Citation for published version:
Grammatopoulos, G, Thomas, GER, Pandit, H, Beard, DJ, Gill, HS & Murray, DW 2015, 'The effect of orientation of the acetabular component on outcome following total hip arthroplasty with small diameter hard-on-soft bearings', The Bone & Joint Journal, vol. 97-B, no. 2, pp. 164-72. https://doi.org/10.1302/0301-620X.97B2.34294

DOI:
10.1302/0301-620X.97B2.34294

Publication date:
2015

Document Version
Early version, also known as pre-print

Link to publication

THE EFFECT OF CUP ORIENTATION ON OUTCOME FOLLOWING TOTAL HIP ARTHROPLASTY WITH SMALL DIAMETER HARD-ON-SOFT BEARING

ABSTRACT

We assessed the acetabular orientation in 1,070 primary THAs with hard-on-soft, small diameter bearings, aiming to determine the size and site of the target zone that optimises outcome. Outcome measures included complications, dislocations, revisions and ∆OHS (difference between pre-operative and at 5-year Oxford Hip Scores). A wide scatter of cup orientations was observed (2SD ±15°). Lewinnek's zone was not associated with improved outcome. Of the different zone sizes tested (±5°, ±10° and ±15°) only ±15° was associated with a decreased dislocation rate. The dislocation rate of cups inside an inclination/anteversion zone of 40°/15° ±15° was four times lower than those outside. The only zone size associated with statistically significant and clinically important improvement in OHS was ±5°. Best outcomes (∆OHS >26) were achieved with a 45°/25° ± 5° zone. This study demonstrated that with traditional technology surgeons can only reliably achieve a target zone of ±15° (2SD). As the optimal zone to diminish dislocation risk is also ±15°, surgeons should be able to achieve this. This is the first study to demonstrate that optimal orientation improves functional outcome. However the target zone is small (±5°) and cannot, with current technology, be consistently achieved.

INTRODUCTION

Recent complications associated with hard-on-hard bearings have stimulated increased interest in optimal acetabular component (cup) orientation in hip arthroplasty[1,2]. Amongst all studies reported it is evident that a wide scatter of cup orientation is achieved even in the practice of experienced hip surgeons[3]. A recent study identified minimally invasive surgical approach, low-volume surgeons and obesity as factors increasing the risk of cup mal-orientation[3]. Component orientation is considered an important factor in improving range of movement, function and survival[4-6], and minimising complications following Total Hip Arthroplasty (THA), although the evidence is weak for hard-on-soft bearings.

The most common early and mid-term THA failure mode is dislocation, with a reported incidence up to 10%[7,8]. Cup orientation has been shown in some[9,10], but not all[11,12], studies to influence stability and different safe- or optimal zones have been described in order to reduce dislocation-risk. The most commonly referenced zone is that described by Lewinnek[9], which comprises an inclination/anteversion of 40°/15°(±10°) measured on post-operative supine radiographs. However, this study had small number of patients (n=122) and a 3% dislocation rate. A recent, larger (n=469), case-control study showed that although a safe zone for dislocation could not be determined, cups with inclination of 45° and anteversion of 15° had the lowest dislocation-risk[6]. Although various studies have attempted to define the location (on an inclination/anteversion plot) of an optimal zone, none have investigated different sized zones.

In addition to end-points such as revision and dislocation in the assessment of THA, patient-reported-outcome-measures (PROMs) have become more common and important in recent years[13]. A validated PROM designed specifically for THA patients is the Oxford Hip Score (OHS), which assesses pain and function[14]. We are not aware of any previous studies that have attempted to correlate acetabular orientation with function.

The aims of the current study were firstly to identify factors influencing cup orientation following THA and secondly to investigate the relationship between cup orientation and complications (dislocation and revision) and mid-term clinical outcome (OHS), in order to identify the location and size of the zone for optimal cup orientation.

METHODS

The EPOS (Exeter-Primary-Outcome-Study) is a prospective, non-randomised, IRB-approved, multicentre study (7 centres), in which a cohort of 1,501 THAs (1,437 patients) was recruited between January 1999 and January 2002. The cohort has previously been reported with studies investigating the effects of obesity, approach and surgical grade on outcome post hip arthroplasty[15].

