Pelvic Positioning in the Supine Position Leads to More Consistent Cup Orientation after Total Hip Arthroplasty

Abstract

Aims: This study aims to 1) Determine the difference in pelvic position that occurs between surgery and radiographic, supine, post-operative assessment; 2) Examine how the difference in pelvic position influences subsequent cup orientation and 3) Establish whether pelvic position, and thereafter cup orientation differences exist between THAs performed in the supine versus the lateral decubitus positions.

Materials and Methods: 321 THAs who had intra-operative, post-cup impaction, AP pelvic radiograph, in the operative position were studied; 167 were performed with patient supine (anterior approach), whilst 154 were performed in lateral decubitus (posterior approach). Cup inclination/anteversion was measured from intra- and post-operative radiographs and difference (Δ) was determined. The target zone was inclination/anteversion of 40/20°±10°. Change in pelvic position (tilt, rotation, obliquity) between surgery and post-operatively was calculated from Δinclination/anteversion using the Levenberg-Marquardt algorithm.

Results: The post-operative inclination/anteversion was 40°±8/23°±9. 74 had $\Delta_{inclination}$ and/or $\Delta_{anteversion}$>±10° (21%). Intra-operatively (compared to post-operative), the pelvis was on average 4°±10 anteriorly tilted; 1°±10 internally rotated and 1°±5 adducted. Having $\Delta_{inclination}$ and/or $\Delta_{anteversion}$ >±10° was associated with a 3.5 odds ratio of having a cup outside the target.

A greater proportion of hips operated in the lateral decubitus had $\Delta_{inclination}$ and/or $\Delta_{anteversion}$ >±10° (54/153), compared to supine (8/167) (p<0.001). A greater number of cups achieved the target orientation in supine (120/167;73%), compared to lateral position (67/153;44%) (p<0.001). Intra-operatively, pelvis was more anteriorly tilted (p<0.001) and hemi-pelvis was more internally rotated (p=0.04) in lateral position.

Conclusion: Pelvic movement is significantly less in supine position, which leads to more consistent cup orientation. Significant differences in pelvic tilt and rotation were seen in the lateral position.

Clinical Relevance: Understanding the differences in pelvic orientation and cup orientation between supine and lateral decubitus positions may facilitate better intraoperative practices for surgeons.

Introduction

Acetabular component (cup) orientation is an important determinant of outcome following total hip arthroplasty (THA)[1-3]. Radiographic assessments are typically, based upon post-operative, supine radiographic assessments[1, 3-5]. The resultant radiographic cup orientation is dependent upon a. the orientation the surgeon impacts the cup with and b. the position of the pelvis at impaction. Ideally, intra-operatively, the pelvis would have the same position (i.e. tilt, obliquity or rotation) relative to the operating table as the position at the time of radiographic assessment. In such conditions, the difference in cup orientation between operative and radiographic orientations is small and predictable from Murray's nomograms[6].

In vivo studies have shown that the great variability in post-operative cup orientations is largely due to the inconsistency in pelvic position at the time of impaction[7-11]. This occurs because of the great variability in the pelvic position at set-up and due to the inconstant amount of pelvic movement that occurs during the procedure. However, none of the studies to-date has characterized what the position of the pelvis is during non-navigated THA relative to the pelvic position at the time of the typical, post-operative assessment and whether patient-position during the procedure has an effect.

The aims of this study were to 1) Determine the difference in pelvic position (tilt, obliquity, rotation) that occurs between the time of surgery and the time of radiographic, supine, post-operative assessment; 2) Examine how the difference in pelvic position influences subsequent cup orientation and 3) Establish whether pelvic orientation, and thereafter cup orientation, differences exist between THAs performed in the supine (Direct anterior approach (DAA)) versus the lateral (posterior approach) decubitus positions.

Methods

This is an IRB-approved, retrospective, multi-surgeon, consecutive case series from a single tertiary center. Inclusion criteria included a well-fixed acetabular component and a good quality, intra-operative, AP pelvic radiograph performed post-cup impaction with the patient in the operated position.

