup alignment; however variability of the femoral neck anteversion affected the range of motion and induced impingement and the effects of pelvic obliquity or tilting were not included in the study. Third, our technique was used only for hip replacement surgery in supine position with anterior approach to the hip joint. The ICC for reliability of both inclination and anteversion measurements in this study were also at an excellent level. To the best of our knowledge, this was the first clinical study that used a smartphone to measure cup anteversion combining with a digital angle ruler to measure cup inclination during hip replacement surgery in supine position.

Conclusion

The combination of a relevant smartphone application and a digital angle ruler technique could assist the acetabular cup positioning with acceptable percentage in the Lewennek safe zone (82.61%) and the inclination measurements were more accurate than the anteversion measurements. This technique was considerably less invasive, less time-consuming, and less costly than other sophisticated technology approaches, such as the computer navigation.

Acknowledgement

The authors would like to thank Dr.Anuwat Pongkunakorn for his consultation and Mr. Martin Whitaker for proofreading this article.

Potential conflict of interest

None.

References

1. Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, Stockl B. Reduction the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. J Bone Joint Surg Br. 2005; 87(6): 762-9.
2. Hirakawa K, Mitugi N, Koshino T, Saito T, Hirasawa Y, Kubo T. Effect of acetabular cup position and orientation in cemented total hip arthroplasty. Clin Orthop Relat Res. 2001; (388): 135-42.
3. Little NJ, Busch CA, Gallagher JA, Rorabeck CH, Bourne RB. Acetabular polyethylene wear and acetabular inclination and femoral offet. Clin Orthop Relat Res. 2009; 467(11): 2895-900.
4. Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocation after total hip replacement arthroplasties. J Bone Joint Surg. 1978; 60(2): 217-20.
5. Callanan MC, Jarrett B, Bragdon CR, Zurakowski D, Rubash HE, Freiberg AA, et al. The John Chanley Award: risk factors for cup malpositioning: quality improvement through a joint registry at a tertiary hospital. Clin Orthop Relat Res. 2011; 469(2): 319-29.
6. Digioia AM, III, Jaramaz B, Plakseychuk AY, Moody JE Jr, Nikou C, Labarca RS, et al. Comparison of a mechanical acetabular

alignment guide with computer placement of the socket. J Arthroplasty. 2002; 17(3): 359-64.
7. Beckmann J, Stengel D, Tingart M, Gotz J, Grifka J, Luring C. Navigated cup implantation in hip arthroplasty: a meta-analysis. Acta Orthop. 2009; 80(5): 538-44.
8. Iwana D, Nakamura N, Miki H, Kitada M, Hananouchi T, Sugano N. Accuracy of angle and position of the cup using computed topography-based navigation systems in total hip arthroplasty. Comput Aided Surg. 2013; 18(5-6): 187-94.
9. Kim TH, Lee SH, Yang JH, Oh KJ. Computed topography assessment of image-free navigation-assisted cup placement in THA in an Asian population. Orthopedics. 2012; 35(10 Suppl): 13-7.
10. Ryan JA, Jamali AA, Bargar WL. Accuracy of computer navigation for acetabular component placement in THA. Clin Orthop Relat Res. 2010; 468(1): 169-77.
11. Xu K, Li YM, Zhang HF, Wang CG, Xu YQ, Li ZJ. Computer navigation in total hip arthroplasty: a meta-analysis of randomized controlled trials. Int J Surg. 2014; 12(5); 528-33.
12. Moskal JT and Capps SG. Acetabular component positioning in total hip arthroplasty: an evidence-based analysis. J Arthroplasty. 2011; 26(8): 1432-7.
13. Peter FM, Greeff R, Goldstein N, Frey CT. Improving acetabualr cup orientation in total hip arthroplasty by using smartphone technology. J Arthroplasty. 2012; 27(7): 1324-30.
14. Kurosaka K, Fukunishi S, Fukui T, Nishio S, Fujihara Y, Okahisa S, et al. Assessment of accuracy and reliability in acetabular cup placement using an iPhone/iPad system. Orthopedics. 2016; 39(4): 621-6.
15. Kulendran M, Lim M, Laws G, Chow A, Nehme J, Darzi A, et al. Surgical smartphone applications across different platforms: their evolution, uses and users. Surgical Innovation. 2014; 21(4): 427-40.
16. Franko OI. Smartphone apps for orthopaedic surgeons. Clin Orthop Relat Res. 2011; 469(7): 2042-8.
17. Sukapan H. Smartphone improves accuracy of alignment guide for acetabular cup positioning: a study in plastic bone model. Lampang Med J. 2014; 35(2): 56-67.
18. Tay XW, Zhang BX, Gayagay G. Use of iPhone technology in improving acetabular component position in total hip arthroplasty. Arthroplas Today. 2017; 3(3): 167-70.
19. Pongkunakorn A, Chatmaitri S, Diewwattanawiwat K. Use of smartphone to improve acetabular component positioning in total hip arthroplasty: a comparative clinical study. J Orthop Surg (Hong Kong). 2019; 27(1): 1-8.
20. Uthaicharatratsame C, Sahajarupat S, AdullayathumT. Accuracy and reliability of combining a smartphone and digital angle ruler technique to assist acetabular cup placement: a pelvic model study. Thai J Orthop Surg. 2019; 43(3-4): 8-14.
21. Murray DW. The definition and measurement of acetabular orientation. J Bone Joint Surg Br. 1993; 75(2): 228-32.