Patients from the EPOS were included in this study if they had adequate radiographs (antero-posterior pelvis radiograph with minimal rotation and tilt with a corresponding lateral radiograph). 431 (29%) hips had no (n=377) or inadequate quality [e.g. hip only, (n=54)] radiographs and hence were excluded. The remaining 1070 formed the current study's cohort (Figure 1). There was no selection bias as evidenced by the fact that the cohort included in this study had similar gender mix (p=0.83), age (p=0.10), diagnosis leading to surgery (Primary OA: 84%, dysplasia: 5%, inflammatory arthropathy: 6%, other: 5%) (p=0.4), OHS (p=0.53) and complication rate (p=0.45) as the cohort of patients excluded.

The majority of THAs were performed in females 668 (62%). The mean age at surgery was of 68 years (27 - 91 years) and primary osteoarthritis was the most common diagnosis (n=898, 84%). The mean body mass index (BMI) was 27.3 kg/m^2 (16 - 53 kg/m^2) (Table 1).

Surgical Details

Surgery was performed by numerous surgeons (>60) across different centres with majority performed by consultants (n=685, 64%). Surgical details are given in Table 2. In all cases a cemented Exeter femoral component (Stryker Howmedica, Newbury, UK) was used. A variety of cementless and cemented acetabular components were used including Trilogy (Zimmer, Inc, Warsaw, IN, USA), Elite Plus, Charnley Standard, Ogee and Flanged (DePuy, Warsaw, IN, USA), Exeter (Stryker Howmedica Osteonics, Newbury, UK) and Plasma Cup (Aescular, Tuttlingen, Germany). All bearing couples were hard-on-soft. Femoral head sizes used were either 22, 26, or 28 mm.

Outcome measures

The OHS (0–48 ,worst – best outcome) was used as a validated method for assessing patient-reported clinical outcome[14]. OHS was recorded pre-operatively, at 3 months, oneyear, two-years and five-years post-operatively. The power of the study was sufficient (85%) to detect a 2-point difference in the primary outcome measure, which was the change between the pre-operative and five-year post-operative scores (ΔOHS; $\Delta OHS = OHS_{5years} - OHS_{pre}$). A two-point difference in ΔOHS has been reported to be clinically important change from the patient's perspective[14].

Pre-operative and five-year data were available for 818 hips (76%). Amongst the 252 that had no OHS available, 28 (3%) were lost to follow-up without implant status or outcome being known, 75 (7%) died, 45 (4%) refused further participation, 32 (3%) were withdrawn from study for other reasons (e.g. moved out of region), 11 (1%) had been revised. For 61 hips (6%), although not lost to follow-up, OHS data was incomplete.

Secondary outcome measures included complications such as dislocation and revision. Secondary outcome measures were available for all but the 28 hips (3%) that were lost to follow-up.

Radiological assessment – cup orientation

Standardised, supine antero-posterior (AP) pelvic and lateral hip radiographs were performed. The Ein-Bild-Roentgen-Analysis (EBRA) software, a validated method of estimating orientation with an accuracy of 2°, was used to calculate radiographic cup inclination and version from AP radiographs[16,17],[18]. Lateral hip radiographs allowed determination of anteversion or retroversion. Measurements were performed independently by two observers (omitted for review) blinded to outcome with excellent intra- and inter-observer correlation (interclass correlation coefficients>0.95, p<0.001).

Analyses

The average orientation and the variability (defined as 2 Standard Deviations (SD)) in the orientation of all cases was determined. For the 18 surgeons who did more than 5 hip replacements the variability within the surgeons practice was also determined. The effect of different patient and surgical related factors including gender, diagnosis, BMI, patient position during surgery, surgical approach and surgeon's grade on acetabular component orientation and dislocation were assessed. In addition, it was determined whether the cups were in Lewinnek's Zone (LZ) or not.

