INTRODUCTION

During total hip arthroplasty (THA) native global offset must be restored in order to achieve proper function of the abductor muscles and to ensure that the hip is stable (1-5). Femoral offset is defined as the perpendicular distance between the centre of the femoral head and the axis of the femur (1, 6-8). Recently, acetabular offset has been defined as the distance between the centre of the femoral head and the inner wall of the quadrilateral plate, also called true floor of the acetabulum (1, 6-9). There has been considerable focus on femoral offset both in terms of research and from the implant companies and as a result femoral offset can be restored using prosthetic stems with a wide variety of head neck combinations. There has been substantially less interest and fewer published studies concerning acetabular offset (6, 9-12).

Conventional acetabular preparation consists of reaming down to the true floor, which medialises the centre of rotation of the hip (CRH) and reduces the acetabular offset. This medialisation decreases the lever arm of the body weight during monopodal stance, which lessens the

ABSTRACT: Acetabular offset (AO) is the distance between the centre of the femoral head and the true floor of the acetabulum. We quantified the AO in normal hips and compared the displacement of the centre of rotation of the hip (CRH) after conventional and anatomical cup implantation during THA. 100 CT-scans of normal hips were analysed before and after simulating implantation of the acetabular component.

Mean AO was 30.8 mm ± 3. The medial shift of the CRH was 1.6 mm ± 1.2 with the anatomical and 4.8 mm ± 1.9 with the conventional technique (p<0.0001). Medialisation was greater than 5 mm in 44% of the cases when the conventional technique was used, but occurred in no case when using the anatomical technique. Differences between men and women were significant: 5.6 mm ± 1.6 and 3.5 mm ± 1.7 with the conventional technique; 2.0 mm ± 1.1 and 0.9 mm ± 0.9 with the anatomical technique (p<0.0001 for both measurements).

The concept of hip offset cannot be limited to that of the femoral offset. AO widely varies and cannot be neglected. In patients with significant AO, surgeons should pay close attention to the preparation of the acetabulum. This should be done conservatively so that the acetabular cup can be placed anatomically in order to restore the native hip biomechanics.

KEY WORDS: Hip joint, Arthroplasty, Biomechanics, Anatomy, Hip offset, Acetabular offset

Accepted: May 03, 2012
resultant force on the femoral head. This has been shown to improve THA survival (13-16). In contrast some authors would rather preserve the acetabular offset by maintaining a space between the true floor of the acetabulum and the acetabular cup (9, 10, 17-19). To do this, they ream the acetabular cavity conservatively by stopping at the subchondral bone. This technique is more anatomical and makes it possible to limit the displacement of the CRH, improves Hip Range of Motion and decreases the risk of bony impingement (19, 20).

Few studies have focused on the modification of acetabular offset after THA and in those that have the measurements were performed only on arthritic hips (6, 9, 12). To our knowledge no anatomic studies have addressed this specific aspect of hip anatomy or quantified the acetabular offset via morphometric studies. The purposes of this study were (1) to quantify the acetabular offset in a population of healthy hips, (2) to analyse and compare the displacement of the CRH after simulated implantation of a THA with two acetabular positioning techniques, one conventional and one anatomical and (3) to identify the factors influencing medialisation of CRH.

Our hypothesis was that the “anatomical” technique makes it possible to achieve a better restoration of hip centre of rotation.

PATIENTS AND METHODS

One hundred CT-scans of normal hips were selected from our large data bank of combined hip and knee scans that have been routinely performed in our centre prior to total knee arthroplasty since 2004 (21). All patients signed an informed consent form and the IRB of our institution (Centre Orthopédique Santy, Lyon France) approved this retrospective study. Exclusion criteria were the presence of a THA, a history of previous hip or femoral trauma or surgery and or the presence of hip osteoarthritis or of any hip joint disease. This provided us with the CT scans of 100 patients who had a total knee arthroplasty between 2008 and 2009. Their mean age was 72 years ± 8 (51 to 88), with 40 women (age: 71.5 years ± 8, BMI: 27.9 kg/m² ± 7) and 60 men (age: 72 years ± 7, BMI: 27.7 kg/m² ± 3.8).

