HIP

Restoration of the centre of rotation in primary total hip arthroplasty

THE INFLUENCE OF ACETABULAR FLOOR DEPTH AND REAMING TECHNIQUE

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Aims
One goal of total hip arthroplasty is to restore normal hip anatomy. The aim of this study was to compare displacement of the centre of rotation (COR) using a standard reaming technique with a technique in which the acetabulum was reamed immediately peripherally and referenced off the rim.

Patients and Methods
In the first cohort the acetabulum was reamed to the floor followed by sequentially larger reamers. In the second cohort the acetabulum was only reamed peripherally, starting with a reamer the same size as the native femoral head. Anteroposterior pelvic radiographs were analysed for acetabular floor depth and vertical and horizontal position of the COR.

Results
Horizontally, the mean medial displacement of the COR was 0.8 mm (standard deviation (SD) 1.4) in the peripheral remaing group and 5.0 mm (SD 3.30) in the standard reaming group (p < 0.001). Vertically, the mean superior displacement of the COR was 0.7 mm (SD 1.3) in the peripheral reaming group and 3.7 mm (SD 2.6) in the standard reaming group (p < 0.001). In the standard reaming group, there was a strong correlation between the pre-operative acetabular floor depth and displacement of the COR (p < 0.001).

Conclusion
Reaming the acetabulum to the floor can lead to significant displacement of the COR medially and superiorly. This displacement is related to the pre-operative acetabular floor depth and cannot always be compensated by using a high offset stem.

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One of the objectives of total hip arthroplasty (THA) is to restore normal hip anatomy. In the majority of patients, the native acetabulum is subhemispherical but the acetabular components used for THA are hemispherical, which inadvertently leads to displacement of the centre of rotation (COR) when the implant is fully contained.1 Traditionally, reaming of the acetabulum is started directly medial to the floor beginning with a small reamer and followed by sequentially larger reamers in the anticipated position of the implanted component.2 However this could lead to displacement of the COR.

The acetabular offset has been defined as the distance between the centre of the femoral head and the inner wall of the quadrilateral plate, which is the true floor of the acetabulum.3–7 Restoration of the COR and therefore maintenance of the native acetabular offset and height may have some advantages: preservation of acetabular bone stock, decreased risk of bone or soft-tissue impingement and therefore providing improved range of movement and reduction in the risk of dislocation,3,8–10 improved kinematics of the hip and abductor function,11–13 improved patient outcome scores,14,15 decreased wear,16 and decreased long-term loosening.17–19

In order to avoid the adverse effects of displacement of the COR, it has been suggested that the COR should be restored < 3 mm superiorly and < 5 mm medially.3

Although the literature generally refers to global or femoral offset, the role of the acetabular offset has only recently been emphasised.1,4,20,21 Acetabular offset varies widely between individuals and the acetabular floor distance can be up to 13 mm.22 In a CT study of 100 normal hips, Bonnin et al22 demonstrated that with a standard reaming technique the COR was displaced medially > 5 mm in 46%. They proposed an alternative reaming technique by which the acetabulum is reamed only peripherally to avoid displacement of the
COR. Other studies have documented the importance of the position of the hip COR to maintain muscle function,11,23-27 stability,4,8-10,28-32 and longevity of the THA.17-19,33

The aim of this clinical study was to compare vertical and horizontal displacement of the COR, as measured on plain radiographs, using a standard reaming technique with a technique in which the acetabular component is not deliberately medialised and the acetabulum is reamed peripherally and referenced to the rim.

Patients and Methods

Between September 2012 and March 2014, 100 consecutive patients (100 hips) who underwent primary uncemented THA with normal anatomical COR on the contralateral hip were included in this prospective comparative study. The inclusion criteria were unilateral primary osteoarthritis, osteoarthritis secondary to osteonecrosis or rheumatoid arthritis or an acute neck of femur fracture. Exclusion criteria were patients in whom the COR was planned to be restored in a different position to the contralateral THA. The study was approved by the Ethical Board and all patients gave informed consent.

Surgical procedure. All operations were performed by the same surgeon (GM) through a posterior approach using the transverse acetabular ligament as an intra-operative landmark for anteverision of the acetabular component.34,35 A digital inclinometer (WR 300 Digital Angle Gauge, Barry Wixey Development, Seattle, Washington) was used to guide the acetabular component inclination angle.36

In the first 50 patients, a standard reaming technique was used and in the second 50 patients, a peripheral reaming technique was applied. A Pinnacle 100 Duofix acetabular shell (Depuy, Leeds, United Kingdom) with a crosslinked polyethylene, 10° lipped liner was used in all patients.