Patients BMI was divided into two groups: non-obese (BMI<30, n=784) and obese (BMI≥30, n= 247). BMI was not available for 39 patients (4%). Patient position during surgery was divided into supine (213, 20%) or lateral (857, 80%). Surgical approach was divided into antero-lateral (n=787, 74%) and posterior (n=277, 26%); in 6 cases the details of approach used were missing. Patient and surgical factors were correlated to LZ inclination and anteversion angles independently. Cross-tabulation was used in order to identify which factors were associated with mal-orientation.

In order to determine the optimum orientation for improved ΔOHS and reduced dislocation and revision risk the following analyses were performed. As suggested by Lewinnek[9], it was assumed that a surgeon can implant a component within ±10° of a target. For every possible combination of inclination in the range (30°–60°) and anteversion in the range (0°–30°), a ±10° zone about it was constructed; the mean ΔOHS, dislocation and revision rates of THAs with cups within each zone were determined and compared with the mean ΔOHS, dislocation and revision rates of THA with cups outside the zone. This was repeated for every possible zone and contour plots of the mean ΔOHS and percentages of dislocation and revision rates as functions of inclination and anteversion were generated. The ΔOHS, dislocation and revision rates within and outside the zones were compared statistically and p-values for ΔOHS, dislocation and revision rates were plotted. The process was repeated for zones of ±5°, and ±15°. Analyses were performed using custom routines written in Matlab (version R2009a, The MathWorks Inc., Natick, Massachusetts, USA).

Statistical significance was defined as $p \leq 0.05$. For normally distributed outcome measures (OHS, ΔOHS), ANOVA was used for data analysis. Non-parametric, scale data were analysed with Mann-Whitney U test, whilst categorical and frequency data were analysed with chi-square and Fisher's exact tests. SPSS 17.0.1 for Windows (IBM, New York, US) and Matlab Statistics Toolbox (v7.1) were used for all statistical analyses.

RESULTS

The acetabular component orientation showed a wide scatter (Figure 2). The mean inclination was 45.7° (20.7° – 73.6°) and the mean anteversion was 10.3° (-33.0° – 39.3°). The variability, defined as 2SD, in both inclination and anteversion was about 15°. The variability in orientation for individual surgeons was about 13°. 70% of cups (n=749) were within LZ's inclination range, whilst 74% of cups (n=796) were LZ's anteversion range. 50% of cups were within both the LZ's inclination and anteversion ranges.

Cups inserted in the supine position and cementless cups had significantly higher inclination (Figure 2, Table 3). Significantly higher anteversion was observed in females, hips operated via the posterior approach (Figure 3, Table 3) and those operated on by consultants. Females and patients operated on via the posterior approach were more likely to have cups within the LZ's anteversion range.

Patients with cups within the LZ did not have better ΔOHS (23.6 vs. 24.4, p=0.2) compared to patients with cups outside the LZ.

Twenty-two hips sustained a dislocation (2%) and 11 hips required revision (1%). Reasons for revision included: recurrent dislocation (n=4), infection (n=2), aseptic loosening (n=2) and fracture (n=3). Cup orientation was not different between dislocated and non-dislocated hips, or between hips that did or did not require revision (Table 4, Figure 4). Dislocated hips that had an anterio-lateral approach had similar cup orientations to the dislocated hips that were operated via the posterior approach (Table 5). There were 4 patients with recurrent dislocations that subsequently underwent revision (0.4%), with satisfactory outcome. In two patients, the cup was retained (inclination/anteversion: 48°/14° - posterior approach, inclination/anteversion: 48/33° - lateral approach) and the femoral component and liner were exchanged; one patient underwent cup-only revision for gross mal-orientation: (inclination/anteversion: 59°/-33°

(retroversion) – posterior approach) and one patient underwent exchange of both components (inclination/anteversion: 37°/9°– lateral approach).

There was no ±5°, or ±10° zones about any cup orientation with statistically reduced dislocation rate ($p=0.06$ to 1.00). However, analysis with a size of zone of ± 15° showed a statistically reduced chance of dislocation about an orientation with inclination/anteversion of 42°/12° (Figure 5). THAs with cups outside this wide zone had a significantly higher dislocation rate (7%) compared to THAs with cups within the zone (1.8%) ($p=0.01$). There were no zones that had statistically different revision rates.