All CTs were performed using the same protocol with a multibar scanner (Siemens® Sensation, Munich, Germany). The patients were placed in supine position, with extended knees, their feet in neutral rotation. The hip was scanned from the antero-inferior iliac spine down to the lesser trochanter every 2 mm. The knee from 5 cm above the upper rim of the patella down to the anterior tibial tuberosity. The study was carried out using the OsiriX software, dedicated to the analysis of DICOM images (open-source software; http://www.osirix-viewer.com/index.html).

Native acetabular anteversion was determined on the transverse or horizontal cross section running through the middle of the femoral head. We defined acetabular version as the angle between a line connecting the lateral anterior and posterior margins of the acetabulum and the sagittal plane (22). In the transverse plane, the measurements were made on the section going through the level of the true floor of the acetabulum and cutting through the femoral head at its greatest diameter (Fig. 1). The centre of the femoral head (CF) was referenced first. The Acetabular offset (AO) was defined as the distance from CF to the true floor of the acetabulum. The Acetabular Floor distance (AF) was defined as the distance between the most medial point of the femoral
head and the true floor of the acetabulum. We defined the head-floor ratio as the ratio between femoral head diameter and acetabular floor distance (head diameter/AF). The CRH was then determined after simulated implantation of the acetabular implant using each of the two techniques; firstly (A) with the acetabular cup in contact with the true floor of the acetabulum ("conventional" technique) and secondly (B) preserving acetabular offset, by positioning the cup at the level of the subchondral bone ("anatomical" technique). Measurements of acetabular cup placement were then made in both the transverse and coronal planes. Each cup was aligned such that its anterior rim sat just deep to the anterior wall of the bony acetabulum so as to avoid any impingement with the tendon of the iliopsoas. The diameter of the acetabular cup with these two techniques was measured in the transverse plane. The CF – CRH distance was measured with respect to global distance, but also in terms of all three axes; the mediolateral and anteroposterior shift in the transverse plane and the longitudinal shift in the coronal plane.

For each of the two techniques, the global acetabular protrusion was defined as the distance measured between the centre of the simulated acetabular cup and the line joining the anterior and posterior walls of the acetabulum. The posterior overhang of the cup relative to the posterior wall of the acetabulum was measured as well as cup anteversion.

Statistical analysis: We conducted statistical analyses for comparison of morphometric data between the conventional and anatomical techniques and between males and females using unpaired t-tests. Correlations between variables were calculated using the Pearson product moment coefficient of correlation (r). The significance level was set at 0.05. The statistical package we used was Microsoft® Excel and its statistical software (Microsoft Corp).

RESULTS

Morphometric characteristics of the series are summarised in Table I. Acetabular offset values ranged from 22 mm to 37 mm, with higher values in males compared with females (p<0.0001) (Fig. 2A). Distance AF was also significantly

| TABLE I - RESULTS OF ANATOMIC MEASUREMENTS IN THE GLOBAL SERIES AND IN THE MEN/WOMEN SUBGROUPS |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Age (years)                     | 71.8 ± 8 (51-88)                | 71.5 ± 8 (51-87)                | 72 ± 8 (56-88)                  | 0.3                             |
| Head diameter (mm)              | 46.4 ± 4 (37-56)                | 42.5 ± 2 (37-47)                | 48.9 ± 3 (42-56)                | <0.0001                         |
| Acetabular anteversion (°)      | 22.7 ± 6 (11-37)                | 23.5 ± 7 (11-37)                | 20.8 ± 4 (15-38)                | 0.19                            |
| Acetabular offset (mm)          | 30.8 ± 3 (22-37)                | 27.6 ± 2 (22-31)                | 33 ± 2 (28-37)                  | <0.0001                         |
| Acetabular floor distance (mm)  | 7.6 ± 1.9 (3-13)                | 6.3 ± 1 (3-9)                   | 8.5 ± 2 (5-13)                  | <0.0001                         |