Cohort

Cases studied included THAs performed in the period of 2014–5. It is routine practice in our centre to obtain an intra-operative anteroposterior (AP) pelvic radiograph following component implantation, with the patient in the operated (lateral- or supine-) position prior to choosing optimum femoral head length. None of the surgeons use fluoroscopy during any stage of the procedure.

Intra-operative radiographs were obtained in a standardized fashion (Figure 1). Prior to obtaining the radiographs all of the retractors were removed and the reduced hip joint and leg were placed in neutral, resting, position as per approach used (legs straight in supine and hips/knees slightly flexed in lateral). With the patient in the supine position, on the orthopaedic positioning table with the non-surgical limb in slight counter-traction, the cassette was placed in an allocated slot (at right angle relative to the longitudinal axis of the operating table), at the level of the pelvis (centered just proximal to the pubic symphysis/ post of table) by a radiographer; the surgeon also confirmed appropriate placement. Thereafter, the radiographer placed the beam source at approximately 1100 mm from the cassette and an AP radiograph was obtained. In cases operated in the lateral decubitus, a cassette holder was placed behind the pelvis at the same level (just proximal to symphysis) by the surgeon. The holder was positioned parallel to the operating-table and the cassette was held at right angle relative to the transverse axis of the operating-table. Thereafter, the radiographer positioned the beam source at approximately 1100 mm from the cassette and an AP radiograph was obtained. Post-operatively, all patients had supine AP pelvic radiographs prior to discharge with a standardized, previously described method.[12]

Three arthroplasty-trained staff surgeons performed the procedures. Surgeon A has performed to date over 1000 THAs; his elective THAs during the initial study period, up to April 2015, were via a posterior approach (lateral decubitus), using a peg board (pegs inserted at level of ASISs and pubis). In April 2015, he switched to performing all THAs via the DAA with the patient supine using an orthopaedic positioning table. During the study period he performed 241 cases that were all enrolled in the study. The Dynasty acetabular component (MicroPort Orthopaedics, Arlington, USA) was used for the posteriorly approached THAs, whilst the G7 cup (Zimmer Biomet, Warsaw, IN, USA) was used for the DAA-THAs; alignment guides aided cup implantation.

In order to prevent any surgeon-related biases, consecutive cases from 2 additional surgeons, performed over the same period, were included in the study. Surgeon B is an experienced arthroplasty surgeon having performed over 3000 cases. Since 2006 all THAs in his elective practice are performed via the DAA using an orthopaedic positioning table; the G7 cup (Zimmer Biomet, Warsaw, IN, USA) was implanted. Surgeon C is a fellowship-trained arthroplasty surgeon who has performed 400 cases to-date. All of his THAs are performed with the patient in a lateral decubitus position, supported by a peg-board in a similar arrangement to Surgeon A, using a posterior approach; the G7 cup (Zimmer Biomet, Warsaw, IN, USA) was implanted in all cases. Surgeons B and C used alignment guides to aid cup implantation.

Overall, 340 consecutive, cases were reviewed over the study period (Figure 2), of these 326 fulfilled the study's criteria and were included for further analysis. The cohort included 228 THAs from surgeon A (118 DAA-THA and 110 Posterior-THA), 50 DAA-THAs from Surgeon B and 48 Posterior-THAs from Surgeon C. Patient demographics, including surgical details are included in Table 1.

Radiographic assessments

Using a validated software (EBRA-cup)[13], cup orientations (inclination/ anteversion) were measured from intra- and post-operative pelvic radiographs. An arthroplasty fellow performed all measurements; 20 cases underwent repeat analysis by the same reader in order to test intra-observer reliability. Furthermore, a second reader performed 20 measurements to assess inter-observer reliability.

The differences between intra- and post-operative cup orientations, $\Delta_{inclination}$ and $\Delta_{anteversion}$, were calculated as:

$\Delta_{inclination} = Inclination_{post\text{-}op} - Inclination_{intra\text{-}op}$

$\Delta_{anteversion} = Anteversion_{post\text{-}op} - Anteversion_{intra\text{-}op}$

Differences in pelvic orientation

Pelvic orientation was defined in terms of rotation along the 3-axes of the body; namely rotation (Longitudinal-axis), obliquity (Antero-posterior-axis) and tilt (Transverse-axis) (Figure 3). The differences in pelvic orientation between the intra-operative and post-operative assessments were determined using the AP pelvic radiographs.

