

- 1 **HOW ACCURATELY CAN SURGEONS ACHIEVE THEIR DESIRED**
- 2 **ACETABULAR COMPONENT ORIENTATION?**

ABSTRACT

Introduction:

Wide variability in cup orientation achieved is reported. Cup orientation dialled by the surgeon at implantation determines the resultant component orientation. The aims of this study were to determine how accurate surgeons are at orientating the acetabular component and whether factors such as visual cues and side of operating table improved accuracy.

Methods:

A pelvic model was positioned in neutral alignment on a theatre table and prepared as per a posterior approach. 21 surgeons (10 trainers and 11 trainees) were tasked with positioning an acetabular component in a series of target orientations. The orientation of the component was measured using stereo-photogrammetry and the difference between the achieved and the target orientation was calculated. Tasks included: stating what surgeon's preferred orientation is and thereafter placing the cup in that orientation; reproducing visual cues (transverse acetabular ligament and alignment jig), altering orientation by 10° and estimating orientation whilst on the assistant's side.

Results:

The preferred inclination/anteversion was 42/21°. On average surgeons decreased the inclination by 4° and increased the anteversion by 11° when tasked with replicating their desired orientation. The intra- and inter-surgeon variability (defined as 2SD) in achieving a target orientation was 10-16°. The use of visual cues, such as the transverse acetabular ligament or the alignment guide, significantly improved accuracy for both inclination and anteversion to 3°. In addition, the use of an alignment guide reduced the variability by a third. Trainees and trainers had similar accuracy and variability. There is greater variability in assessing cup inclination when standing on the assistants' compared to the surgeon's side of the table, which has implications for training.

28 ***Conclusions:***

29 Surgeons overestimate operative inclination and under-estimate anteversion, which is of
30 benefit as this, on average, helps achieve the desired radiographic cup orientation. Although
31 the use of visual cues helps, conventional techniques result in a large variability in acetabular
32 component orientation. New and better guides and methods for training need to be developed.

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34 Level of evidence: II (Prospective cohort study)

INTRODUCTION

Acetabular component (cup) orientation is an important determinant of outcome following hip arthroplasty. It can influence range of movement¹, dislocation², wear³, functional outcome⁴ and implant survival⁵. Although surgeons aim to achieve optimal cup orientation, many studies demonstrate their inability to consistently achieve this. Evidence suggests there is $\pm 15^\circ$ of variability in cup orientations, even in the hands of experienced surgeons^{6,7}. It is generally thought that $\pm 10^\circ$ is acceptable⁸. More recent evidence suggests that to decrease the dislocation rate $\pm 15^\circ$ is required, whereas to optimise clinical outcome a zone as small as $\pm 5^\circ$ may be necessary⁴.

Factors that may contribute to this large variability include patient anatomy, positioning and movement during surgery⁹. An important surgical factor is the surgeon's ability to correctly orientate the cup at implantation⁷. Whilst some surgeons aim for a given cup orientation, others utilise anatomical cues, such as the transverse-acetabular-ligament (TAL), aiming to reproduce native acetabular version¹⁰⁻¹².

The ability of surgeons to estimate uniplanar angles has been tested in spinal and deformity surgery, with reported errors of around 5° and a variability of 10° ^{13,14}. However, cup orientation angles are complex 3-dimensional angles that are measured in different ways depending whether the angles are assessed operatively, radiographically or anatomically¹⁵. The accuracy with which surgeons can achieve specific cup inclination and anteversion angles and the accuracy to which surgeons can assess these angles has not previously been studied.

The study's primary aim was to determine the accuracy with which surgeons can achieve cup orientation angles. Secondary aims were to: a) investigate whether anatomical and visual cues affected that ability; b) evaluate whether trainees or trainers are more accurate and c) determine whether standing on the assistant's side of the table affected ability to estimate cup orientation.