Radiological analysis. Assessments were performed on supine anteroposterior (AP) pelvic radiographs at six weeks post-operatively using Orthoview software (Materialise, Leuven, Belgium). Magnification was corrected on post-operative radiographs using the known acetabular component size for reference. On pre-operative radiographs it was corrected by using the diameter of the contralateral, non-operated femoral head measured on the post-operative radiographs as a reference. On the pre-operative radiographs the acetabular floor depth was calculated by measuring the distance between the most medial part of the femoral head and the medial part of the quadrilateral plate, parallel to the inter-teardrop line. The COR was determined by using the centre of a circle encompassing the prosthetic femoral head on the ipsilateral side and the native femoral head on the contralateral side on the post-operative radiographs. Horizontally, the distance between the COR and the vertical axis of the pelvis was determined by drawing a line through the COR perpendicular to the midline of the pelvis (a line connecting the middle of the pubic symphysis and the middle of the inter-sacroiliac line).

Vertically, the distance between COR and inter-teardrop line was determined by drawing a line through the COR and perpendicular to the inter-teardrop line (Fig. 1). A positive value corresponded to medial or superior displacement, a negative value to lateral or inferior displacement of the COR. Radiographic inclination was defined as the angle between the inter-teardrop line and the plane of opening of the acetabular component.17 The radiographs were standardised: a distance between the symphysis and the sacroccygeal joint of approximately 30 mm (10 mm to 40 mm) in men and 50 mm (40 mm to 60 mm) in women, to exclude abnormal pelvic tilt in the sagittal plane,37,38 and the coccyx centred on the symphysis to exclude rotation of the pelvis in the transverse plane.38 All measurements were done by an observer blinded to the surgical technique used. Intra-observer variations were determined from all radiographs measured initially and after three months by the same observer (I. Goetheer-Smits). Inter-observer variations were determined by another observer (GM) who conducted an independent assessment of all radiographs.

Outcome. The main outcome measures were the position of the COR horizontally and vertically after THA compared with the contralateral side. The secondary outcome measures were the number of outliers, the effect of the pre-operative depth of the acetabular floor on displacement of the COR and the radiographic inclination angle of the acetabular component. Outliers were defined as displacement of the COR > 5 mm medially and > 3 mm superiorly.

Statistical analysis. This was performed using a chi-squared test for binary variables, a Kolmogorov–Smirnov test for
Gaussian distribution, a Student’s t-test for continuous variables and an F test to compare variances. A linear regression analysis was undertaken to correlate the floor distance and the displacement of the COR. A p-value < 0.05 was considered significant. Statistical analysis was done using GraphPad Prism 6.0 (GraphPad Software, San Diego, California). Based on the standard deviation (SD) of displacement of the COR found by Bonnin et al.22 a sample size analysis using Statmate 2 (GraphPad Software) with the conventional 80% power and p < 0.05 showed that 50 patients per group would be required to detect a 1 mm difference between groups. Intraclass correlation was measured using Landis and Koch’s grouping.39 Scores between 0.61 and 0.8 represented substantial agreements and those greater than 0.81 almost perfect agreements. The intraclass correlation analysis was done using SPSS Statistical Software (version 15.0; SPSS Inc, Armonk, New York).

Results

The demographic data were similar in both groups (Table I). The position of the COR horizontally and vertically on the contralateral side and the ipsilateral pre-operative acetabular floor depth was similar in both groups. There were no acetabular components in which the implant was not fully seated intra-operatively or on the post-operative radiograph. The implant sizes required and radiographic inclination angles were similar in both groups, but there were more implants that were uncovered laterally in the peripheral reaming group (Table II). There was almost perfect agreement for all intra- and inter-observer measurements (Table III).

After THA, the position of the COR comparing the ipsilateral and contralateral side was similar in the peripheral reaming group, but significantly different in the standard reaming group (p = 0.001; Student’s t-test). Horizontally, the mean displacement of the COR was medially 0.8 mm (SD 1.4; -2 to 3; 95% confidence interval (CI) 0.4 to 1.2) in the peripheral reaming group and in the standard reaming group 5.0 mm (SD 3.3; -2 to 14; 95% CI 4.0 to 6.0), which represented a statistically significant difference (p < 0.001; Student’s t-test) (Fig. 2a). Vertically, the mean displacement of the COR was superiorly 0.7 mm (SD 1.3; -2 to 4; 95% CI 0.4 to 1.1) in the peripheral reaming group and 3.7 mm (SD 2.6; -1 to 9; 95% 2.9 to 4.4) in the standard reaming group (p < 0.001; Student’s t-test) (Fig. 2b). The variances for horizontal and vertical displacement of the COR were greater in the standard reaming group (p < 0.001; F test). There were 17 medial outliers in the standard reaming group compared with none in the peripheral reaming group (p < 0.001; chi-squared test). There were 11 superior outliers in the standard reaming group compared with two in the peripheral reaming group (p = 0.015; chi-squared test).
In the standard reaming group, there was a strong correlation between the pre-operative acetabular floor depth and horizontal displacement of the COR ($r^2 = 0.85; p < 0.001$) and vertical displacement of the COR ($r^2 = 0.47; p < 0.001$) (Fig. 3).