Obliquity was determined from the radiographs as the angle between the inter-tear drop line and the horizontal. As the cassette was placed in line with the operating/radiographic table, an inter-tear drop line parallel to the horizontal would equate to zero obliquity. Positive rotation about the frontal axis leads to abduction of the operated hemipelvis.

The difference in pelvic obliquity (Δobliquity) was calculated as:

$\Delta_{obliquity} = Obliquity_{post\text{-}op} - Obliquity_{intra\text{-}op}$

Having determined $\Delta_{obliquity}$, $\Delta_{inclination}$ and $\Delta_{anteversion}$, the change in pelvic tilt and rotation between the two times-points (intra-operative and post-operative) was calculated.

Since obliquity is a measure about the frontal axis this was corrected for by a rotation about the frontal axis to neutral. An optimization approach (Levenberg-Marquardt algorithm) was used to determine the rotation angles about the transverse (tilt) and longitudinal (rotation) axes required for the intra-operative inclination and anteversion to match the measured post-operative inclination and anteversion angles (Appendix A, Figure 4). These angles represented Δ_{tilt} and $\Delta_{rotation}$ respectively. The calculations were performed using a custom routine (Matlab 2014b, The Maths Works Inc., USA).

The combined (for both inclination and anteversion) angular error on obtaining the post-operative from the intra-operative angles, by rotating the pelvic coordinate system was 0.14° (SD: 1.0°). Cases with angular errors (n=6) greater than 2° were excluded from further analysis as they did not fit the mathematical model accurately enough.

Outcome measures

Outcome measures of interest included intra-/post-operative inclination/anteversion, $\Delta_{inclination/anteversion}$, and $\Delta_{obliquity/tilt/rotation}$ for the whole cohort. Furthermore, we aimed to identify how $\Delta_{obliquity/tilt/rotation}$ influence $\Delta_{inclination/anteversion}$ and the ability to achieve a cup within a defined target zone. Lastly, the above parameters were compared as per patient position during THA (supine vs. lateral) and surgeon.

The target zone for all surgeons was inclination/anteversion of 40/20°±10°. A $\Delta_{inclination}$ or $\Delta_{anteversion}$ > ±10° was considered significant, as most zones have a 10° margin of error about a target.

Statistics

Variability was defined as 2 x standard deviations (SD). Non-parametric tests (Mann-Whitney U, Kruskal-Wallis, Spearman's rho) were used. The χ^2 test was used for cross-tabulated data. Statistical significance was defined as a $p \leq 0.05$. Analyses were performed with SPSS Statistics version 21, (IBM, Chicago, Illinois).

Results

Excellent intra- and inter- (interclass correlation coefficients>0.95, $p<0.001$) observer correlations were detected.

The cohort's mean intra-operative cup inclination/anteversion was 41/25°, whilst the mean post-operative cup inclination/anteversion was 40/23° (Table 2). Overall, 58% of cups (n=187/320) were within the target zone. The mean $\Delta_{inclination}$ was -1° (range: -37 to 26°), whilst the mean $\Delta_{anteversion}$ was -2° (range: -28 to 24°); 62 hips (19%) had either $\Delta_{inclination}$ or $\Delta_{anteversion}$ > ±10°. Intra-operatively (compared to post-operatively), the pelvis was on average 3.1° (range: -41 to 33°) anteriorly tilted; the operated hemi-pelvis was on average 0.2° (range: -39 to 38°) internally rotated and 1° (range: -19° to 12°) abducted (See appendix B). To-date none of the hips have dislocated, nor been revised.

