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Improving Acetabular Component Positioning in Supine Direct Anterior Total Hip Arthroplasty with a Transparency Template: A Novel, Simple, and Cost-effective Technique

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Purpose: A novel and simple method to ensure accurate acetabular component anteversion and inclination intraoperatively with the use of a transparency template is described.
Materials and Methods: Patients who underwent total hip arthroplasty (THA) via direct anterior approach (DAA) from June 2019 to January 2020 were included. A transparency template that can be placed over the image intensifier monitor to allow surgeons an accurate reading of the acetabular component position intraoperatively was designed, developed and utilized to determine effectiveness. The first template consists of two perpendicular lines indicating the “trans-ischial line” and the “pubic symphysis/coccyx”. The second template consist of a line indicating 45° inclination and parallel lines of corresponding distances apart required to achieve 20° anteversion based on Lewinnek’s formula: version=$\sin^{-1}$ (D1/D2), where D1: minor axis and D2: major axis of the component. This template was used throughout the acetabular part of the surgery, from reaming to impaction of component. Postoperative acetabular inclination, anteversion, surgical duration, length of stay, as well as complications were recorded.
Results: Twenty-six patients were included in this study. Mean postoperative acetabular cup inclination was 43.46±3.09° and mean version was 19.98±2.89°. A total of 21 patients (80.8%) fell within the Callanan safe zone and all 26 patients (100%) were within the Lewinnek safe zone.
Conclusion: The transparency template is a simple, reproducible, and effective tool with a minimal learning curve and no requirement for expensive equipment. This template has the potential to assist surgeons, especially those who are less experienced with DAA THA, in obtaining better postoperative radiographic outcomes.

Key Words: Total hip arthroplasty, Acetabular component, Accurate implant position

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INTRODUCTION

Total hip arthroplasty (THA) is one of the most commonly performed and successful orthopaedic surgeries in the world. With the mean age of the global population and prevalence of obesity increasing, the global burden of hip osteoarthritis will continue to rise, leading to a corresponding increase in demand for THA[1]. For example, by 2030, the demand for primary THA in the United States is estimated to grow by 174% to 57,200 per year[2].

Along with an increasing demand for THA, efforts to improve the success of THA by making results more reproducible and eliminating human error are abundant. Correct positioning of the acetabular and femoral implants plays an important role in THA outcomes and has largely been dependent on surgeon experience. Advancements in technology aim to address this issue by removing variability through robotics and navigated systems[3]. However, most of these approached require expensive equipment, preoperative imaging for templating, and a steep learning curve for the surgeon[4]. Although results from computer-navigated THA is promising and will no doubt play a huge role in the future of THA, there should be other more readily available ways to ensure improved implant accuracy.

Compared to the traditional posterior approach, the direct anterior approach (DAA) THA has shown to have less immediate postoperative pain, reduced hospital stays and days to mobilization, and faster return to premorbid ambulatory status[5-7]. One other interesting caveat of DAA THA is that it allows for an anterior-posterior radiograph of the pelvis to be taken intraoperatively during acetabular component placement as patients are positioned supine on the operative table. This allows for the additional benefit of capture of 'real-time' radiographs to ensure satisfactory implant position. However, even with this on-table radiograph, without computer measurement tools, surgeons can only judge the acetabular inclination and version to the best of their estimation.

In this pilot study, a novel and simple method of calculating acetabular component inclination and version intraoperatively with the use of a transparency template is evaluated.

MATERIALS AND METHODS

This is a prospective cohort study of all patients who underwent unilateral THA via the DAA from June 2019 to January 2020 in Singapore General Hospital, Singapore. All surgeries were performed by a single fellowship-trained Adult Reconstruction surgeon who was the senior author in this study. This study was approved by the hospital's review board (CIRB: 2018/2991), and the written informed consent was obtained from all patients.

1. Design of Transparency Template

Two templates were designed for the conduct of this study.

The first template was printed on an A3 size (29.7 cm × 42.0 cm) transparency material. Two perpendicular lines indicating the "trans-ischial line" and the "pubic symphysis/coccyx" were marked on the transparency material (Fig. 1A).