*Males versus females.
Acetabular offset: morphometric CT-analysis

greater in males than in females. It was greater than 6 mm in 95% of hips in males and 57% in females. It was greater than 10 mm in 18% of hips in males but never in females (Fig. 2B). A positive correlation was identified between AF distance and head diameter ($r = 0.38$ and $p<0.001$) in the global series but not in the male and female subgroups. The head-floor ratio was significantly greater in females than in males (respectively $6.7 \pm 1.3$ and $5.7 \pm 1.2$; $p = 0.0017$), females having a smaller AF distance for a given head size (Fig. 3).

After simulated cup implantation the global shift of the CRH was $1.9 \text{ mm} \pm 1.4$ (0 to 9.6) with the anatomical technique and $5.1 \text{ mm} \pm 1.9$ (0 to 10) with the conventional technique ($p<0.0001$) (Tab. II). Among the three components of the global shift, pure medialisation was $1.6 \text{ mm} \pm 1.2$ with the anatomical technique and $4.8 \text{ mm} \pm 1.9$ with the conventional technique ($p<0.0001$). Medialisation was greater than 5 mm in 44% of the cases with the conventional technique, but occurred in no case when using the anatomical technique (Fig. 4). Medialisation did correlate positively with distance AF with both techniques ($p<0.0001$) and the difference of medialisation of CRH between the two techniques (mean $3.2 \text{ mm} \pm 1.9$; range, 0 mm to 7.5 mm) was correlated with the distance AF ($p<0.0001$). Medialisation was correlated with upward shift with anatomical technique only ($p = 0.01$) and with posterior shift with conventional and anatomic techniques ($p = 0.004$ and 0.001).

### TABLE II - CUP DIAMETER WITH THE TWO TECHNIQUES AND SHIFT OF THE HIP CENTRE OF ROTATION IN THREE DIMENSIONS WITH THE TWO TECHNIQUES AND IN MALES AND FEMALES

<table>
<thead>
<tr>
<th>Technique</th>
<th>Series</th>
<th>Females</th>
<th>Males</th>
<th>$p$-value**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean ± SD (min-max)</td>
<td>mean ± SD (min-max)</td>
<td>mean ± SD (min-max)</td>
<td></td>
</tr>
<tr>
<td>Cup diameter</td>
<td>Classic</td>
<td>52.0 ± 4.1 (44-60)</td>
<td>48.1 ± 2.1 (44-54)</td>
<td>54.7 ± 2.7 (47-60)</td>
</tr>
<tr>
<td></td>
<td>Anatomic</td>
<td>52.9 ± 4.1 (44-63)</td>
<td>48.9 ± 1.9 (44-53)</td>
<td>55.6 ± 2.9 (47-63)</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>&lt;0.062*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global</td>
<td>Classic</td>
<td>5.0 ± 1.9 (0-10)</td>
<td>3.8 ± 1.5 (0-6.6)</td>
<td>5.9 ± 1.8 (2.5-10)</td>
</tr>
<tr>
<td></td>
<td>Anatomic</td>
<td>1.9 ± 1.4 (0-9.6)</td>
<td>1.4 ± 1.6 (0-9.6)</td>
<td>2.2 ± 1.1 (0-4.6)</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>&lt;0.0001*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial</td>
<td>Classic</td>
<td>4.8 ± 1.9 (-1.5-9.8)</td>
<td>3.5 ± 1.7 (-1.5-6.4)</td>
<td>5.6 ± 1.6 (2.4-9.8)</td>
</tr>
<tr>
<td></td>
<td>Anatomic</td>
<td>1.6 ± 1.2 (-1.8-4.6)</td>
<td>0.9 ± 0.9 (-1.5-2.8)</td>
<td>2.0 ± 1.1 (-1.8-4.6)</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>&lt;0.0001*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior</td>
<td>Classic</td>
<td>0.8 ± 0.5 (-1.3-2)</td>
<td>0.8 ± 0.7 (0-3.3)</td>
<td>0.9 ± 0.9 (-1.2-3.5)</td>
</tr>
<tr>
<td></td>
<td>Anatomic</td>
<td>0.2 ± 0.6 (-1.3-2)</td>
<td>0.2 ± 0.4 (-1.3-1.6)</td>
<td>0.3 ± 0.5 (-0.8-2)</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>&lt;0.0001*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior</td>
<td>Classic</td>
<td>3.3 ± 1.3 (0-5.7)</td>
<td>3.2 ± 1.4 (0.4-6.7)</td>
<td>3.5 ± 1.6 (0-7.7)</td>
</tr>
<tr>
<td></td>
<td>Anatomic</td>
<td>2.1 ± 1.5 (0-5.7)</td>
<td>1.9 ± 1.3 (0-5.7)</td>
<td>2.2 ± 1.3 (0-5.4)</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>&lt;0.0001*</td>
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</tr>
</tbody>
</table>