$\Delta_{inclination}$ strongly correlated with Δ_{tilt} (rho=0.78, $p<0.001$) and $\Delta_{rotation}$ (rho=0.80, $p<0.001$) (Table 3). $\Delta_{anteversion}$ moderately correlated with Δ_{tilt} (rho=0.63, $p<0.001$) and weakly with $\Delta_{rotation}$ (rho=-0.35, $p<0.001$). Having a $\Delta_{inclination}$ or $\Delta_{anteversion}$ > ±10° was associated with an odds ratio of 3.5 in having a cup orientation outside the target zone (Figure 5). Hips with cups outside target zone had significantly greater $\Delta_{obliquity}$ (-1.7°±4.7 Vs. 0.4°±4.4; p=0.02) and $\Delta_{rotation}$ (-1.5°±11.3 Vs. 0.6°±7.9; p=0.01) compared to those with cups within target.

Similar mean cup inclination/anteversion were achieved between lateral decubitus (38/24°) and supine (41/23°) positions (Table 2). However, a greater variability (2xSD) in both inclination (18° Vs. 12°) and anteversion (21° Vs. 14°) was seen with the lateral compared to the supine position. A significantly greater number of cups achieved the target orientation in the supine (120/167;73%), compared to the lateral position (67/153;44%) ($p<0.001$). Hips operated in the lateral decubitus had a significantly greater $\Delta_{anteversion}$ (-5°±8°) compared to the supine (0°±5°) position ($p<0.001$). A greater proportion of hips operated in the lateral decubitus had $\Delta_{inclination}$ and/or $\Delta_{anteversion}$ > ±10° (54/153), compared to the supine position (8/167) ($p<0.001$) (Figure 6). A significantly greater pelvic tilt, obliquity and rotation was seen in the lateral position as detailed in Table 2.

No significant differences in cup and pelvic orientations were detected between surgeons in the supine position (Table 4). On the contrary, significant differences were detected between surgeons in the lateral position; $\Delta_{inclination}$ was different between Surgeon A (-4°) and surgeon B (+4°). This was due to differences in both Δ_{tilt} (-7° vs. 0°) and $\Delta_{rotation}$ (-2° vs. 8°) ($p<0.001$) observed in their THAs.

Discussion

In this study, similar to others[3, 14-17], a wide variability in cup inclination (16°) and anteversion (18°) is reported. Complimenting previous *in vivo work*[7, 9, 10], we measured what the difference in cup orientation is between the intra-operative and post-operative radiographs. Any such difference in cup orientation stems from the difference in pelvic position provided the cup is securely fixed. Although, on average no significant difference in Δinclination (-1°) and Δanteversion (-2°) was detected, the variability of both values was considerable (12° and 14°, respectively). Furthermore 1/5 of cases had a $\Delta_{\text{inclination}}$ and/or $\Delta_{\text{anteversion}} > \pm 10°$; therefore even if all cups seemed in the centre of the target zone intra-operatively, the resultant cup orientation would be outside the zone in 20% of cases. In addition, we were able, for the first time in non-navigated THA, to calculate the difference in pelvic position about the 3 axes, between surgery and post-operative, supine, radiographic assessment – the gold standard of cup evaluation. Although, the mean differences in pelvic position were close to zero about all 3 axes, the variability detected was large (9-20°). By studying a number of surgeons and patient positions during surgery, we were able to show better ability to achieve cup orientation target with the supine position. This improved ability was secondary to the more reliable pelvic position when the patient was operated supine and demonstrated minimal inter-surgeon differences. With the patient in the lateral decubitus with the hips flexed (similar to a seated position), the variability was greater and furthermore, significant inter-surgeon differences were detected. It is evident, therefore, that when operating in the lateral decubitus, improved methods and devices are necessary, in non-navigated THA, in order to consistently position and hold the pelvis.

Non-navigated cup implantation is associated with great variability in post-operative orientation (12-21°) and inconsistent ability to achieve the target zone (44–88%)[3, 14, 15, 17-19]. Our findings (variability:18°, 58% within target) are in line with the above observations.

Similar to others, we found that cases operated supine illustrated superior accuracy and greater consistency[20-22].