The second template was printed on an A4 size (21.0 cm × 29.7 cm) transparency material. A horizontal line indi-

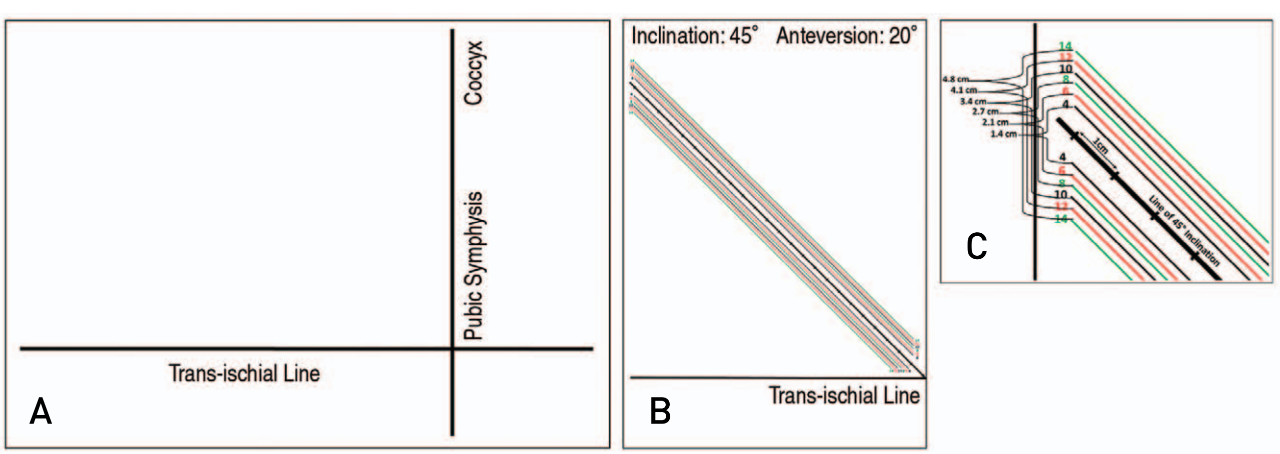

Fig. 1. Transparency templates. (A) A3 sized transparency denoting trans-ischial line and line through pubic symphysis. (B) A4 sized transparency with 45° inclination and 20° anteversion. (C) Zoom in view of corresponding distance required to achieve 20° anteversion. Note: Figures are for illustration and not drawn to scale.

cating the "trans-ischial line" and a line 45° to the horizontal line indicating 45° inclination were marked. Markings of 1 cm intervals were made on the line of inclination (Fig. 1B). In order to determine the cup version on an anterior-posterior (AP) view of a radiograph, Lewinnek's formula for version was used[8].

Lewinnek's formula for version=$\sin^{-1}$ (D1/D2), where D1: minor axis and D2: major axis.

A target version of 20° was used to design the template and D2 (major axis) is based on the number of 1 cm intervals marked on the line of inclination.

To achieve 20° version (Table 1):

$20° = \sin^{-1}$ (D1/D2)

D1/D2=sin 20°

D1/D2≈0.342

Lines parallel to the line of inclination at a distance corresponding to the required D1 distance to achieve 20° version were marked (e.g., for a D2 of 10 cm on the major axis, D1 of 3.4 cm was marked parallel to the line of inclination) (Fig. 1C). The lines are color coded to allow ease of identification intraoperatively.