* Between Classic and Anatomic technique in the global series.
** $p$-value between females and males.
The diameter of the simulated cup was 52.9 mm ± 4 (44 to 63) with the anatomical technique and 52.0 mm ± 4.1 (44 mm to 60 mm) with the conventional technique (p = 0.062). The protrusion of the centre of the cup relative to the anterior and posterior walls of the acetabulum was 1.6 mm ± 3.2 (-8.4 mm to 5.1 mm) with the anatomical technique and -1.7 mm ± 2 (-8.4 to 0.7 mm) with the conventional technique (p<0.0001). The posterior overhang was 5.7 mm ± (0 to 14.9 mm) with the anatomical technique and 0.62 mm ± (0 to 3.6 mm) with the conventional technique (p<0.0001).

**DISCUSSION**

Two important findings arise from this study. Firstly acetabular offset widely varies between individuals and the acetabular floor distance can be up to 13 mm, which should not be ignored by surgeons. Secondly the resultant hip centre of rotation following THA is influenced by both the acetabular anatomy and by the surgical technique used to implant the acetabular component.

The strength of this study was that we were able to quantify the acetabular offset and the shift of the CRH during THA using a non-arthritic healthy hip as a reference and by comparing two surgical techniques. DICOM image analysis using the OsiriX® software eliminated the lack of accuracy linked to X-ray magnification and made it possible to make measurements with an accuracy higher than that of radiographic studies, studies on cadavers, and even those using navigation (23). Furthermore the analysis of healthy hips made it possible to eliminate the alteration caused to CRH by degenerative change. Our objective was not to determine the best technique or the best strategy, but to analyse the anatomic consequences of the conventional and anatomical techniques.

The limitations of this study are linked to the uncertainty of the positioning of the simulated prosthetic cup, to the limit of the subchondral bone for the anatomical technique, and to the contact with the acetabular floor for the conventional technique. In vivo reaming depends on the bone density and it is possible that the theoretical positioning does not correspond precisely to the surgical reality. Another weakness concerns the measurement of the posterior overhang of the simulated cup. Indeed, the anteversion was measured from the transverse section scan views, which were perpendicular to the longitudinal axis. This does not correspond to the definition of operative anteversion (24). Also because our scans commenced below the anterior superior iliac spines we were unable to determine the anterior pelvic plane.