The position of the pelvis has an influence on subsequent cup orientation and any deviation from ‘neutral’ will affect cup orientation in a predictable way. The optimization approach allowed us to determine the effect of pelvic movements on subsequent cup orientation *in vivo*. If the pelvis is tilted (rotation around transverse axis), this will affect primarily anteversion but also inclination; pelvic rotation (rotation around longitudinal axis) would influence primarily inclination and thereafter anteversion. Similar observations have been reported *in vitro*[23]. Pelvic tilt is subject-specific and in cohort studies has been shown to vary significantly both when supine (range: -21 to 25°) and when moving from the supine to the seated position (-48 to 39°)[24-26]. The small differences in Δ_{tilt} measured in the supine position may be secondary to the capsular releases or the anaesthetic effect; similar changes of mostly less than 10° have been reported when measuring tilt pre- and post-arthroplasty[24, 27, 28]. The large difference in $\Delta_{tilt/rotation}$ in the lateral approach is probably a reflection of the pelvis being similar to a seated position when in the lateral decubitus (hips and knees flexed) and illustrates the surgeons’ inability to consistently have the pelvis in ‘neutral’ position as when in the supine position; this is further exacerbated by the movement that takes place during surgery[10, 11].

An additional factor contributing to the wide range of cup orientations reported in multi-surgeon series is the inter-surgeon variability in practice. This relates to: 1. The ability to judge and reproduce complex, 3-dimensional cup inclination/anteversion angles[29], 2. The perceived, individual, target zone each surgeon has[9, 30], 3. The ability to set the patient ‘square’ relative to the operative table[10] 4. The use of varying pelvic supports, which lead to different degrees of movement intra-operatively[10]. Although the ability to determine cup angles as they relate to a desired target zone is surgeon specific, ensuring that the patient is appropriately positioned and securely stabilized does provide opportunity for improved standardization. This may be less of a challenge in the supine position, with the pelvis having very little deviation from 'square' relative to the table. As a result, $\Delta_{tilt/rotation/obliquity}$ were similar between Surgeon A and Surgeon B and the difference in the post-operatively anteversion obtained was secondary to the varying anteversion used at impaction. On the contrary, inter-surgeon comparisons in the lateral position, showed significant differences in Δ_{tilt} and $\Delta_{rotation}$ and a resultant 8° difference in $\Delta_{inclination}$. As there was no difference in the post-operative cup inclination/anteversion achieved between Surgeons A and C, they must have used different orientations intra-operatively to impact the cup.

This study has a number of limitations. Firstly, it is a retrospective study and hence suffers from all limitations associated with retrospective studies. Secondly, despite every effort to standardize technique and placement of the beam centered on the middle of the pelvis in both radiographs, cassette and origin of beam variability is likely to occur due to a number of factors (e.g. inconsistency in identifying bony landmarks, body habitus, number of radiographers obtaining x-rays during study period). However, patients with poor quality films were excluded and only cases with small errors in the optimization scheme were included for analysis. Thirdly, a change in cup orientation between intra- and post-operatively may be a result of a loose cup. In order to minimize this possibility any cups with any lucent lines were excluded. Fourthly, this study did not include more contemporary intraoperative imaging techniques like digital radiography. With this technology, the AP pelvis radiograph can be optimized, minimising the effect of pelvic orientation when taking intraoperative radiographs and improve cup orientation achieved[31]. Lastly, our results have to be interpreted in view of the approach, the patient position and the type of supports used. For example, it is possible that an antero-lateral approach in the lateral position, an antero-lateral approach in the supine position or an anterior approach in the lateral position could all lead to different results. Similarly, different supports have been shown to influence pelvic movement *in vivo*[10] and hence the findings with the peg-board may not apply to other supports, which may provide greater stability.

In conclusion, big difference (±10°) in pelvic position between surgery and post-operative assessment is associated with a 3.5 times increase in cup mal-orientation. Pelvic position differences are less in the supine position, compared to the lateral decubitus, which results in more consistent cup orientation (smaller standard deviations). Greater differences in pelvic tilt and rotation were seen in the lateral position, illustrating the inability of surgeons to consistently position the pelvis when in the lateral decubitus. If radiographs are obtained in the lateral decubitus position, strong consideration should be given to contemporary techniques that account for pelvic position.