2. Surgical Technique

Patients were positioned supine on the operating table. After induction of General Anesthesia, both lower limbs were cleaned and draped. Standard DAA to the hip with longitudinal incision over the anterior hip was made and dissection down to tensor fascia lata (TFL). The TFL fascia was incised and the interval between Sartorius and TFL was entered. Anterior capsulectomy was performed and femoral head removed after neck osteotomy. An image intensifier (II) machine was sterile draped and brought into the surgical field. An AP radiograph was taken before acetabulum reaming to ensure correct position of the II machine. The radiograph was focused on the operated hip and both the pubic tubercle as well as the pubic symphysis were ensured to be clearly visible. The image was rotated so that the pubic symphysis was 90° to the horizon. To account for potential pelvic tilt, the II machine was tilted in the sagittal plane to ensure an estimated equal vertical distance between the upper edge of the pubic symphysis and the mid-point of the sacrococcygeal joint was achieved between the intraoperative supine and preoperative standing AP radiograph. Studies have shown that there is a strong relationship between this distance and the pelvic tilt[9,10]; by ensuring this distance was the same on the intraoperative supine and preoperative standing radiograph, surgeons can help ensure the acetabular anteversion seen intraoperatively is a true reflection of the actual standing anteversion.

Table 1. D1 and D2 Length to Achieve 20° Version

	D2	D1
Length (cm)	4	1.4
	6	2.1
	8	2.7
	10	3.4
	12	4.1
	14	4.8
	16	5.5

Once the position of the II machine was satisfactory, an Operating Theatre staff placed the 1st transparency template on the II machine monitor and secured it with adhesive tape (Fig. 2A). The template was placed with the trans-ischial line at the ischial tuberosity and the line demarcating pubic symphysis ran vertically through the pubic symphysis. Occasionally the coccyx could be visible on the II machine depending on the patient habitus and machine used and the pubic symphysis line could be aligned with the coccyx to achieve better accuracy.

The second transparency template could be used during reaming, impaction of the trial implant, and impaction of final implant. The second template was placed over the first with the 2 trans-ischial line lining up and then slid along the trans-ischial line to the position of the reamer/cup. A 45° inclination was achieved when the long axis of the reamer/cup aligns with the 45° line printed on the second template. To achieve 20° of version, the assistant would first need to count the number of 1 cm intervals along the long axis of the implant. Once this was done, the corresponding parallel line that translates into 20° version according to the Lewinnek's formula was identified. The surgeon could then adjust the reamer/cup impactor accordingly to match the short axis of the cup with the corresponding parallel line (Fig. 2) (for example, after placing the first transparency template with the anatomical land marks matching the II image, the second template can be overlaid on the first and slide to the position of the acetabular cup. The surgeon can adjust the cup's inclination to match the diagonal line on the second template to ensure correct inclination. After the long axis of the cup matches the line of inclination, the surgeon then counted the number of centimeter markings along the long axis of the cup, e.g., 12 markings. Adjustments to the anteversion were then required so that the short axis of the cup matched the corresponding parallel line on the template, e.g., the second line from top and bottom in red to ensure a 20° anteversion for 12 markings (Fig. 2).

3. Caveats

(1) As this template made use of the ratio between the long and short axis, it is independent of the II magnification and surgeons does not need to take the magnification into account.
(2) The same principle could be used to print templates of different inclination and target version based on surgeons' preference.
(3) Only 1 set of templates with the desired inclination and version needs to be created as it could be flipped over to be used for either left or right hip.
(4) During reaming and impaction of trial implant/final implant there is likely to be movement of patient position on the II. OT staff will have to adjust the transparency accordingly to obtain accurate reading.
(5) When using the template intraoperatively, release of the tension on Hoffman retractors and ensuring both anterior superior iliac spines are leveled before taking the II image to minimize tilting of the pelvis.

4. Postoperative Measurements

All patients had supine pelvic AP radiograph taken on postoperative day one as well as standing pelvic AP radiograph taken on first outpatient follow-up appointment two weeks postoperatively. Pelvis indices were measured using TraumaCad software program (Orthocrat, Petach-Tikva, Israel). Acetabular component inclination was calculated by the acute angle formed by the trans-ischial line and the line through the long axis of the acetabular cup (Fig. 3A). Due to the lack of standardization and proof of superiority of anteversion measurement, three methods of measurements were used. First method: Liaw et al.[11]; version=$\sin^{-1}\tan\alpha$ (α is the angle between the long axis of the component and the line connecting the long axis with the end-point of the ellipse). Second method: Lewinnek et al.[8]; version=$\sin^{-1}$ (short axis of the ellipse ['CD']/long axis of the component ['AB']). Third method: TraumaCad; version determined by drawing a semi-circle of best fit over the ellipse (Fig. 3B).