Optimal zone analysis findings are detailed in Table 6. There were many zones of ±5°, ±10° and ±15° that had statistically significantly improved OHS. The p-values tended to be lower with smaller zone sizes, and were centred on 45°/23° (Figure 6). The differences in ΔOHS within and outside zones were small (<2 points) for ±10° and ±15° zones. The contour plot for ±5° zones (Figure 6) showed that the best outcome (ΔOHS >26) was with components with an inclination between 40° to 50° and anteversion between 20° to 30°, whereas worst outcome (ΔOHS<22) tended to be when both inclination and anteversion were at the extremes of the location of the plot. Orientations with statistically significant lower ΔOHS had inclination/anteversion of 57°/30° (ΔOHS=18) and 52°/0° (ΔOHS=21).

DISCUSSION

In this large, multi-centre study of hard-on-soft THA we found that there was great variability (2SD ±15°) in acetabular orientation. It has generally been accepted that the optimal orientation is within Lewinnek's Zone. However, due to the variability in orientation, only 50% of cases were within this Zone. In addition we found that there was no advantage in terms of functional outcome or complications of being in this zone, suggesting that Lewinnek's Zone is of little relevance. We therefore studied all potential target zones to see if there was one that could be recommended.

Zones of ±5° or ±10° did not significantly reduce the dislocation or revision rate. However when zones of ±15° were assessed a significantly reduced risk of dislocation was identified about an orientation of inclination/anteversion of 42°/12°. For simplicity, and to take into account the observation that to achieve a specific orientation on post-operative radiographs surgeons should aim for slightly more anteversion and less inclination[17], we recommend that surgeons should aim for 40°/15° ±15°. Using current technology, surgeons should be able to reliably achieve this orientation within the margin of ±15°. If they do, the odd's ratio of the hip sustaining a dislocation is 1/4 ($p=0.01$) compared with when the cup is outside the zone. The absolute dislocation risk was 1.8% for cups within the zone and 7% for cups outside the zone.

This is the first study that we are aware of that has investigated the effect of cup orientation on functional outcome. It was found that there were statistically significant but small clinical advantages of achieving orientations in the region of 45°/25°, with zone sizes of ±10° or ±15°. However with a zone of ±5° there was not only a statistically significant but also a clinically important advantage. Worse functional outcomes were obtained if the cups were in zones of ±5° around 57°/30°, and 52°/0°. These zones with poor outcome fall within the ±15° zone for reducing dislocation, and the zones with good outcome are near the edge of the dislocation zone. Therefore with current technology, which can only reliably achieve ±15°, surgeons should focus on implanting the socket is a position that will minimise the risk of dislocation. If they aim for the optimal target for improved function they may end up outside the zone for minimising dislocation. However, with improved technology, the ability to accurately implant a cup within ±5° could potentially be achieved and surgeons should aim for 45°/25° ±5° as this would minimise dislocation and maximise outcome.

As most sockets were within the 40°/15° ±15° zone, most dislocations also occurred within this zone. For these dislocations the socket orientation probably had little influence on the dislocation and other factors were more important. Other factors that have been shown to influence stability, include head-neck-ratio[8], leg-length discrepancy, soft-tissue balance[19,20], capsular repair[21], offset[22], relative cup/femoral orientation[23], and hip joint centre location[24]. It is likely that for an increased risk of dislocation at least two factors need to be involved.

The wide scatter of cup orientation suggests that, although surgeons aim for a specific orientation, they frequently fail to achieve it. This study identified various factors that influence orientation that surgeons should bear in mind when positioning a socket. Factors that increased inclination include cementless fixation and supine position during surgery. The native acetabulum has a higher inclination than the optimal for THA[25].