References

1. **Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, Stockl B.** Reducing 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. **Patil S, Bergula A, Chen PC, Colwell CW, Jr., D'Lima DD.** Polyethylene wear and acetabular component orientation. *J Bone Joint Surg Am*. 2003;*85-A Suppl 4:56-63*.
3. **Grammatopoulos G, Thomas GE, Pandit H, Beard DJ, Gill HS, Murray DW.** The effect of orientation of the acetabular component on outcome following total hip arthroplasty with small diameter hard-on-soft bearings. *Bone Joint J*. 2015;*97-B(2):164-72*.
4. **Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR.** Dislocations after total hip-replacement arthroplasties. *J Bone Joint Surg Am*. 1978;*60(2):217-20*.
5. **Esposito CI, Walter WL, Roques A, Tuke MA, Zicat BA, Walsh WR, et al.** Wear in alumina-on-alumina ceramic total hip replacements: a retrieval analysis of edge loading. *J Bone Joint Surg Br*. 2012;*94(7):901-7*.
6. **Murray DW.** The definition and measurement of acetabular orientation. *J Bone Joint Surg Br*. 1993;*75(2):228-32*.
7. **Asayama I, Akiyoshi Y, Naito M, Ezoe M.** Intraoperative pelvic motion in total hip arthroplasty. *J Arthroplasty*. 2004;*19(8):992-7*.
8. **Hill JC, Gibson DP, Pagoti R, Beverland DE.** Photographic measurement of the inclination of the acetabular component in total hip replacement using the posterior approach. *J Bone Joint Surg Br*. 2010;*92(9):1209-14*.
9. **Grammatopoulos G, Pandit HG, da Assuncao R, McLardy-Smith P, De Smet KA, Gill HS, et al.** The relationship between operative and radiographic acetabular component orientation: which factors influence resultant cup orientation? *Bone Joint J*. 2014;*96-B(10):1290-7*.
10. **Grammatopoulos G, Pandit HG, da Assuncao R, Taylor A, McLardy-Smith P, De Smet KA, et al.** Pelvic position and movement during hip replacement. *Bone Joint J*. 2014;*96-B(7):876-83*.
11. **Ezoe M, Naito M, Asayama I, Ishiko T, Fujisawa M.** Pelvic motion during total hip arthroplasty with translateral and posterolateral approaches. *J Orthop Sci*. 2005;*10(2):167-72*.
12. **Clohisy JC, Carlisle JC, Beaule PE, Kim YJ, Trousdale RT, Sierra RJ, et al.** A systematic approach to the plain radiographic evaluation of the young adult hip. *J Bone Joint Surg Am*. 2008;*90 Suppl 4:47-66*.
13. **Langton DJ, Sprowson AP, Mahadeva D, Bhatnagar S, Holland JP, Nargol AV.** Cup anteversion in hip resurfacing: validation of EBRA and the presentation of a simple clinical grading system. *J Arthroplasty*. 2010;*25(4):607-13*.
14. **Digioia AM, 3rd, 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*.
15. **Callanan MC, Jarrett B, Bragdon CR, Zurakowski D, Rubash HE, Freiberg AA, 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(2):319-29*.
16. **Barrack RL, Krempec JA, Clohisy JC, McDonald DJ, Ricci WM, Ruh EL, et al.** Accuracy of acetabular component position in hip arthroplasty. *J Bone Joint Surg Am*. 2013;*95(19):1760-8*.

