An In Vivo Comparison of the Orientation of the Transverse Acetabular Ligament and the Acetabulum

Andrew R. Griffin, MPhty, BSc(ExSc&Nutrition), Diana M. Perriman, PhD, MSc, BAppSc (Physio), Claire J. Bolton, MBBS, BSc, Paul N. Smith, BMBS, FRACS (Ortho)

Department of Medicine, Australian National University, Canberra, Australia
Trauma and Orthopaedic Research Unit, The Canberra Hospital, Canberra, Australia

Abstract
Aligning the acetabular component with the Transverse Acetabular Ligament (TAL) to ensure optimal anteversion has been reported to reduce dislocation rates. However, to our knowledge in vivo measurement of the TAL angle has not yet been reported in a large cohort of normal hips. CT scans of 218 normal hips were analyzed. The TAL and four acetabular rim anteversion angles were measured (superiorly to inferiorly) relative to the anterior pelvic plane. The mean TAL anteversion angle was 20.5° ± 7.0°, and the acetabular rim angles from superior to inferior were 11.0° ± 12.9°, 19.9° ± 8.8°, 20.9° ± 6.2° and 25.1° ± 6.2° respectively. Both the TAL and the acetabular rim were significantly more anteverted in females than in males. The TAL anteversion angle was comparable to the predominant orientation (central rim section) of the native acetabulum while the superior acetabulum was comparatively retroverted and the inferior was relatively more anteverted.
conduct at the Canberra Hospital between January 2007 and December 2011. The study protocol was approved by the ACT Health Human Research Ethics Committee (ETHLR.11.162).

Participants

Patients over the age of 18 years with normal hip joint anatomy who received a CT scan of the ‘Abdomen and Pelvis’ between January 2007 to December 2011 at The Canberra Hospital were included in this study.

Exclusion Criteria

Patients were excluded if they had any abnormal hip pathology or the TAL was not clearly visible as a straight line between the two horns of the acetabular notch on 3D CT imaging. If the TAL was visible on one side but not the other, measurements of the acetabular rim from the visible side only were included in the results.

Measurements Conducted

Two observers (ARG and CJB) conducted all measurements after intra-observer and inter-observer reliability was established (ICC2,1: TAL = 0.96 and Acetabulum = 0.90; TAL = 0.95 and Acetabulum = 0.95 respectively). Pelvic and abdominal CT was performed using a Toshiba Aquilion 16 slice scanner. Hospital protocols dictate that patients are positioned supine and central in the gantry and images are obtained at 1 mm intervals at a rotation speed of 0.5 s from the pubic symphysis to the diaphragm. For this study the images were uploaded to OsirIX v.4.0 32-bit Digital Imaging and Communications in Medicine format (DICOM) Viewer (Kanteron Systems, Valencia). Scans were viewed and measured in a multiplanar reconstruction using 3D MPR format.

In the coronal plane the images were rotated to align with the anterior pelvic plane (APP) as described by Lewinnek et al [32] from which the version angles were referenced. The transverse plane was aligned using the ‘tear drops’ of the pelvis (inferior rims of the acetabular fossae and the parasagittal surface of the ilium). Because the scans were rotated to achieve true planar views, a correction angle was recorded (Fig. 1). This correction angle was used to calculate the degree of anteversion and retroversion.

The angle of the acetabular rim in relation to the true sagittal plane (version) was measured at the most supero-lateral point of the acetabular rim (Figs. 2A & 3A), at 10 mm and 20 mm below this point (Fig. 2B & C and Fig. 3B & C respectively), and finally at the most inferior point of the acetabular rim (Figs. 2D & 3D). These measurements were made for both the left and right sides when the TAL was visible.

The TAL lies in a parasagittal plane. Therefore, to be viewed as a straight line between the anterior and posterior horns of the acetabulum, the scan was rotated from the reference position (APP) until it was visible (Fig. 4A). The angle between the parasagittal plane in which the TAL was viewed and the APP was measured (Fig. 4B). The TAL angle was calculated by subtracting the correction angle from this angle. All angles were then subtracted from 90° to conform with Murray’s definition of radiographic anteversion [31] to allow accurate comparison with the existing literature [33].

In order to confirm that we were measuring the TAL from the CT images a cadaveric study was conducted. A cadaveric pelvis and hip were imaged pre-disarticulation following which two 1 mm tantalum beads which located the labral-TAL junctions were inserted. Subsequently, post-disarticulation imaging clearly identified that we had located the correct structure (Fig. 5).