METHODS

Setting and Subjects

This *in-vitro* study was undertaken in a theatre suite of a university teaching hospital. IRB approval was obtained and all participants gave informed consent. The participants (n=21) included arthroplasty attending surgeons and orthopaedic trainees/residents. Consultants had been appointed for at least 5-years and had performed between 800 – 6000 hip arthroplasties to date, with an annual rate of at least 30 cases. Post-fellowship surgeons had performed over 150 arthroplasties. To be eligible for inclusion, each trainee had to have completed at least an arthroplasty placement and performed at least 20 hip arthroplasties; evidence suggests that the learning curve for cup orientation, stabilizes after 20 procedures^{16,17}. Consultants (n=7) and post-fellowship participants (n=2) were considered as trainers, whilst residents were considered as trainees (n=12).

Measurement Technique

Measurements of cup orientation were made using a validated (Appendix A) stereo-photogrammetry protocol⁷ with an accuracy of 1°. Stereo-photogrammetry allows the spatial measurement of three-dimensional (3-D) objects from a stereo-pair set of images. Common points are identified on each image and if the location of each camera relative to the image plane is known, the 3-D coordinates and hence location can be determined. A custom

application, FotopTM, written in Matlab (R2011, The MathWorks, Natick, MA, USA) was developed to perform the measurements.

The object of interest was the cup introduce and it's 3-D location was captured. The resulting measurements allowed determination of cup orientation. A stereo-pair of images were captured following each of the tasks with the introducer still attached in order to measure the 3-D location of the cup introducer. Knowledge of the 3-D location of the cup introducer relative to theatre table enabled calculation of the operative cup inclination and anteversion¹⁵.

Benchtop Hip Model

A SAWBONES®hemipelvis model (ERP 1174) was used. The model has a hemipelvis articulating with a proximal femur and includes articular capsule, acetabular labrum and simulated gluteus maximus and medius muscles. The acetabular size of the model used was 48mm. The model was prepared with a posterior approach to the hip as this is the most commonly performed approach in our institution. The approach was performed by two of the co-authors; the distal insertion of gluteus maximus was released in order to expose the capsule (no external rotators in the model) and a T-capsulotomy was performed. The hip was then dislocated and the femoral neck was cut as per standard practice. The exposure allowed 360° visualisation of the acetabulum without any soft-tissue impingement during the tasks.

Cup Orientations Tasks

A standard theatre table (Schaerer, Moosseedorf, CH) was used and was placed in the centre of the laminar flow enclosure of the theatre suite. The hemipelvic model was secured to the operating theatre in a 'neutral' position with all 3 planes of the model positioned orthogonal to the theatre table and suite (Figure 1). **The Anterio-Superior-Iliac-Spine and the Pubic-**

Symphysis were equi-distant from the edge of the operating table, therefore the anterior pelvic plane relative to the operating table was zero-degrees. The model was then draped and the table was set at the desired height for each subject. Theatre space was calibrated and subjects were asked to perform several tasks. All tasks involved placing a 48mm Trilogy (Zimmer, Warsaw, USA) cup, mounted on its introducer, in the requested operative orientation within the model's unreamed acetabulum. Prior to the tasks, the subjects were informed of the hemipelvis' neutral position relative to the table and theatre enclosure and identified all anatomical features required for acetabular preparation and cup implantation. Thereafter they stood where the operating surgeon stands, an assistant provided good exposure of field and they were provided with the cup on its introducer. During the tasks, subjects were photographed when they were satisfied that they had achieved the desired cup orientation for that particular task. The stereopair of images obtained was used to capture the cup's introducer, enabling calculation of the operative cup orientation (Figure 2).

Five tasks were performed; four of which tested subjects as the "Primary" surgeon and one tested them as the "Assistant" (standing on opposite side of table, i.e. anterior surface of hemi-pelvis). Inbetween each task, subjects were asked to remove the cup from within the hemipelvis. The tasks were the following:

1. Preferred Vs. Measured cup orientation:

Subjects stated what their preferred cup inclination/anteversion is; they were then asked to position the cup in this orientation and a stereopair of photographs was captured. Thereafter the intended, preferred orientation was compared with the measured (actual) orientation.

2. Effect of anatomical cues on actual vs intended inclination.

Orientating the cup parallel to the model's TAL with an inclination of the subject's preference.

