Accuracy of acetabular cup placement using an angle-adjusting alignment guide with laser pointer in total hip arthroplasty

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Abstract

**Purpose:** To evaluate cup-positioning accuracy in total hip arthroplasty (THA) using a novel angle-adjusting alignment guide with laser pointer and determine whether level of surgical experience affects accuracy of cup placement or not.

**Methods:** We included 117 hips in 104 patients who underwent THA using the novel guide. We retrospectively reviewed 44 hips in 40 patients who underwent THA before the novel guide was introduced. We compared differences in cup angles between the novel guide group and the conventional guide group as well as the discrepancies in targeted angles between the experienced surgeon group and the inexperienced surgeon group.

**Results:** There were 114/117 hips (97.4%) within the Lewinnek safe zone in the novel guide group and 32/44 hips (72.7%) within the safe zone in the conventional guide group. There were significantly fewer outliers in the novel guide group (p < 0.001). In the experienced surgeon group, the mean absolute errors in inclination and anteversion were 2.0 \( \pm \) 1.7\(^\circ\) and 2.1 \( \pm \) 2.3\(^\circ\), respectively; which were not significantly different from those in the inexperienced surgeon group (2.3 \( \pm \) 2.1\(^\circ\) and 2.8 \( \pm \) 2.3\(^\circ\), respectively).

**Conclusion:** The novel angle-adjusting alignment guide with laser pointer is a simple tool that provides better accuracy of cup position than that obtained using conventional guides. Accurate cup placement is possible using the novel guide, regardless of surgeons’ experience.

**Keywords**

acetabulum, hip dislocation, laser pointer, total hip arthroplasty

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Introduction

Acetabular cup position has a significant effect on postoperative outcomes of total hip arthroplasty (THA). Cup malposition can cause impingement and edge loading, which consequently leads to dislocation, polyethylene wear, and aseptic loosening.\(^1\)-\(^5\) Cup malposition is one of the most important factors that affect rates of revision surgery. A computer navigation system has been developed to improve implant positioning in THA, in which positions of the pelvis and acetabular cup are intraoperatively tracked in real time.\(^6\) Several reports described clinical outcomes, in terms of precision of acetabular cup position, of using navigation systems.\(^7\)-\(^10\). These systems are not widely used due to high cost, technical complexity, large size of equipment, and prolonged operative times. Alternatively, conventional positioning of the cup is usually achieved using...
alignment guides. However, it is difficult to accurately position a cup using only conventional alignment guides. Studies have reported significant reductions in the variability of cup-positioning accuracy using conventional alignment guides between experienced and inexperienced surgeons. Therefore, it was necessary to develop an inexpensive and simple-guided method to enable accurate cup positioning regardless of surgeons’ experience. To address the technological gap in cup positioning, we developed a novel angle-adjusting acetabular cup alignment guide using a laser pointer (Figure 1). This study aimed to evaluate cup-positioning accuracy using the novel alignment guide and determine whether the level of surgical experience affects accuracy of cup placement or not.

Materials and methods

Study population

This was a retrospective study that we started when the angle-adjusting alignment guide with a laser pointer was firstly introduced. From April 2015 to October 2016, we included a total of 117 hips in 104 patients (80 females and 24 males) who underwent THA using angle-adjusting alignment guide with a laser pointer. By the time of surgery, the mean age of the patients was 68 years (range: 31–87 years) and mean body mass index (BMI) was 24.2 kg/m² (range: 14.6–33.8). The underlying pathologies were osteoarthritis in 96 hips (secondary to hip dysplasia (DDH) in 93 hips), avascular necrosis of the femoral head in 13 hips, rheumatoid arthritis (RA) in 3 hips, and rapidly destructive coxopathy (RDC) in 5 hips. Preoperative Crowe classifications were type I in 86 hips, type II in 20 hips, type III in 6 hips, and type IV in 2 hips. All operations were performed by three surgeons: one experienced surgeon (total surgical volume >500; surgeries, 60) and two inexperienced surgeons (total surgical volume <50; surgeries, 57). We also retrospectively evaluated 44 hips in 40 patients who underwent THA before the angle-adjusting alignment guide with a laser pointer was introduced between April 2014 and March 2015 by examining medical records and postoperative radiographs. By the time of surgery, the mean age and the BMI of these 40 patients were 65 years (range: 47–82 years) and 23.6 kg/m² (range: 14.6–33.8), respectively. Their underlying pathologies were osteoarthritis in 37 hips (secondary to hip dysplasia in 36 cases), avascular necrosis of the femoral head in 4 hips, and rheumatoid arthritis in 3 hips. Preoperative Crowe classifications were type I in 32 hips, type II in 10 hips, and type III in 2 hips (Table 1).