The Shapiro–Wilk test was used to test for normality of the data. The Wilcoxon signed-rank test, root mean square error (RMSE), and intraclass correlation coefficient (ICC) between inclination and anteversion were calculated between the supine pelvic AP radiograph taken intraoperatively and standing pelvic AP radiograph postoperatively. Surgical duration, length of stay, as well as immediate

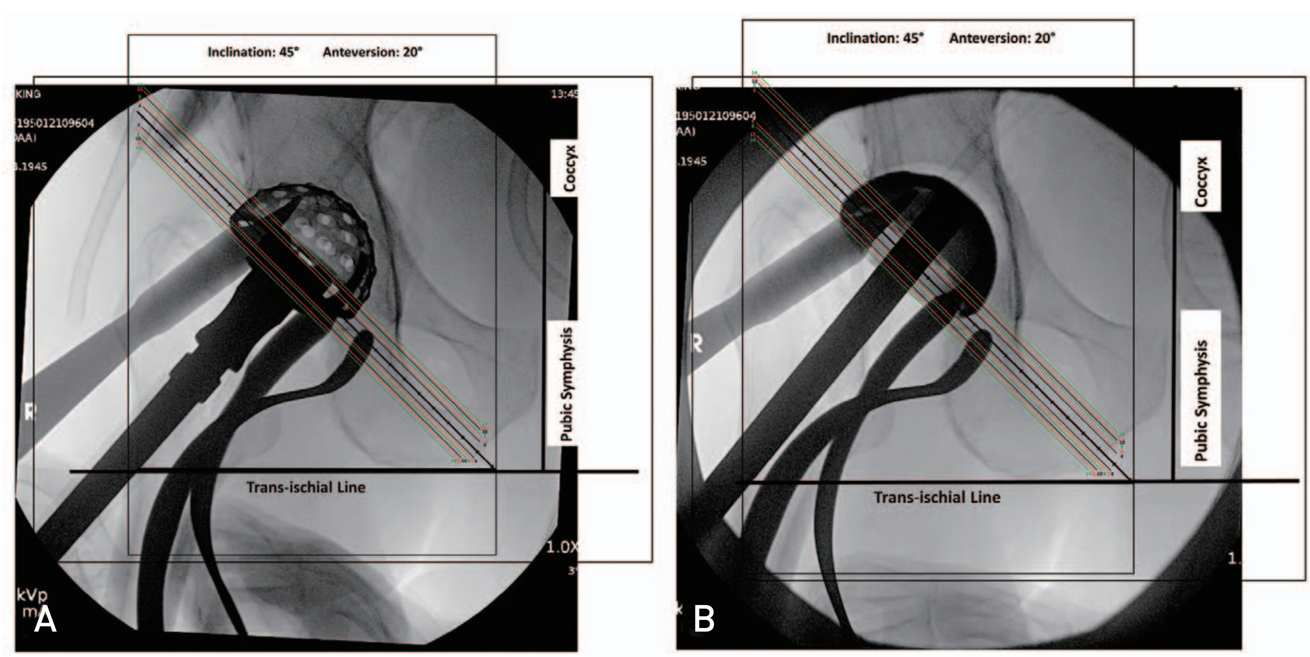

Fig. 2. Transparency template use intraoperatively. (A) Transparency template overlay onto image intensifier monitor during reaming. (B) Transparency template overlay onto image intensifier monitor during impaction of implant.