การศึกษาการใช้สมาร์ทโฟน ร่วมกับ ไม้บรรทัดวัดมุมแบบดิจิทัล เพื่อช่วยในการตั้งเบ้าข้อสะโพกเทียม : การศึกษาทางคลินิก

เจริญวัฒน์ อุทัยจรัสรัศมี, พบ, ศุภวุฒิ พฤฒิวรนันทน์, พบ, ประชา สืบพงษ์ศิริ, พบ

วัตถุประสงค์: เพื่อศึกษาถึงจำนวนเปอร์เซ็นต์ของเบ้าข้อสะโพกเทียมที่สามารถถูกจัดวางให้อยู่ภายใน Lewennek safe zone ได้อย่างถูกต้องด้วยวิธีการใช้สมาร์ทโฟนร่วมกับไม้บรรทัดวัดมุมแบบดิจิทัล เพื่อช่วยในการตั้งเบ้าข้อสะโพกเทียม รวมถึงการศึกษาความถูกต้องของวิธีดังกล่าวโดยการเปรียบเทียบค่าของมุม inclination และ anteversion ของเบ้าสะโพกเทียมในระหว่างการผ่าตัด และค่าของมุม inclination และ anteversion ที่คำนวณได้ภายหลังการผ่าตัดจากภาพถ่ายรังสี และเอกซเรย์คอมพิวเตอร์

วัสดุและวิธีการ: การศึกษาเชิงพรรณนาในกลุ่มตัวอย่าง คือข้อสะโพกที่ได้รับการผ่าตัดเปลี่ยนข้อสะโพกเทียมในท่านอนหงาย จำนวน 23 ข้อ โดยการใช้สมาร์ทโฟนร่วมกับไม้บรรทัดวัดมุมแบบดิจิทัล เพื่อช่วยในการตั้งมุม anteversion และ inclination ของเบ้าข้อสะโพกเทียมตามลำดับในระหว่างการผ่าตัด หลังจากนั้นอย่างน้อย 1 เดือน จะทำการถ่ายภาพรังสีและเอกซเรย์คอมพิวเตอร์ของข้อสะโพกทั้งสองข้างเพื่อคำนวณค่าของมุม inclination และ anteversion ตามลำดับ และนำข้อมูลดังกล่าวมาเปรียบเทียบกับข้อมูลที่ได้ในระหว่างการผ่าตัด

ผลการศึกษา: ค่าเฉลี่ยของมุม inclination ที่วัดได้จากไม้บรรทัดวัดมุมแบบดิจิทัลและภาพถ่ายรังสีของข้อสะโพกทั้งสองข้างมีค่า 42.1 ± 2.1 องศา และ 42.2 ± 5.3 องศา ตามลำดับ โดยที่ค่าเฉลี่ยของความแตกต่างของมุมทั้งสองอยู่ที่ 0.39 ± 4.8 องศา ซึ่งไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ ($p = 0.97$) ส่วนค่าเฉลี่ยของมุม anteversion ที่วัดได้จากสมาร์ทโฟนและเอกซเรย์คอมพิวเตอร์ของข้อสะโพกทั้งสองข้างมีค่า 7.4 ± 3.1 องศา และ 11.9 ± 5.9 องศา ตามลำดับ โดยที่ค่าเฉลี่ยของความแตกต่างของมุมทั้งสองอยู่ที่ 4.52 ± 4.3 องศา ซึ่งมีความแตกต่างอย่างมีนัยสำคัญทางสถิติ ($p < 0.05$) จำนวนเบ้าข้อสะโพกเทียมที่สามารถจัดวางให้อยู่ภายใน Lewennek safe zone ได้อย่างถูกต้องเท่ากับ 82.61%

สรุป: การใช้ไม้บรรทัดวัดมุมแบบดิจิทัลร่วมกับแอพพลิเคชั่นจากสมาร์ทโฟนเพื่อช่วยในการตั้งเบ้าข้อสะโพกเทียมสามารถจัดวางเบ้าของข้อสะโพกเทียมให้อยู่ภายใน Lewennek safe zone ในจำนวนเปอร์เซ็นต์ที่ยอมรับได้ โดยที่ช่วยในการตั้งมุม inclination ของเบ้าสะโพกเทียมได้ถูกต้องมากกว่ามุม anteversion