Operation technique

Anteroposterior and lateral pelvic radiographs were taken with the patient in the lateral decubitus position with the pelvis locked perpendicular to the operating table after anesthesia was administered. The pelvic tilt in the sagittal and coronal planes was measured on radiographs using CIS-image (IBM Corporation, Tokyo, Japan). The pelvic tilt in the sagittal plane was expressed as the anterior pelvic plane (APP) angle or sacral slope. Pelvic lateral tilt angle was measured on the anteroposterior pelvic radiograph between the interteardrop line and the perpendicular line to the operation table (Figure 2). The goniometer (Angle Viewer, MIZUHO Corporation, Tokyo, Japan) was used to assure that operating table was parallel to operation theater floor. As a transverse-axis guide, a Kirschner wire and a pelvic goniometer were inserted into the iliac crest, vertical to the operation table (Figure 3). In positioning the acetabular cup, the pelvic tilt was measured by recording the intraoperative pelvic tilt amount monitored by using this goniometer. The target was placed on the extension of the body axis. This allowed drawing five concentric circles obtained using trigonometric functions with the distance from the guide to the target remaining constant. We calculated that each time the concentric circle grows larger, the angle changes by 1° with respect to the reference axis from the guide point to the target (Figure 4).
### Table 1. Patient demographic data.\textsuperscript{a}

|                      | With laser pointer guide | Conventional guide (n = 44) | \(p\) Value |
|----------------------|--------------------------|-----------------------------|-------------|
|                      | Experienced surgeon (n = 60) | Inexperienced surgeon (n = 57) |             |
| Age (years)          | \(67 \pm 16.5\) (31–87) | \(69 \pm 11.2\) (48–80) | \(65 \pm 12.8\) (47–82) | 0.369\textsuperscript{b} |
| Gender: female/male  | 40/13                    | 42/11                       | 33/11       | 0.772\textsuperscript{c} |
| Diagnosis            |                          |                             |             |
| OA                   | 3                        | 0                           | 1           | 0.640\textsuperscript{c} |
| OA (DDH)             | 44                       | 49                          | 36          |             |
| Osteonecrosis        | 8                        | 5                           | 4           |             |
| RA                   | 2                        | 1                           | 3           |             |
| RDC                  | 3                        | 2                           | 0           |             |
| BMI (kg/m\(^2\))    | \(24.4 \pm 4.9\)         | \(23.7 \pm 3.1\)            | \(23.6 \pm 3.1\) | 0.664\textsuperscript{b} |
| Crowe G1/2/3/4       | 41/13/4/2                | 46/9/2/0                    | 32/10/2/0   | 0.531\textsuperscript{b} |

OA: operative anteversion; BMI: body mass index; SD: standard deviation.
\(\text{a}\) Age and BMI are expressed as mean \(\pm\) SD and range.
\(\text{b}\) Mann–Whitney U-test.
\(\text{c}\) Pearson’s \(\chi^2\) test.

**Figure 2.** Anteroposterior and lateral pelvic radiographs were taken with the patient in the lateral decubitus position with the pelvis locked perpendicular to the operating table.

**Figure 3.** The target is placed on the extension of the body axis.
All THAs were performed using the direct lateral approach. In cases where the combined anteversion (CA) technique was used, preparation of the femur was performed first so that the anteversion of the femur was determined prior to cup placement. Femoral rasping was done sequentially until appropriate fitness and stability were achieved. The anteversion of the final rasping was measured as the angle between the lower leg and rasp axes by flexing the knee and placing the tibia vertically using a stem anteversion goniometer (Figure 5). Then, the cup positioning angle was aimed based on the stem anteversion, in which the CA ranged from 30° to 50° of cup anteversion and 40° of cup abduction on the radiographic angle. At that time, adjustments were made by considering the functional pelvic plane in standing, supine, and lateral decubitus positions. The relations between the operative and the radiographic angles were derived according to Murray’s equation. After reaming was completed, the acetabular cup was inserted using the alignment guide with a laser pointer. We marked the target and referred to it for cup positioning. Once the acetabular cup was impacted, we marked the place where the laser pointer designated to the target, as a later indicator (Figure 6). If the cup could not be placed in the target position due to incorrect acetabular reaming, re-reaming was performed and the cup was reinserted. Simultaneously, a level gauge was used to validate the horizontal plane. It was important to correct inclination of the pelvis tilt to indicate the same position as prior to the surgery by using a Kirschner wire and a goniometer as a transverse-axis guide inserted in the iliac crest.