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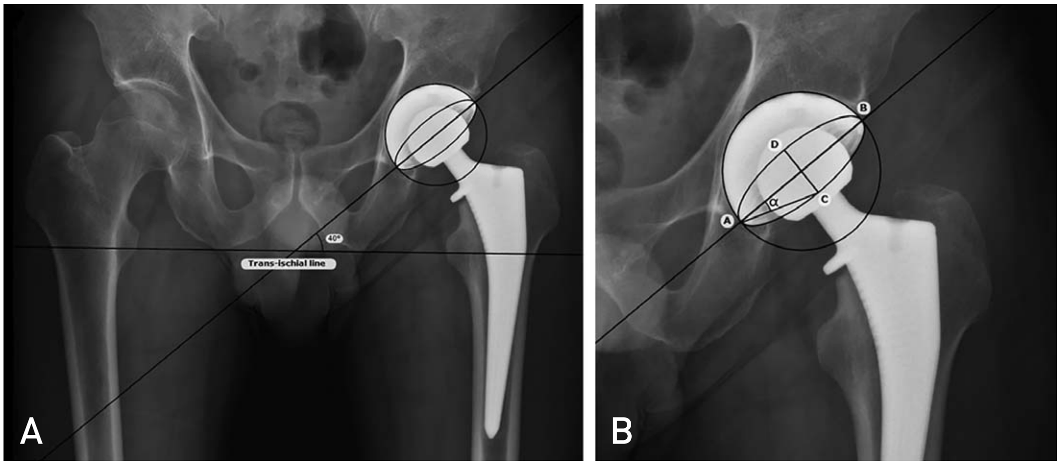

Fig. 3. Measuring of postoperative indices. (A) Acetabular component inclination. (B) Acetabular component version. Liaw et al.[11]: version=$\sin^{-1}\tan\alpha$; Lewinnek et al.[8]: version=$\sin^{-1}CD/AB$; TraumaCad: semicircle of best fit over ellipse.

Table 2. Patient Demographics

Variable	Value
Mean age (yr)	57.7±13.8
Body mass index (kg/m²)	26.8±3.9
Sex, male:female (n)	12:14
Side of surgery, left:right (n)	9:17
Surgical duration (min)	105.7±17.8
Length of stay (day)	2.2±1.9

Values are presented as mean±standard deviation or ratio.

complications were also recorded.

RESULTS

A total of 26 patients (12 males, 14 females) underwent unilateral DAA THA using the transparency template from June 2019 to January 2020. Thirteen patients had osteoarthritis, 7 with hip dysplasia, and 6 with avascular necrosis. Thirteen patients received Corail® Pinnacle® Hip System (DePuy Synthes, Raynham, MA, USA) and 13 received Polarstem® R3® implants (Smith & Nephew, Memphis, TN, USA). Patient demographics and surgical details are shown in Table 2.

The mean postoperative acetabular cup inclination was 43.46±3.09° and the mean version taking the average of three methods of measurement was 19.98±2.89° (Table 3). A total of 21 patients (80.8%) fell within the Callanan zone of safety (5° to 25° for anteversion and 30° to 45° for inclination) and all 26 patients (100%) were within the Lewinnek zone of safety (5° to 25° for anteversion and 30° to 50° for inclination) (Fig. 4).

There was no statistically significant difference in inclination (P=0.424) or anteversion (P=0.439) measured on the intraoperative supine and postoperative standing AP radiograph. The average RMSE for acetabular cup inclination between intraoperative supine and postoperative standing AP radiograph was 1.40° and the average RMSE for acetabular cup anteversion was 1.50°. ICC analysis demonstrated good correlation between intraoperative supine and postoperative standing AP radiographs (0.982 for inclination, 0.923 for anteversion).

There were no immediate postoperative complications nor dislocations noted within the study period.

DISCUSSION

Acetabular cup position plays a crucial role in the success of THA. Accurate cup position is required to achieve stability[12,13], reduce wear[14,15], restore limb length discrepancy[16], and achieve optimal hip biomechanics[17]. Dislocation is one of the most feared post-THA complications and is the leading cause for revision surgery within the early postoperative period[18,19]. Classical teachings have always advocated two 'zones of safety' that can potentially minimize the risk of dislocation. The first being Lewinnek's zone of safety[8] with acetabular component within 5-25° of anteversion and 30-50° of inclination, and more recently Callanan's zone of safety[20] with acetabular component within 5-25° of anteversion and 30-45° of inclination. However, conventional THA is still largely dependent on surgeon's experience; a study by Callanan et al.[20] of 1,823 hips found that the incident of cup malposition is still significant with only 50% of acetabular components placed within their defined zone of safety.