Therefore to achieve better cementless fixation with greater peripheral bony contact surgeons may aim for an increased inclination. Alternatively, it may be because the cementless introducers are generally set to 45° inclination, whereas the cemented ones are usually set to less. Factors shown to influence anteversion included gender, surgical approach and surgeon's grade. The increased anteversion females possibly reflects the increased native anteversion or pelvic flexion seen in females[25,26]. The greater amount of anteversion seen with the posterior approach is not surprising given the historically increased risk for posterior dislocation using this approach[8], and the consequently recommendation to increasing anteversion[27]. The difference in anteversion between surgeon's grades probably reflects the greater proportion of cases performed via the posterior approach amongst consultants (30%) in comparison to trainees (20%) ($p < 0.001$).

The strengths of this study include its prospective nature with detailed data capture. It is adequately powered and the large multicentre cohort ensures adequate variability in patients' demographics and surgeons' practice, therefore representing general orthopaedic practice, including the training setting. It only includes hard-on-soft bearings and therefore only relates to hard-on-soft bearings as there are different failure mechanisms with hard-on-hard bearings[28]. Cup orientation measurement was performed with validated software (EBRA-cup) on appropriate radiographs improving accuracy of measurements. Limitations of the study include the small number of complications, dislocations and revisions. Lack of cross-sectional imaging prevented calculation of femoral stem version and the ability to evaluate the influence of combined anteversion on outcome and complications. However, surgeons tend to implant the acetabulum first so they do it without knowing the femoral component anteversion. So surgeons need to know information about acetabular position independently of femoral component position, which is what this study provides. We did not know when offset liners were used. This would not have substantially affected the conclusions relating to the large (±15°) zones, but might have influenced the orientation of the optimal zone for function as this was small (±5°). Although this study was adequately powered, the lack of radiographs in a significant proportion of patients reduced the cohort available for analysis. However, the cases excluded had similar characteristics to those in the study so should not introduce a bias. We do not know the individual surgeons' cup orientation target; however as the variability in cup orientation in the whole cohort (2SD≈15°) was similar to that of individual surgeons (2SD≈13°) it would seem that the variability was not a result of surgeons aiming for different targets. Although different head sizes were used we did not analyse them separately as, in the cohort, the dislocation rate was not related to head size even when allowing for orientated within or outside LZ (Table 7). Lastly, the unavailability of longer than 5-year follow-up does not allow for conclusions on the effect of cup orientation on wear-related complications and revisions.

In conclusion, a wide scatter of cup orientation was observed suggesting that surgeons can only reliably achieve a target zone of ±15°. We did, however, find that the optimal zone (40°/15° ±15°) to minimise the dislocation risk was of this size suggesting that current technology is good enough to achieve the target orientation that minimises dislocation rate. Our study is the first to demonstrate that function can be improved by optimising orientation; however the target is small (45°/25° ± 5°) so it cannot be reliably achieved at present. In the future, with improved technology, we should be able to improve the functional benefit achieved with hip arthroplasty.

REFERENCES

1. Grammatopoulos G, Pandit H, Glyn-Jones S, McLardy-Smith P, Gundle R, Whitwell D, Gill HS, Murray DW. Optimal acetabular orientation for hip resurfacing. *J Bone Joint Surg Br 2010;92-8:1072-8.*

2. Langton DJ, Jameson SS, Joyce TJ, Webb J, Nargol AV. The effect of component size and orientation on the concentrations of metal ions after resurfacing arthroplasty of the hip. *J Bone Joint Surg Br 2008;90-9:1143-51.*

3. Callanan MC, Jarrett B, Bragdon CR, Zurakowski D, Rubash HE, Freiberg AA, Malchau H. 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.*

4. Kummer FJ, Shah S, Iyer S, DiCesare PE. The effect of acetabular cup orientations on limiting hip rotation. *J Arthroplasty 1999;14-4:509-13.*

5. D'Lima DD, Urquhart AG, Buehler KO, Walker RH, Colwell CW, Jr. The effect of the orientation of the acetabular and femoral components on the range of motion of the hip at different head-neck ratios. *J Bone Joint Surg Am 2000;82-3:315-21.*

6. 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.*

7. Phillips CB, Barrett JA, Losina E, Mahomed NN, Lingard EA, Guadagnoli E, Baron JA, Harris WH, Poss R, Katz JN. Incidence rates of dislocation, pulmonary embolism, and deep infection during the first six months after elective total hip replacement. *J Bone Joint Surg Am 2003;85-A-1:20-6.*