There is now a consensus on the importance of the restoration of the offset in total hip arthroplasty (1-5, 25, 26). However the literature generally refers to the global or to the femoral offset and the role of the acetabular offset has been emphasised only recently (6, 9, 12). This present study shows that the concept of hip offset cannot be limited to that of the femoral offset. The mean acetabular offset reported here represents 72% of the mean femoral offset measured with a similar CT-scan technique by Sariali (respectively 30.8 ± 3 mm and 42.2 ± 5.1 mm) (8). Also, ranges of variation of acetabular offset and of AF distances reported in our study represent respectively half and one third of the variations reported with femoral offset, which is important in terms of restoration of hip biomechanics (8).
In this study, the conventional technique of acetabular cup positioning led to the CRH being medialised by greater than 5 mm in 44% of cases and as much as 9.8 mm in one case. In contrast, the conservative technique makes it possible to better maintain the CRH, which was medialised by 2 mm or less in 68% of the cases. In their series of THA, Dorr (11) and Dastane (6) report a mean 3 to 6 mm medialization of the CRH measured intra-operatively whilst using a navigation system. A medial shift less than 5 mm with an upward shift less than 3 mm was observed only in only 26% of the patients. Likewise, Eggli (18) and Knight (27) report a medialisation of the acetabular cup of 3.4 mm and 5 mm respectively relative to their pre-operative X-rays. After conservative reaming of the acetabulum, Sariali reported a restoration of the position of the CRH with a mean precision of 0.73 mm in the craniocaudal direction, of 1.2 mm in the mediolateral direction, and 0.05 mm in the antero-posterior direction (19). It must be noted that in these studies the measurements included the correction required to account for the arthritis-induced acquired offset.

Thus, two strategies may be used by the surgeon during primary THA in order to restore global hip offset: (i) Anatomical restoration by maintaining the acetabular offset through an anatomical positioning of the cup and accurate reproduction of the femoral offset; (ii) Restoration of the global offset by compensating for the acetabular medialization through an increase in the initial femoral offset (28, 29). Interestingly, the additional offset in high offset stems, which ranges from 4 mm to 8 mm (30-33), is very close to the medial shift of the CRH reported in this study and by others authors (6, 11, 18, 27). A third option would be to use lateralised acetabular implants, but higher wear rates have been reported with this type of implants (34). The main anatomic characteristics of the hip joint identified in our study as influencing the medial shift of HCR, was the acetabular floor distance (AF). Males and females had different head-floor ratios, which explains the greater medialisation observed in males. The difference of medialisation with the two techniques increases with the AF distance, from 0 mm difference in patients with low AF distance, up to 7.5 mm difference in patients with a 12 mm AF distance. The natural conclusion of this study could be that the best option is to preserve natural acetabular offset with conservative reaming of the acetabular floor, hoping to preserve the CRH. However, biomechanical consequences of a lack of restoration of femoral and acetabular offset are different. In the first situation, the lever arm of the abductor muscles is decreased and their line of action is verticalised, which can have dramatic consequences (35-37). In the second situation, the lever arm of the abductors is not modified and the lever arm of body weight is decreased, which compensates for the negative effect of a more vertical line of action of the gluteus medius muscle (29).

A more conservative technique of acetabular preparation has several advantages. It increases the range of motion of the hip and decreases the risk of bony or soft tissue impingements (9), the risk of dislocation (10, 38) and the occurrence of head-cup microseparations, source of squeaking or bearing deterioration (39, 40). However this option can decrease the quality of bone fixation, which combined with an increased body-weight lever arm can have an adverse clinical effect. This technique can also modify the orientation or the size of the acetabular cup and generate a posterior overhang that can reach up to 15 mm.

CONCLUSION

This study confirms that the concept of the offset cannot be limited to that of the femoral offset. Acetabular offset widely varies between individuals and the Acetabular Floor distance can be up to 13 mm, which should not be ignored by surgeons. In patients with significant acetabular offset, with an AF distance greater than 5 mm, surgeons should pay attention to reaming the acetabulum conservatively and to position the acetabular cup anatomically in order to restore the native hip biomechanics (19). Such an anatomic positioning, follows anatomic landmarks (10), and must satisfy the main goals of acetabular preparation: good primary fixation, good orientation and no anterior overhang.

Financial support: No financial support was received for this study.

Conflict of interest: Some authors (MPB and MHF) received Royalties from Depuy. The research unit of DEB receives financial support from Biomet and Depuy.

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Acetabular offset: morphometric CT-analysis