**Discussion**

One goal of THA is precise restoration of the biomechanics of the hip although this cannot always be achieved. Several studies have documented the importance of the hip COR for muscle function, stability and longevity of the hip replacement.

Miles and McNamee demonstrated that medial displacement of the COR resulted in increased compressive stresses on the medial wall and tensile stresses on the lateral wall of the acetabulum which predisposed to loosening of the component. Other studies highlighted the influence of the position of the COR on the lever arms of the hip muscles and demonstrated that superior displacement of the COR induced alterations in hip kinematics. We found that the COR was significantly more displaced both medially and superiorly when using a standard reaming technique compared with a peripheral reaming technique.

Others have also reported the displacement of the COR after THA, showing that the mean medial displacement ranges from 1.0 mm to 10.7 mm ($-10.6$ to 21.3) and the mean superior displacement ranges from 0.9 mm to 6.8 mm ($-20.15$ to 18.9). For the most commonly used stems in the National Joint Registry for England, Wales, Northern Ireland and the Isle of Man in 2014, the difference between a standard and a high offset stem ranges from 3 mm to 8 mm for cementless stems and from 4 mm to 12.5 mm for cemented stems. This means that the loss in offset on the acetabular side cannot always be compensated on the femoral side, especially when using a cementless stem. In hip resurfacing, there is even less flexibility to adjust limb length and offset if the acetabular component is displaced medially and/or superiorly.
In a CT study of 100 normal hips, Bonnin et al.\(^\text{22}\) compared the effect of both reaming techniques and found that the global shift of the COR was a mean of 1.9 mm (SD 1.4) with peripheral reaming and 5.1 mm (SD 1.9) with standard reaming. Medial displacement of the COR was a mean 1.6 mm (SD 1.2) \textit{versus} 4.8 mm (SD 1.9) and superior displacement 2.1 mm (SD 1.5) \textit{versus} 3.3 mm (SD 1.3) with a peripheral and standard technique respectively, which mirrored our results.

Sariali et al.\(^\text{21}\) performed 3D pre-operative THA planning in 223 patients and showed that the COR was restored with a mean accuracy of 0.73 mm (SD 3.5) vertically, 1.2 mm (SD 2) laterally and 0.05 mm (SD 1.8) horizontally. Using an anatomical model, Honl et al.\(^\text{15}\) found that the COR could be reproduced more accurately when using an image-free navigation system compared with a freehand reaming technique \((p = 0.001)\). Kanawade et al.\(^\text{48}\) investigated the precision of robotic-guided instrumentation for acetabular component positioning and reported that precision of COR could be achieved in 81.5% of a group of 27 patients.

In addition to the mathematical models, clinical studies have examined the influence of displacement of the COR on muscle function after THA. In 30 patients with a unilateral THA, Asayama et al.\(^\text{11}\) found that in order to maximise post-operative abductor function the COR should be restored to near normal or slightly inferomedially. In 26 patients with a THA, Rosler and Perka\(^\text{36}\) observed deterioration in gait when the COR was displaced superiorly.

In a computer model, Kurtz et al.\(^\text{4}\) found that changes in COR had a greater effect on range of movement before impingement than equivalent changes in femoral offset and femoral height. Improving the hip joint reactive force by increased femoral offset sacrifices range of movement, as had been noted by Charnley.\(^\text{29}\) Sariali, Klouche and Mamoudy\(^\text{9}\) demonstrated that in a group of 27 patients who had had a dislocation after THA, the COR was shifted medially and superiorly compared with the native anatomy and Robinson et al.\(^\text{12}\) concluded that inability to restore the overall offset of the implant to the normal hip increases the chance of dislocation. However, García-Rey and García-Cimbrello\(^\text{8}\) found in a series of 1414 THA that acetabular components with a greater distance to the approximate COR had a higher risk of dislocation \((p = 0.018)\) and Timperley et al.\(^\text{19}\) noted in a cohort of 1578 patients that the risk of dislocation was higher when the acetabular component was implanted with a proximalised COR.