8. Berry DJ, von Knoch M, Schleck CD, Harmsen WS. Effect of femoral head diameter and operative approach on risk of dislocation after primary total hip arthroplasty. *J Bone Joint Surg Am 2005;87-11:2456-63.*

9. 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.*

10. Dorr LD, Wan Z. Causes of and treatment protocol for instability of total hip replacement. *Clin Orthop Relat Res 1998-355:144-51.*

11. Rittmeister M, Callitsis C. Factors influencing cup orientation in 500 consecutive total hip replacements. *Clin Orthop Relat Res 2006;445:192-6.*

12. Hassan DM, Johnston GH, Dust WN, Watson G, Dolovich AT. Accuracy of intraoperative assessment of acetabular prosthesis placement. *J Arthroplasty 1998;13-1:80-4.*

13. Bream E, Black N. What is the relationship between patients' and clinicians' reports of the outcomes of elective surgery? *J Health Serv Res Policy 2009;14-3:174-82.*

14. Murray DW, Fitzpatrick R, Rogers K, Pandit H, Beard DJ, Carr AJ, Dawson J. The use of the Oxford hip and knee scores. *J Bone Joint Surg Br 2007;89-8:1010-4.*

15. Palan J, Gulati A, Andrew JG, Murray DW, Beard DJ. The trainer, the trainee and the surgeons' assistant: clinical outcomes following total hip replacement. *J Bone Joint Surg Br 2009;91-7:928-34.*

16. Ilchmann T, Kesteris U, Wingstrand H. EBRA improves the accuracy of radiographic analysis of acetabular cup migration. *Acta Orthop Scand 1998;69-2:119-24.*

17. Wilkinson JM, Hamer AJ, Elson RA, Stockley I, Eastell R. Precision of EBRA-Digital software for monitoring implant migration after total hip arthroplasty. *J Arthroplasty 2002;17-7:910-6.*

18. Murray DW. The definition and measurement of acetabular orientation. *J Bone Joint Surg Br 1993;75-2:228-32.*
19. Bourne RB, Rorabeck CH. Soft tissue balancing: the hip. *J Arthroplasty 2002;17-4 Suppl 1:17-22.*
20. Charles MN, Bourne RB, Davey JR, Greenwald AS, Morrey BF, Rorabeck CH. Soft-tissue balancing of the hip: the role of femoral offset restoration. *Instr Course Lect 2005;54:131-41.*
21. Goldstein WM, Gleason TF, Kopplin M, Branson JJ. Prevalence of dislocation after total hip arthroplasty through a posterolateral approach with partial capsulotomy and capsulorrhaphy. *J Bone Joint Surg Am 2001;83-A Suppl 2-Pt 1:2-7.*
22. McGrory BJ, Morrey BF, Cahalan TD, An KN, Cabanela ME. Effect of femoral offset on range of motion and abductor muscle strength after total hip arthroplasty. *J Bone Joint Surg Br 1995;77-6:865-9.*
23. Herrlin K, Selvik G, Pettersson H, Kesek P, Onnerfalt R, Ohlin A. Position, orientation and component interaction in dislocation of the total hip prosthesis. *Acta Radiol 1988;29-4:441-4.*
24. Timperley JA. Early complications relating to acetabular component after total hip replacement. *Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences.* Vol. DPhil. Oxford, UK: University of Oxford, 2006:40-61.
25. Murtha PE, Hafez MA, Jaramaz B, DiGioia AM, 3rd. Variations in acetabular anatomy with reference to total hip replacement. *J Bone Joint Surg Br 2008;90-3:308-13.*
26. Tannast M, Murphy SB, Langlotz F, Anderson SE, Siebenrock KA. Estimation of pelvic tilt on anteroposterior X-rays--a comparison of six parameters. *Skeletal Radiol 2006;35-3:149-55.*
27. Wasielewski RC. *Pelvis, hip and Femur Reconstruction.* New York: Thieme, 1999:495-516.
28. Campbell P, Beaule PE, Ebramzadeh E, LeDuff M, De Smet K, Lu Z, Amstutz HC. The John Charnley Award: a study of implant failure in metal-on-metal surface arthroplasties. *Clin Orthop Relat Res 2006;453:35-46.*