Table 3. Postoperative Inclination and Version

	Postop inclination	Postop anteversion (Liaw et al.[11])	Postop anteversion (Lewinnek et al.[8])	Postop anteversion (TraumaCad)	Average postop anteversion
	43.46±3.09°	20.16±2.95°	19.94±2.75°	19.85±2.06°	19.98±2.89°
Callanan zone of safety (n)	21	25	26	26	26
Lewinnek zone of safety (n)	26	25	26	26	26

Values are presented as mean±standard deviation or number only.
Postop: postoperative.

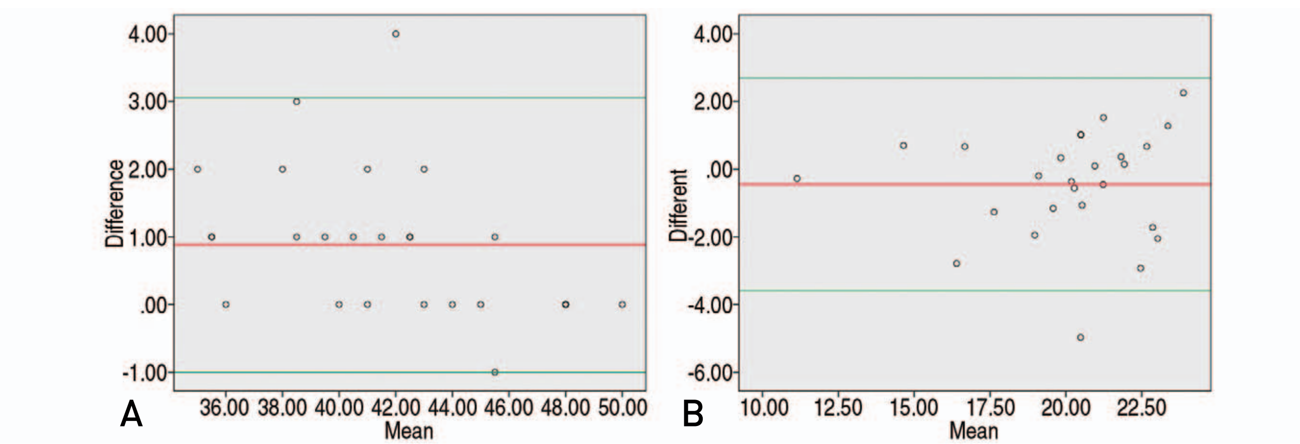

Fig. 4. Bland–Altman plot. (A) Inclination. (B) Anteversion. Red line=mean, Green line=95% confidence interval.

In this study, the authors designed a simple transparency template that can be placed over the image intensifier monitor to allow surgeons an accurate reading of their acetabular component position intraoperatively. The use of this template is dynamic and can be employed in all stages of acetabular implantation, from reaming to final impaction of component, thus allowing the surgeon to adjust as necessary throughout the acetabular part of the surgery. With this technique, the authors aimed for an acetabular inclination of 45° and anteversion of 20° in all patients and were able to achieve a mean postoperative acetabular component inclination of 43.46±3.09° and a mean version of 19.98±2.89°. In a retrospective study by Soderquist et al.[21] examining the accuracy of freehand DAA THA, 85% of their patients fell within the Lewinnek safe zone and 61% within the Callanan safe zone. Another study by Slotkin et al.[22] found 88% of patients who underwent DAA THA fell within the Lewinnek zone of safety. In this study, the authors were able to achieve 100% of patients within Lewinnek zone of safety and 80.8% within Callanan zone of safety.