17. **Domb BG, El Bitar YF, Sadik AY, Stake CE, Botser IB.** Comparison of robotic-assisted and conventional acetabular cup placement in THA: a matched-pair controlled study. *Clin Orthop Relat Res*. 2014;*472(1):329-36*.
18. **Beamer BS, Morgan JH, Barr C, Weaver MJ, Vrahas MS.** Does fluoroscopy improve acetabular component placement in total hip arthroplasty? *Clin Orthop Relat Res*. 2014;*472(12):3953-62*.
19. **Eilander W, Harris SJ, Henkus HE, Cobb JP, Hogervorst T.** Functional acetabular component position with supine total hip replacement. *Bone Joint J*. 2013;*95-B(10):1326-31*.
20. **Hamilton WG, Parks NL, Huynh C.** Comparison of Cup Alignment, Jump Distance, and Complications in Consecutive Series of Anterior Approach and Posterior Approach Total Hip Arthroplasty. *J Arthroplasty*. 2015;*30(11):1959-62*.
21. **Slotkin EM, Patel PD, Suarez JC.** Accuracy of Fluoroscopic Guided Acetabular Component Positioning During Direct Anterior Total Hip Arthroplasty. *J Arthroplasty*. 2015;*30(9 Suppl):102-6*.
22. **Soderquist MC, Scully R, Unger AS.** Acetabular Placement Accuracy With the Direct Anterior Approach Freehand Technique. *J Arthroplasty*. 2017;*32(9):2748-54*.
23. **Ranawat CS, Ranawat AS, Lipman JD, White PB, Meftah M.** Effect of Spinal Deformity on Pelvic Orientation from Standing to Sitting Position. *J Arthroplasty*. 2016;*31(6):1222-7*.
24. **Babisch JW, Layher F, Amiot LP.** The rationale for tilt-adjusted acetabular cup navigation. *J Bone Joint Surg Am*. 2008;*90(2):357-65*.
25. **DiGioia AM, Hafez MA, Jaramaz B, Levison TJ, Moody JE.** Functional pelvic orientation measured from lateral standing and sitting radiographs. *Clin Orthop Relat Res*. 2006;*453:272-6*.
26. **Pierrepont J, Hawdon G, Miles BP, Connor BO, Bare J, Walter LR, et al.** Variation in functional pelvic tilt in patients undergoing total hip arthroplasty. *Bone Joint J*. 2017;*99-b(2):184-91*.
27. **Maratt JD, Esposito CI, McLawhorn AS, Jerabek SA, Padgett DE, Mayman DJ.** Pelvic tilt in patients undergoing total hip arthroplasty: when does it matter? *J Arthroplasty*. 2015;*30(3):387-91*.
28. **Murphy WS, Klingenstein G, Murphy SB, Zheng G.** Pelvic tilt is minimally changed by total hip arthroplasty. *Clin Orthop Relat Res*. 2013;*471(2):417-21*.
29. **Grammatopoulos G, Alvand A, Monk AP, Mellon S, Pandit H, Rees J, et al.** Surgeons' Accuracy in Achieving Their Desired Acetabular Component Orientation. *J Bone Joint Surg Am*. 2016;*98(17):e72*.
30. **Beverland DE, O'Neill CK, Rutherford M, Molloy D, Hill JC.** Placement of the acetabular component. *Bone Joint J*. 2016;*98-B(1 Suppl A):37-43*.
31. **Penenberg BL, Samagh SP, Rajaee SS, Woehnl A, Brien WW.** Digital Radiography in Total Hip Arthroplasty: Technique and Radiographic Results. *J Bone Joint Surg Am*. 2018;*100(3):226-35*.

Table 1. Demographics of the Cohort

		Cohort (n=321)	Surgeon A (n=223)	Surgeon B (n=50)	Surgeon C (n=48)	p-value
Age/ years old						
Gender	Male	152 (47)	114	19	19	0.15
	Female	171 (53)	114	31	29	
Height (m)		1.69	170	168	164	0.63
Weight (Kg)		81.5	83.0	83.5	80.0	0.42
BMI (Kg/m^2)		28.5 ±6	27.9 ±6	29.9 ±7	29.7 ±5	0.11
Side	Right	172	120	28	24	0.65
	Left	147	103	22	24	
Patient Position	Supine	167 (52)	118 (53)	50	-	n/a
	Lateral	159 (48)	111 (47)	-	48	
Approach	DAA	167 (52)	117 (53)	50	-	n/a
	'Posterior'	159 (48)	111 (47)	-	48	
Cup size/mm		53.7	54.2	53.1	53.8	0.12