		Cohort	**Gender**		
			Male (n=402)	Female (n=668)	p Value
Age (Years)		67.5 (SD:10.6)	66.5 (SD:10.9)	68.2 (SD: 10.3)	0.01
BMI (kg/m^2)		27.3 (SD:5)	27.4 (SD: 4)	27.2 (SD: 5)	0.12
Diagnosis	1° OA	898	339	559	0.51
	2° OA	59	21	38	
	Inflammatory	64	20	44	
	Fracture	17	8	9	
	Osteonecrosis	28	11	17	
	Metabolic	4	3	1	
OHS pre-op		15.7 (SD:7.6)	17.3 (SD: 7.7)	14.8 (SD: 7.4)	<0.001
OHS 5 years post-operatively		40 (SD: 8.8)	41.6 (SD: 7.9)	39.0 (SD: 9.2)	<0.001
ΔOHS		24 (SD:9.7)	23.8 (SD: 9.6)	24.1 (SD: 9.7)	0.67

Table 1. Patient demographics, pre-operative diagnosis and OHS.

		Cohort
Surgeons Grade	Consultant	685
	Trainee	385
Patient Position	Supine	213
	Lateral	855
Surgical Approach	Anterolateral	787
	Posterior	277
Cup Fixation	Cemented	946
	Uncemented	124
Acetabular Component implanted	Exeter	416
	Elite Plus	317
	Charnley Ogee	112
	Trilogy	76
	Other	149
Bearing couple	Stainless Steel on Polyethylene	957
	Zirconia on Polyethylene	102
	Alumina on Polyethylene	11
Cup Size/ mm		46.8 (SD: 4.7)
Femoral Head Size/ mm	**22**	208 (20%)
	26	335 (31%)
	28	527 (49%)
Cup Inclination/ degrees		45.7° (SD: 7.4°)
Cup Anteversion/ degrees		10.3° (SD: 7.1°)

Table 2. Surgical details of cohort.

	Gender			BMI			Diagnosis			Patient Position			Surgical Approach			Surgeon's Grade			Cup Fixation		
	Male n=402	Female n=668	p-value	Not-Obese n= 784	Obese n=247	p-value	1° OA n= 898	Other n= 172	p-value	Supine n= 213	Lateral n= 857	p-value	Anterio-Lateral n=784	Posterior n=277	p-value	Consul. n= 685	Trainee n= 385	p-value	Cement n=946	Cement-less n=124	p-value
Cup Inclination (RCI)/°	45.2 (24 - 74)	46 (21 -70)	0.14	45.7 (24–74)	46.2 (21–67)	0.17	45.6 (21 – 72)	46.5 (27 –74)	0.39	47.9 (24-74)	45.2 (21 -69)	0.001	45.5 (21-74)	46.3 (26-68)	0.12	45.7 (24–74)	45.8 (21–68)	0.65	45.6 (24 – 74)	46.8 (21 – 64)	0.03
Cup Anteversion (RCA)/°	9.5 (-33 – 39)	10.7 (-4 – 37)	0.02	12.7 (1 – 39)	10.1 (-16–33)	0.46	10.2 (-32 – 39)	10.5 (-4 – 30)	0.65	11 (-4 –30)	10.1 (-33– 39)	0.15	9.4 (-16–39)	12.9 (-33 – 34)	0.001	10.8 (-16–34)	9.3 (-33–39)	0.001	10.1 (-33 – 39)	11.4 (-2 – 34)	0.06
% within LZ RCI (30 – 50°)	n= 284 71%	n= 465 70%	0.72	n=659 84%	n=169 68%	0.69	n=635 71	n= 114 66%	0.03	n=128 60%	n=621 72%	<0.01	n= 561 72%	n=183 66%	0.10	n=484 74%	n=265 69%	0.53	671 71%	78 63%	0.07
% within LZ RCA (5 – 25°)	n=286 71%	n=510 76%	0.06	n=585 75%	n=177 72%	0.11	n= 665 74%	n= 131 76%	0.56	n=165 78%	n= 631 74%	0.25	n=554 70%	n= 237 86%	0.001	n=519 76%	n=277 72%	0.17	695 74%	101 82%	0.06
% within LZ	n= 191 48%	n= 343 51%	0.22	n=384 49%	n=122 49%	0.91	n= 450 50%	n= 84 49%	0.76	n=95 45%	n=439 51%	0.08	n=374 47%	n=156 56%	0.01	n=355 52%	n=179 46%	0.09	472 50%	62 50%	0.3