In the long-term, displacement of the COR could lead to both acetabular\(^\text{17-19}\) and femoral loosening.\(^\text{33}\) In a 12- to 18-year radiographic follow-up study of 95 THA, Karachalios et al.\(^\text{18}\) observed that displacement of the COR \(\geq 2\) mm strongly correlated with radiographic signs of loosening at long-term follow-up. In a study of 83 cemented THA in patients with juvenile rheumatoid arthritis, Lachiewicz et al.\(^\text{19}\) documented progressive radiolucencies and acetabular migration in components placed \(\geq 5\) mm superior or medial to the anatomical position. Yoder et al.\(^\text{33}\) found that femoral components with the COR placed in a nearly anatomical location loosened at a statistically significant lower rate than hips with the COR superiorly or laterally positioned. Little et al.\(^\text{16}\) reported that reproduction of reconstructed femoral offset \(> 5\) mm of the native femoral offset was associated with a 32% to 33% increase in linear and volumetric wear of ultra-high molecular weight polyethylene.

There are several limitations to our study. First, measurements were performed on plain radiographs. Although others have reported more accurate measurement of the femoral offset on CT,\(^\text{7,57,58}\) in patients with end-stage osteoarthritis the acetabular offset can be accurately determined on AP pelvic radiographs.\(^\text{59,60}\) Secondly, only patients with unilateral hip disease were included. Although there are various methods to locate the native COR on standard pelvic radiographs,\(^\text{61-64}\) these methods have a limited accuracy and only allow prediction of the COR within 5 mm.\(^\text{65}\) The COR is not always symmetrical, but the mean difference comparing both sides was found to be 2.54 mm which allows a better prediction of the location of the COR.\(^\text{66}\)

Thirdly, patients with dysplasia and protrusio acetabuli were excluded although the importance of the hip COR to both longevity of the hip arthroplasty in DDH\(^\text{67-71}\) and protrusio acetabuli has been studied.\(^\text{64,72}\) Fourthly, long-term clinical outcomes were not assessed. Fifthly, there are no generally accepted boundaries to define outliers for the COR. Dastane et al.\(^\text{3}\) demonstrated that only by limiting superior displacement to 3 mm and medial displacement to 5 mm can the increase in offset on the femoral side be kept within 5 mm, avoiding increased polyethylene wear.\(^\text{16}\)

Finally, we only used cementless acetabular components, however Wegner et al.\(^\text{73}\) compared the position of the COR in cemented and cementless component and found that the fixation technique had no significant effect on the position of COR.

There are potential pitfalls in peripheral reaming. First, the acetabular component is uncovered more superolaterally, but inappropriate medialisation should be avoided as this leads to more vertical placement if the acetabular component is referenced off the superior rim.\(^\text{22,74,75}\) Secondly, if the component is not anteverted enough there is a higher risk for anterior overhang and iliopsoas impingement in comparison to a medialised component.\(^\text{76}\) Thirdly, the COR directly influences limb length and care has to be taken that the femoral component is correctly implanted in order to avoid limb length discrepancy.\(^\text{77}\)

Another way to reconstruct the COR is using an extended offset polyethylene liner to move the COR away from the plane of the acetabular metallic shell. However, this results in an eccentric loading pattern and increased torsional forces at the liner-shell and bone-implant interface.\(^\text{78}\) Clinical data have demonstrated a higher wear and acetabular aseptic loosening with offset polyethylene liners.\(^\text{79,81}\)

The results of our study demonstrate that reaming to the acetabular floor can lead to significant displacement of the
COR medially and superiorly. A peripheral reaming technique may avoid major displacement of the COR, especially in patients who have a thick pre-operative acetabular floor. If the aim of surgery is to reconstruct the anatomical COR, surgeons need to consider using a more conservative medial reaming technique.

Take home message:
Standard acetabular reaming to the floor can lead to displacement of the centre of rotation, depending on the acetabular floor depth. Peripheral reaming leads to more accurate reconstruction of the centre of rotation.

Supplementary material
Tables showing displacement of the centre of rotation in hip arthroplasty and the difference between a standard and high offset stem of the most commonly used stems in the National Joint Registry for England, Wales, Northern Ireland and the Isle of Man, and a figure showing the effect of different acetabular component types and position on the centre of rotation, are available alongside the online version of this article at www.bjj.boneand-joint.org.uk

Author contributions:
G. Meermans: Designed and co-ordinated the study, Performed surgeries, Analysed the data, Wrote the manuscript, Approved the final manuscript.
J. Van Doorn: Analysed the data, Revision of the manuscript, Read and approved the final manuscript.
J.-J. Kats: Contributed to the study design, Collected and analysed the data, Revision of the manuscript, Read and approved the final manuscript.
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