3. Ability to achieve a given orientation and alter it by small amounts

Orientating the cup (freehand) at an estimated inclination/anteversion angle of 40°/15°; thereafter increasing the anteversion by 10° to achieve an orientation of 40°/25°; and thereafter increasing the inclination by 10° in order to achieve an orientation of 50°/25°.

4. Instrumented cup placement (replicating alignment guide)

Using the alignment device with the impactor in order to achieve the pre-determined orientation of the device relative to the pelvic plane/axis of table. The alignment jig is a X-bar type with a predetermined inclination/anteversion of 45/20°^{18,19}.

5. Effect of operator vs assistant perspective

Positioning themselves in the assistant's side and estimating the cup angle when held in position by another surgeon (assistant task).

Analyses

Each task was analysed separately. Variability was defined as 2x Standard Deviation (SD). Measurements obtained were operative inclination/anteversion¹⁵. These measurements were converted to radiographic measurements using Murray's equations¹⁵. The optimum cup orientation zone was defined as having a radiographic inclination/anteversion of 45°/15° ± 10°⁸.

Differences between measured operative values and intended (as per task) orientation values were defined as Δ orientation and calculated as:

Δ inclination= Measured operative inclination – Intended inclination

$\Delta\text{anteversion} = \text{Measured operative anteversion} - \text{Intended anteversion}$

Differences between calculated radiographic values and intended values were defined as

$\Delta\text{Radiographic } (\Delta R)$ and calculated as:

$\Delta R_{\text{inclination}} = \text{Calculated radiographic inclination} - \text{Intended inclination}$

$\Delta R_{\text{anteversion}} = \text{Calculated radiographic anteversion} - \text{Intended anteversion}$

Subanalyses

In order to identify whether reproducing visual cues aid surgical accuracy, $\Delta\text{inclination}$ of task 4 (reproducing alignment guide inclination) was compared to all other tasks; and $\Delta\text{anteversion}$ of tasks 2 and 4 (use of TAL and alignment guide) were compared to the other tasks. In order to assess whether surgical experience affected accuracy, the ability of trainers was compared to that of trainees. Lastly, the influence of surgeon location relative to the operating table, on the ability to estimate angles was tested by comparing findings between tasks 1 and 5.

Statistics

Statistical analyses were performed with IBM SPSS Statistics version 19, (SPSS, IBM, Chicago, IL, USA). Non-parametric statistical tests (Mann-Whitney *U*, Kruskal Wallis) were used. Chi-square test was used for cross-tabulated data; significance was defined as $p \leq 0.05$.

RESULTS

Preferred Vs Measured cup orientations (Task 1)

The preferred orientation had mean inclination of 42° (SD:3, range: 40–50°) and mean anteversion of 21° (SD:5, range: 5–30°) (Table 1). The measured operative orientation had an inclination of 38° (SD:6, range: 29–52°) and an anteversion of 33° (SD:7, range: 17–47°) (Figure 3). Δ inclination was -4° (SD:4, range: -11–7°) and Δ anteversion was 11° (SD:5, range: 2–20°). The calculated radiographic orientation had an inclination of 43° (SD:3, range: 33–62°) and anteversion of 23° (SD:4, range: 14–28°). Δ R orientation was 1° (SD:6, range: -7–17°) for inclination and 1° (SD:4, range: -7–8°) for anteversion. Fifteen cups (72%) were within LZ.

Cup anteversion relative to TAL (Task 2)

When surgeons were asked to reproduce TAL's anteversion, the mean operative anteversion was 34° (range: 17–45°) (Table 2). Δ anteversion was 2° but variability was 14°.

Ability to increase orientation by small amounts (Task 3)

When asked to increase anteversion by 10°, the mean increase achieved was 9° (SD:4, range: 1–17°) (Figure 4). Similarly, when asked to increase inclination by 10°, the mean increase achieved was 9° (SD:3, range: 3–17°).

Ability to achieve orientation of 45/20° without or with alignment jig (Task 4)

Use of the alignment device improved both accuracy and variability; operative inclination was 43° (SD:5, range: 24–49°) and operative anteversion was 24° (SD:5, range: 13–35°). Using the alignment device, the mean calculated radiographic inclination was 45° (SD:5,

range: 28–51°) and the mean calculated anteversion was 16° (SD:4, range: 10–25°). 20 cups (95%) were with LZ (Figure 5).