**Postoperative evaluation**

Anteroposterior pelvic radiographs in the supine position and computed tomography (CT) images with 3-mm slice intervals from the pelvis to the knee were obtained 2 weeks after surgery. The cup anteversion and abduction angles were semiautomatically measured using 2D-template software (KYOCERA Medical, Kyoto, Japan). Stem anteversion was calculated as the prosthetic femoral neck angle relative to the epicondylar line by CT images. The radiographic abduction angle of the cup was defined as the angle formed by the line connecting tips of the teardrops and the line connecting the upper and lower ends of the open plane of the cup. The anteversion angle was calculated using Lewinnek’s formula: cup anteversion angle = \( \arcsin \left( \frac{D_1}{D_2} \right) \). \( D_1 \) is the short axis distance of an ellipse drawn perpendicular to the long axis of the acetabular component, and \( D_2 \) is the long axis distance (the maximal diameter of the implant). All measurements were performed by an independent observer and author. The differences in radiographic cup angles were compared between the angle-adjusting acetabular cup alignment guide with a laser pointer group and the conventional guide group, and discrepancies in targeted angles in each patient were also compared between the experienced surgeon group and the inexperienced surgeon group. The measurements from a random set of 30 radiographs were repeated after an interval of at least 1 week to determine intraobserver reliability.

All study protocols were approved by our Institutional Review Board and informed consent was obtained from each patient.

**Statistical analysis**

Statistical analysis was performed using Mann–Whitney U-test, Pearson’s \( \chi^2 \) test, and Fisher exact test (IBM SPSS Statistics 26, IBM, Armonk, New York, USA). A \( p \)-value less than 0.05 was considered statistically significant. In
addition, Pearson correlation coefficient test was used to determine inter- and intraobserver correlations.

**Results**

In THA using the angle-adjusting alignment guide with a laser pointer, the mean anteversion of the cup and stem were $14.0 \pm 5.2^\circ$ and $23.9 \pm 6.7^\circ$, respectively. The mean inclination of the cup was $40.2 \pm 2.9^\circ$ and the resulting CA was $37.9 \pm 12.0^\circ$ on average, ranging from $20.0^\circ$ to $55.1^\circ$. There were 111 hips (94.9\%) within 30–50° of CA. Similarly, in THA using the conventional guide, the mean anteversion of the cup and stem were $16.6 \pm 8.6^\circ$ and $23.3 \pm 6.3^\circ$, respectively. The mean inclination of the cup was $42.1 \pm 6.3^\circ$, and the resulting CA was $39.9 \pm 14.9^\circ$ on average, ranging from $22.3^\circ$ to $63.1^\circ$. There were 33 hips (75.0\%) within 30–50° of CA. Thus, there were significantly fewer outliers in the laser pointer guide group ($p < 0.001$; Figure 7).

A total of 114/117 hips (97.4\%) were within the Lewinnek’s safe zone in the laser pointer guide group and 32/44 hips (72.7\%) were in this zone in the conventional guide group. Thus, there were significantly fewer outliers in the laser pointer guide group ($p < 0.001$; Figure 8).

In the experienced surgeon group, the mean absolute errors in radiographic inclination and anteversion were $2.0 \pm 1.7^\circ$ (range: $0–6.0^\circ$) and $2.1 \pm 2.3^\circ$ (range: $0–9.4^\circ$), respectively. However, in the experienced surgeon group, the mean absolute errors in radiographic inclination and anteversion were $2.3 \pm 2.1^\circ$ (range: $0–13.7^\circ$) and $2.8 \pm 2.3^\circ$ (range: $0–10.2^\circ$), respectively. Therefore, no significant difference was found between the groups (Figure 9).

The intra- and interobserver intraclass correlation coefficients were $\geq 0.90$, suggesting good intra- and interobserver agreement of the radiographic measurements.

**Discussion**

Cup placement accuracy using the angle-adjusting alignment guide with a laser pointer was significantly more precise than that without a laser pointer. This could be because the placement angle could be visualized in real time. With existing alignment guides, it is difficult to accurately determine the guide tip direction because surgeons must heavily rely on visualization. However, because this guide is equipped with a laser pointer at its tip, operative anteversion (OA) and inclination (OI) can be easily detected through a point shown at the target. Therefore, even an inexperienced surgeon can place the cup at an optimum angle. When determining the cup placement angle using the CA technique, the angle differs, depending on the stem anteversion angle. Therefore, adjusting the cup placement angle is difficult when using alignment guides.