Table 3: Patient and surgical factors and their effect on acetabular component orientation. LZ: Lewinnek Zone

	Dislocated			Revised		
	Yes (n=22)	**No (n=1048)**	**p value**	**Yes (n= 11)**	**No (n= 1059)**	**p value**
Cup Inclination/°	47.2 (37 – 64)	45.7 (21 – 74)	0.53	47.2 (35 – 59)	45.7 (21 – 74)	0.46
Cup Anteversion/°	7.2 (- 33 – 20)	10.3 (- 16 – 39)	0.29	7.7 (-33 – 33)	10.3 (-16 – 39)	0.89
% within LZ RCI	82% n= 18	84% n=882	0.85	73% n=8	70% n=741	0.84
% within LZ RCA	68% n= 15	75% n=781	0.50	82% n=9	74% n=787	0.57
% within LZ	45% n= 10	50% n= 524	0.67	64% n=7	50% n=527	0.36
Head Size/mm	25.7 (22 – 28)	26.2 (22 – 28)	0.61	25.1 (22 – 28)	26.2 (22 – 28)	0.31
Cup Size/ mm	49.9 (43 – 60)	46.7 (38 – 70)	0.007	48.3 (43 – 56)	46.7 (38 – 70)	0.4

Table 4: Cup orientations grouped by dislocation and revision. LZ: Lewinnek Zone

	Approach of Dislocated Hips (n = 22)		
	Anterio-Lateral (n =16)	Posterior (n=6)	p value
Cup Inclination/°	46.9 (37 – 64)	48 (40 – 59)	0.86
Cup Anteversion/°	8.6 (1.3 – 20)	3.3 (-33 – 14)	0.69
Within LZ RCI	n= 11	n=4	0.93
Within LZ RCA	n= 10	n=5	0.35
Within LZ	n= 6	n=4	0.22

Table 5: Cup orientations of dislocated cases by surgical approach. Statistical values derived from chi-square tests from the cross-tabulation table. LZ: Lewinnek Zone

	Zones of ±5°		Zones of ±10°		Zones ±15°	
	p-values	**Optimal RCI°/RCA°**	**p-values**	**Optimal RCI°/RCA°**	**p-values**	**Optimal RCI°/RCA°**
ΔOHS	0.001 – 1.00	*45°/ 25°*	<0.001 – 1.00	*48°/27°*	0.01 – 1.00	*38°/20°*
Dislocation	0.06 – 1.00	n/a	0.06 – 1.00	n/a	0.01 – 1.00	42°/11°
Revision	0.07 – 1.00	n/a	0.06 – 1.00	n/a	0.06 – 1.00	n/a

Table 6: Statistical values obtained from scatter plot analysis using Mann-Whitney U test for comparing ΔOHS and Fisher's exact test for dislocation and revision rates. In addition the orientation with the minimal p-value was documented as optimal. The difference in ΔOHS was numerically significantly different for many zones tested; however the clinical difference is minimal (0.9 – 1.8) for ±10° and ±15° zone tested. Clinically significant difference (ΔOHS >2) was only seen in zones of ±5°.

Head size	Zone	Dislocation	
		No	Yes
22	Within LZ	107	5
	Outside LZ	94	2
26	Within LZ	164	1
	Outside LZ	167	3
28	Within LZ	253	6
	Outside LZ	263	5

Table 7: Number of dislocations for the different head sizes as per cup orientation within or outside Lewinnek zone (LZ) (p=0.7).