Ability to estimate orientation when on assistant's side (Task 5)

When asked to estimate cup orientation whilst standing on the assistant's side, Δ inclination was -6° (SD:7, range: -20–6°) and Δ anteversion was 8° (SD:6, range: -2–20°). Subject position relative to the operating table had no significant influence on the mean ability to estimate cup inclination ($p=0.6$); however, when subjects were on the assistant's side, they were better in determining anteversion by 3° ($p=0.03$), which is probably not clinically significant. The variability in estimating cup inclination was 14° on the assistant's side, compared to 8° whilst on the surgeon's side (Task 1) (Figure 6).

Subanalyses

Use of the alignment jig significantly reduced Δ inclination (mean:-3°, SD:5, range: -21–4°) compared to all other tasks (mean:-6°, SD:6, range: -24–7°) (Table 3, Figure 5). It similarly reduced Δ anteversion (mean:3°, SD: 5, range: 7–15°) compared to all other tasks (mean:8°, SD: 8, range: -17 – 28°)($p<0.001$). Use of the TAL and alignment jig significantly reduced Δ anteversion (1°, SD:7 , range: -19–15°) compared to all other tasks (11°, SD:7, range: -9–28°) ($p<0.001$). There were no significant differences in any of Δ orientation between trainers and trainees, except for tasks 4 and 5 (Table 4). Trainees showed greater accuracy in reproducing the orientation using the jig and in estimating operative anteversion when on the assistant's side.

DISCUSSION

This is the first study to investigate the ability of surgeon to estimate cup orientation angles. This was assessed both in terms of Δ orientation and variability; the Δ orientation being the mean difference between the orientation angles the surgeons aimed to achieve and the actual angle they achieved and the variability being 2xSDs of this measurement (ie about 95% of times orientations were within the quoted variability). It was found that surgeons were inaccurate, despite them knowing that their accuracy was being assessed. The Δ orientation was commonly about 10° for anteversion and 5° for inclination. The variability was also large being about $\pm 15^\circ$ for anteversion and $\pm 10^\circ$ for inclination. The errors are large and need to be understood so that they can be addressed.

The final position of the acetabular component depends on many factors⁶, not just the cup orientation at implantation⁷. Surgeons may at times adjust cup orientation in order to account for pelvic position at the time of impaction. Furthermore, factors such as body habitus, appearance of acetabulum and its edges, the presence of a patient's thigh can all affect a surgeon's estimation of cup orientation⁶. A standardised pelvic model was used in order to eliminate the above factors which, potentially influence accuracy. Therefore, this study reports on the best accuracy possible in estimating cup orientation.

We measured cup orientation using the surgeons reference system (operative definitions). Clinically, cup orientation is assessed on post-operative radiographs using a different reference system (radiographic definitions). Interestingly although the Δ orientation using the operative definitions was large (Δ inclination approx -5° and Δ anteversion approx 10°) there was no Δ orientation using the radiographic definitions (Tasks 1&5; Δ Rinclination: 0° and Δ Ranteversion: 0°). It is the radiographic definitions that matter as target orientation is

assessed with these definitions. It is difficult to explain why there is no Δ orientation with the radiographic definitions: it may be that surgeons have, through trial and error, appreciated that in order to achieve a given radiographic orientation target they should reduce operative inclination and increase operative anteversion. Whatever the reason, as there is no Δ orientation with the radiographic definition, we do not necessarily need to develop methods to alter the Δ orientation. What really matters is the variability.

Use of an alignment guide improved variability in anteversion by a third (Fig 5). It would therefore seem sensible to routinely use alignment guides. It was however surprising that even with the alignment guide, variability was still about $\pm 10^\circ$. The alignment guide is a mechanical device and it would seem likely that the design could be improved to reduce variability. With the guide there was minimal Δ orientation in achieving the required operative angles (Δ inclination / Δ anteversion was $-3^\circ/3^\circ$), but what is needed is the appropriate radiographic angles. As previously highlighted most current cup alignment guides have too high an operative inclination and perhaps not enough anteversion to achieve radiographic targets¹⁸.