The authors were also able to successfully account for the effect of pelvic tilt on eventual acetabular cup anteversion on standing radiograph. Pelvic tilt is most prominent on standing radiograph of the pelvis and literature has shown there is a correlation between pelvic tilt and acetabular version[23-25]. If the patient has significant pelvic tilt on standing and intraoperative AP radiograph of the pelvis was performed perpendicular to the pelvis without accounting for the pelvic tilt, the acetabular component could be placed in too much anteversion if there is a significant posterior pelvic tilt and vice versa. By tilting the II machine in the sagittal plane to ensure an equal vertical distance between the upper edge of the pubic symphysis and the mid-point of the sacrococcygeal joint is achieved between the intraoperative supine and preoperative standing AP radiograph, the authors were able to ensure that the acetabular anteversion seen intraoperatively was a true reflection of the eventual anteversion on standing.

This study has to be interpreted in light of its limitations. Firstly, the surgeon in this study was an Adult Reconstruction surgeon who specializes in DAA THA with more than 10 years of experience. There is less dependency on the transparency template to achieve satisfactory radiologic outcome intraoperatively and there might not be a significant difference in outcome compared to the THAs performed by the same surgeon without the transparency. Thus, the authors were unable to perform a match-paired analysis to obtain statistically significant results on differences in radiological outcomes or operative duration. This result would have been more significant if conducted by a surgeon who is less experienced with DAA THA. However, as this was a pilot feasibility study to assess template design and development of a workflow for its use, it needs to be carried out with an experienced surgeon to prevent any disruptions intraoperatively that might compromise patient care. Secondly, although this method can potentially increase the accuracy of acetabular component inclination and version, compared to 3D image-guided techniques such as those available with haptically guided robotic surgery, it is unable to assist the surgeon in other aspects of implant position such as acetabular cup placement to restore limb length, center of rotation, and hip offset which has an equally important role in determining the success of THA. However, compared to these other modalities involving preoperative imaging and computer assisted surgical technique, the transparency template incurs no additional cost to the patients, has minimal learning curve, and is readily available to any surgeon in any institution without the need for expensive machinery. The target anteversion used in this transparency template also does not take into account the potential effect of the femoral anteversion on the final combined anteversion. A number of studies have demonstrated that combined anteversion is more important than a single fixed cup anteversion in preventing impingement[26,27]. In order to address this, the authors believe surgeons could still make use of the transparency template and simply adjust the target version and recalculate the D1 (where target version=$\sin^{-1}$D1/D2) to make a transparency template based on a different version. By proving that this transparency template can allow for accurate cup placement in 20° anteversion, its efficacy can also be indirectly extrapolated to other target anteversions. Thirdly, in the original paper by Lewinnek et al.[8], the authors did not define if anteversion measurements were based on pelvis or hip-centered radiographs. In pelvis-centered AP radiographs, the radiation beam is projected towards the center of the pelvis, thus the radiation beam received by the hip joint in pelvis-centered AP radiograph is deviated by about six degrees. In contrast, in hip-centered AP radiographs, the hip joint receives perpendicular radiation beam. Therefore, it can be hypothesized that there could be up to six degrees of difference depending on how the X-ray is acquired. The authors have chosen to use Lewinnek's method of anteversion measurement as studies have shown high inter- and intra-observer reliabilities and no significant differences in anteversion between measurements made on pelvis and hip-centered AP radiographs[28,29]. Lastly, there is a lack of clinical data at short- and long-term follow-up to determine if this accuracy in implant position translates to better clinical outcome in terms of reduced dislocation or revision rate. As this was a pilot study to test the feasibility of the template design and its implementation during surgery, and there is almost no opportunity cost involved in its use, the authors believe that it is a worthwhile tool and future large-scale study with longer follow-up could be conducted to validate the results.

CONCLUSION

The transparency template described here is a simple, reproducible, and effective tool to assist surgeons in reproducing the desired acetabular component inclination and version intraoperatively. There is minimal learning curve and it is cost efficient without the need for expensive equipment or additional imaging studies. It has the potential to assist surgeons, especially those who are less experienced with DAA THA, in obtaining better radiographic outcome postoperatively.

CONFLICT OF INTEREST

The authors declare that there is no potential conflict of interest relevant to this article.

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