Figure 6. The acetabular cup was inserted using the novel angle-adjusting acetabular cup alignment guide with a laser pointer.

Figure 7. Scatterplot showing degrees of cup anteversion and stem anteversion. (a) Laser pointer guide group and (b) conventional guide group. The box shows the Dorr’ safe zone. There were significantly fewer outliers in the laser pointer guide group ($p < 0.001$ Fisher’s exact test).
with fixed angles for guides that indicate OA and OI. However, this novel system can be adjusted freely. In terms of installment costs, it can be used in any facility as long as there is a cup holder attachment and laser pointer, and the cost is substantially lower. The laser pointer can be ethylene oxide gas sterilization and used semipermanently by replacing the battery once every 30 cases.

Generally, cup placement in THA is done using a free-hand technique or using alignment guides with fixed angles for guides that indicate both OA and OI. However, accuracy of these cup placements is by no means high. Approximately 25.7–85% of cases are placed in the safe zone.\textsuperscript{12, 20–22} There are also reports that the cup placement accuracy differs depending on patients’ BMI and surgeons’ experience. Callanan et al. reported that while cup placement in the safe zone among experienced surgeons was 51.1%, the rate was 34.1% for inexperienced surgeons.\textsuperscript{23} The results of the present study show that the accuracy of the experienced surgeon was \(2.0 \pm 1.7^\circ\) for cup inclination and \(2.3 \pm 2.1^\circ\) for cup anteversion. However, the inexperienced surgeons had an accuracy of \(2.1 \pm 2.3^\circ\) for cup inclination and \(2.8 \pm 2.3^\circ\) for cup anteversion. There was no significant difference between the groups. This finding suggests that accurate cup placement is possible using the angle-adjusting alignment guide with a laser pointer, regardless of surgeons’ experience.

Navigation systems have been used since the latter half of the 1990s to improve accuracy of cup placement in THA.
They are divided into three categories: CT-based, fluoroscopy-based, and image-free navigations. Out of these, accuracy of the CT-based navigation is extremely high. Nakahara et al. reported that the average accuracy measurement of the placement angle was 1.2 ± 1.3° for the lateral opening angle and 1.0 ± 0.8° for the anterior opening angle.10 There are many other reports on accuracy of the navigation system placement (Table 2).3,13–16,24 Nevertheless, these systems are expensive, the equipment is large, and they prolong operative times. A simple portable navigation (HipAlineR) has been developed recently that is clinically applied as a surgical support tool to THA. Apparently, not only is this portable navigation less expensive than a small-sized conventional navigation system but also achieves a certain level of cup placement accuracy.25 Although the single device is not expensive, it becomes costly because it can only be used once. There are a few large-scale studies assessing placement accuracy; therefore, we expect further verification in the future. Compared to the existing surgical-support tools, the placement accuracy of this system is comparable, and we believe that it is highly cost-effective.

SD: standard deviation.

There are several limitations to this study. First, the small sample size and the retrospective observational nature with patients as histological controls are among these limitations. Another limitation is X-ray exposure because taking an X-ray image is necessary for grasping the pelvic tilt after fixing the body position. Furthermore, the cup placement angle is determined based on variations in pelvic position on the surgical table. It is essential to know the fixed angle of the pelvis with respect to the surgical table. In addition, not only are two images of the front and side pelvis necessary but also the change in pelvic inclination during surgery is not reflected. Gonzalez et al. reported that the maximum change in pelvic inclination during surgery on average was 17° in the roll direction and 9.3° in the pitch direction.26 Accommodating changes in pelvic inclination are important for accurate cup placement. Currently, the pelvis is returned to the preoperative state before cup placement by referring to the level gauge attached to the pelvis. However, this does not account for pelvic rotation and it may lead to errors. There is a report of an alignment guide that reflects intraoperative pelvic movements using the APP as a reference. This guide uses pins placed on either the superior anterior iliac spines or body-positioning fixtures. Making use of such tools would be necessary going forward.27,28

### Conclusion

The novel acetabular cup alignment guide with a laser pointer is a simple tool that provides better accuracy of acetabular cup orientation than that achieved using conventional devices. Accurate cup placement is possible using the novel cup alignment guide, regardless of surgeons’ experience.