Aiming to reproduce TAL anteversion resulted in the same variability as freehand implantation. If an alignment guide is used, the variability in pelvic orientation at impaction increases the variability in subsequent cup orientation; whereas if TAL is used, the variability in pelvic orientation has less effect on cup orientation (especially version).

Comparing the different surgeons (tasks 1-4), we found that although they were aiming for the same target they implanted the cups in significantly different orientations, and their individual variability was less than the overall variability (Figure 7). In addition we found

there was no difference between trainees and trainees. This suggest that the current method of training is not very good and that accuracy could possibly be improved by new teaching methods. There was greater variability in the ability to estimate inclination whilst on the assistant's side and we therefore suggest caution for trainers when on the assistants' side of the table helping an inexperienced surgeon on the surgeons' side.

This study has a number of limitations. Firstly, it is an *in vitro* study with the use of a hemipelvic model, which does not accurately simulate *in vivo* situations. However, this model allowed for accurate positioning and maintenance of neutral pelvic alignment and enabled testing in the surgical environment without introducing undesired increases in surgical time. Assuming that the *in vivo* setting induces more variables (orientation/hemisphericity of reaming surface, maintaining desired orientation when impacting component, bleeding, compromised visibility, soft-tissue impingement, osteophyte presence), it is likely that variability would be even higher during live surgery; this complies with findings of previous reports⁶. Secondly, orientations were captured without the cup being impacted. However, it is arguable that although cup impaction would have improved stability of the cup within the model it may have affected desired measurements; occasionally after impaction the cup angle is different to the desired one as the cup may catch on one side when impacted. Thirdly, we only tested one alignment jig and hence results may not generalizable to other guides. However, Minoda *et al*¹⁸ showed equivocal ability of the tested guide compared to other guides in the market. Fourthly, this study tested the ability of surgeons to estimate angles - not necessarily the ability to obtain the ideal cup position. Lastly, we were unable to provide rapid feedback of the measurements, nor repeated the task at an interval time in order to establish repeatability. However, the critical role of feedback has previously been highlighted by Gofton *et al*²⁰ who demonstrated that real-time feedback using computer navigation can

304 result in improvement of cup positioning by surgical trainees in a simulated *in vitro*
305 environment.

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307 In summary, surgeons overestimate operative inclination and under-estimate anteversion,
308 which is of benefit as this, on average, helps achieve the desired radiographic cup orientation.
309 However there was large variability in cup orientation angles, which was helped slightly with
310 alignment guides. New and better guides and methods for training need to be developed.

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Figure Legends

Figure 1. Figure illustrating set-up including model, calibration object and theatre enclosure.

Figure 2. Stereo pair images of a trainee surgeon, simulating component at desired cup orientation.

Figure 3. Scatter plot of inclination Vs anteversion coded for preferred (hollow, bigger circles) and achieved (black dots) orientations

Figure 4. Box and whisker plots illustrating cup orientation angles (y-axis) for the different orientations in Task 3 (x-axis). Note colour coded for inclination and anteversion. Blue dot represents target orientation as per task. Graph is illustrating ability to increase either inclination or anteversion by 10° .

Figure 5. Figure illustrating a: Scatter plot of inclination Vs anteversion illustrating orientations achieved with Task 4 (replicating alignment guide orientation ($45/20^{\circ}$)). b/c: Box and whisker plots of Δ inclination(b) and Δ anteversion (c) colour coded for the use of an alignment guide or not.

Figure 6. Box and whisker plots of Δ inclination (a) and Δ anteversion (b) colour coded for the the subject's position relative to the operating table.

Figure 7. Box and whisker plots showing Δ orientation and variability for the different surgeons for inclination (a) and anteversion (b). Note that 17/21 surgeons had variability of 10° within inclination target, whilst 8/21 surgeons had variability of 10° within target anteversion.

Appendix Figure.1. Schematic of the calibration object used for the manufacturing process and photograph of the object during measurements performed at the Oxford Gait Laboratory.

Appendix Figure 2. Photograph captured during technique validation demonstrating the calibration object and the testing wand in the Oxford Gait Laboratory.