Table 2: Cup and pelvic orientation measurements and calculations for the whole cohort and

Parameter	**Cohort** (n=321)	**Patient Position**		
		Supine (n=167)	*Lateral (n=154)*	p-value
Inclination Intra-operatively/°	40.9 ± 8	41.6 ± 7	40.1 ± 9	0.16
Anteversion Intra-operatively/°	25.4 ± 9	22.8 ± 5	28.3 ± 11	<0.001*
Inclination Post-operatively/°	40.0 ± 8	41.1 ± 6	38.8 ± 10	0.02*
Anteversion Post-operatively/°	23.1 ± 9	22.7 ± 7	23.6 ± 10	0.28
% in Optimum Cup Zone	58 %	72%	44%	<0.001*
Δinclination/°	-0.9 ± 6	-0.5 ± 3	-1.3 ± 8	0.2
Δinclination >±10 (n, %)	26 (8)	3 (2)	23 (15)	<0.001*
Δanteversion/°	-2.2 ± 7	-0.1 ± 5	-4.7 ± 8	<0.001*
Δanteversion >±10 (n, %)	46 (14)	7 (4)	39 (26)	<0.001*
Δinclination ± Δanteversion >±10 (n, %)	62 (19)	8 (5)	54 (35)	<0.001*
Δobliquity/°	-1.0 ± 10	-0.9 ± 5	-1.0 ± 4	0.58
Δtilt/°	-3.1 ± 9	-1.4 ± 9	-4.9 ± 10	<0.001*
Δrotation/°	-0.2 ± 10	-1.4 ± 6	1.1 ± 12	0.04*

as per patient position. *: statistical significance

Table 3: Correlation of differences in cup orientation with the differences in pelvic position.

Parameter	Δinclination	Δanteversion
Δobliquity	ρ=0.04 p=0.48	ρ=-0.05 p=0.42
Δtilt	ρ=0.73 p<0.001	ρ=0.63 p<0.001
Δrotation	ρ=0.80 p<0.001	ρ=-0.36 p<0.001

Table 4: Cup and pelvic orientation measurements and calculations as per patient position and surgeon.
*statistical significance

Parameter	**Surgeon-Position**					
	B (n=50)	*A-supine (n=117)*	*p-value*	*C (n=48)*	*A-lateral (n=106)*	p-value
Inclination intra-operatively/°	38.9 ± 6	42.7 ± 6	<0.001*	37.5 ± 10	41.2 ± 8	0.03*
Anteversion intra-operatively/°	21.7 ± 5	23.2 ± 5	0.2	23.4 ± 12	30.5 ± 10	<0.001*
Inclination post-operatively/°	38.0 ± 6	42.4 ± 6	<0.001*	41.6 ± 9	37.5 ± 9	0.03*
Anteversion post-operatively/°	20.7 ± 7	23.5 ± 7	0.03*	18.0 ± 10	26.1 ± 10	<0.001*
% in Optimum Cup Zone	72%	72%	0.6	48%	42%	0.2
Δinclination/°	-0.9 ± 3	-0.4 ± 3	0.07	4.1 ± 6	-3.8 ± 7	<0.001*
ΔInclination >±10 (n, %)	1 (2)	2 (2)	0.9	7 (15)	16 (15)	0.9
ΔAnteversion/°	-1.0 ± 5	0.3 ± 5	0.2	-5.4 ± 7	-4.3 ± 8	0.4
ΔAnteversion >±10 (n, %)	2 (4)	5 (4)	0.9	13 (27)	26 (25)	0.8
ΔInclination or ΔAnteversion >±10 (n, %)	2 (4)	6 (5)	0.7	16 (33)	38 (36)	0.7
Δobliquity/°	-0.9 ± 4	-0.9 ± 5	0.8	-0.9 ± 4	-1.1 ± 4	0.7
Δtilt/°	-3.5 ± 9	-0.6 ± 7	0.03*	0.0 ± 8	-7.1 ± 11	<0.001*
Δrotation/°	-2.5 ± 6	-0.9 ± 6	0.1	8.5 ± 11	-2.5 ± 11	<0.001*