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References
1. Kennedy JG, Rogers WB, Soffe KE, et al. Effect of acetabular component orientation on recurrent dislocation, pelvic osteolysis, polyethylene wear, and component migration. *J Arthroplasty* 1998; 13: 530–534.
2. Patil S, Bergula A, Chen PC, et al. Polyethylene wear and acetabular component orientation. *J Bone Joint Surg Am* 2003; 85-A(4): 56–63.
3. Biedermann R, Tonin A, Krismer M, et al. Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. *J Bone Joint Surg Br* 2005; 87: 762–769.
4. Bozic KJ, Kurtz SM, Lau E, et al. The accuracy of free-hand cup positioning—a CT based measurement of cup placement in 105 total hip arthroplasties. *Int Orthop* 2004; 28: 198–201.
5. Kalteis T, Handel M, Herold T, et al. Greater accuracy in positioning of the acetabular cup by using an image-free navigation system. *Int Orthop* 2005; 29: 272–276.
6. Lin F, Lim D, Wixson RL, et al. Limitations of imageless computer-assisted navigation for total hip arthroplasty. *J Arthroplasty* 2011; 26: 596–605.
7. Dudda M, Gueleryuez A, Gautier E, et al. Risk factors for early dislocation after total hip arthroplasty: a matched case-control study. *J Orthop Surg (Hong Kong)* 2010; 18: 179–183.
8. Digioia AM, Jaramaz B, Blackwell M, et al. Image guided navigation system to measure intraoperatively acetabular implant alignment. *Clin Orthop Relat Res* 1998; 355: 8–22.
9. Fukunishi S, Nishiyama T, Fujishiro T, et al. Evaluation of the accuracy of femoral component orientation by the CT-based fluoro-matched navigation system. *Int Orthop* 2010; 37: 1063–1068.
10. Nakahara I, Kyo T, Kuroda Y, et al. Accuracy of combined anteversion in image-free navigated total hip arthroplasty. *J Bone Joint Surg Br* 2006; 88-B: 163–167.
11. Hayashi S, Hashimoto S, Takayama K, et al. Evaluation of the accuracy of acetabular cup orientation using the HipCOMPASS mechanical intraoperative support device. *SpringerPlus* 2016; 5: 784.
12. Lass R, Kubista B, Olischar B, et al. Total hip arthroplasty using imageless computer-assisted hip navigation. *J Arthroplasty* 2014; 29: 786–791.
13. Dorr LD, Malik A, Dastane M, et al. Combined anteversion technique for total hip arthroplasty. *Clin Orthop Relat Res* 2009; 467: 119–127.
14. Murray DW. The definition and measurement of acetabular orientation. *J Bone Joint Surg Br* 1993; 75: 228–232.
15. Lewinnek GE, Lewis JL, Tarr R, et al. Dislocations after total hip-replacement arthroplasties. *J Bone Joint Surg Am* 1978; 60: 217–220.
16. Reize P, Geiger EV, Suckel A, et al. Influence of surgical experience on accuracy of acetabular cup positioning in total hip arthroplasty. *Am J Orthop (Belle Mead NJ)* 2008; 37: 360–363.
17. Oh KJ, Kim BK, Jo MI, et al. Which one is more affected by navigation-assisted cup positioning in total hip arthroplasty: anteversion or inclination? A retrospective matched-pair cohort study in Asian physique. *J Orthop Surg* 2018; 26: 23094901878075.
18. Gonzalez Della Valle A, Shanaghan K, Benson JR, et al. Clinical efficacy of OrthoPilot navigation system versus conventional manual total hip arthroplasty: a systematic review and meta-analysis. *J Int Med Res* 2019; 47: 505–514.
19. Callanan MC, Jarrett B, Bragdon CR, et al. The John Charnley award: risk factors for cup malpositioning: quality improvement through a joint registry at a tertiary hospital. *Clin Orthop Relat Res* 2011; 469: 319–329.
20. Suda K, Ito T, Miyasaka D, et al. Cup implantation accuracy without a computer-assisted system: a prospective, randomized and controlled study. *J Arthroplasty* 2014; 29: 167–171.
21. Snijders T, Van Gaalen SM and De Gast A. Precision and accuracy of imageless navigation versus freehand implantation of total hip arthroplasty: a systematic review and meta-analysis. *Int J Med Robot* 2017; 13: e1843.
22. Hayashi S, Hashimoto S, Takayama K, et al. Evaluation of the accuracy of acetabular cup orientation using the accelerometer-based portable navigation system. *J Orthop Sci* 2020; 25(4): 612–617.
23. Suda K, Ito T, Miyasaka D, et al. Cup implantation accuracy using the HipCOMPASS mechanical intraoperative support device. *SpringerPlus* 2016; 5: 784.