Statistical Analysis

Descriptive statistics included means and standard deviations (mean ± SD). The data were tested for normality using the Shapiro–Wilk test. Normality was accepted if the P value is > 0.05. Because the data were normally distributed the TAL and the four acetabular rim angles were compared using paired t-tests (two tailed). The TAL and acetabular angles were compared for gender and side differences using an independent t-test (two-tailed). Statistical significance was accepted when P < 0.05. A type 2, 1 intra-class correlation coefficient (ICC2,1) was used to estimate inter-observer and intra-observer reliability. All data were analyzed using SPSS statistics base Version 20 (IBM, New York).

Results

CT scans for 160 patients were identified and from these 218 hips were measured i.e. only those hips where the TAL was clearly visible. One hundred and two hips were excluded because the TAL was insufficiently clear due to: obfuscation from surrounding tissue (53 hip scans), gross deformity of the joint due to arthritis (11 hip scans), artifact from prosthesis, plates or screws (8 hip scans) or where the CT scan did not include the lower acetabulum (30 hip scans). The mean age was 58.7 years (range, 20–96 years). The number of female and male hips reviewed was 111 and 107 respectively (Table 1).

The mean TAL anteversion angle was 20.5° ± 7.0°. The mean acetabular anteversion angles from superior to inferior at 10 mm intervals were 11.0° ± 12.9°, 19.9° ± 8.8°, 20.9° ± 6.2° and 25.1° ± 6.2° respectively. There was a significant difference between the TAL anteversion angle and the supero-lateral and inferior acetabular rim
Anteversion angle ($P < 0.001$ and $P < 0.001$ resp.). However, there was not a significant difference between the TAL anteversion angle and the rim anteversion angles at 10 mm and 20 mm inferior to the superior lateral rim (central rim section) (Table 2 and Fig. 6). The superior rim was retroverted outside Lewinnek’s ‘safe zone’ of $15° ± 10°$ in $30.7\%$ of cases ($n = 67$) and the inferior rim was anteverted outside Lewinnek’s ‘safe zone’ in $53.7\%$ of cases ($n = 117$) (Fig. 6). The mean TAL anteversion angle for males and females was $19.0° ± 6.3°$ and $22.0° ± 7.4°$ respectively. There was a significant difference between males and females for all acetabular and TAL anteversion angles (Table 2). Female average acetabular rims were anteverted between $2.7°$ and $4.3°$ more than males at different heights through the acetabulum, and the TAL was anteverted more in females by $3.0°$ (Table 2). Anteversion of the TAL on the left and right sides of
The body was 20.1° and 21.0° respectively. There was no significant difference between left and right sides.

**Discussion**

The purpose of this study was to determine the relative orientation of the TAL compared to the acetabulum in vivo in normal hips. We hypothesized that the angle of anteverision of the TAL would be the same as the angle of anteverision of the acetabular rim thereby providing a reliable anatomical landmark for reproducing native cup orientation in THA.

There were three major findings from this study. First, the TAL was closely aligned with the central section of the acetabular rim which represented the predominant orientation. Second, the relative version of the acetabular rim changed considerably throughout the height of the acetabulum. The superior rim was relatively retroverted while the inferior rim was relatively anteverted. Relative to Lewinnek’s ‘safe zone’ a significant number of the acetabulae were retroverted superiorly (<−5°) and excessively antverted inferiorly (>25°). Finally, females were significantly more antverted than males for both acetabular and TAL version angles, while there was no significant difference between left and right sides.

To our knowledge this is the first time the orientation of the TAL has been measured in vivo in a large cohort of normal hips. Alignment of the acetabular component during THA using the TAL has been proposed as a method for decreasing the post-operative dislocation rate and limiting excessive wear [1–6,7,9,13,14,39,40]. Previous studies have attempted to measure the orientation of the TAL using radiographic imaging and in vitro methods, but have been limited by imaging accuracy and subject numbers [2,9,40]. In this study we found that the orientation of the TAL was closely aligned with the central rim section of the acetabulum. Our findings are similar to the MRI arthrogram findings of Archbold et al [9] who reported a mean anteverision angle for the TAL of 23.0° ± 7.4° for 25 patients with labral tears. In another paper Archbold et al reported an average post-operative acetabular component anteverision angle of 19.7° when the TAL alone was used for alignment during THA [1]. This is consistent with our average TAL anteverision measurement of 20.5° achieved using retrospective CT scans.

The orientation of the acetabular rim changed superiorly to inferiorly. The orientation of the TAL was significantly different (P<0.001) from both the superior and inferior acetabular rim margins. In comparison to the TAL, the superior acetabular rim was relatively retroverted and the inferior acetabular rim was relatively antverted, while the closest match to alignment of the TAL occurred at the level of the central rim section which represented the predominant orientation. This finding reflects the torsional nature of the acetabular rim moving from a relatively retroverted position superiorly to a relatively antverted position inferiorly. The degree of this torsion was variable both within and between patients. Vandenburgsche et al [41] reported that acetabular anteverision is often assumed to be hemispheric and planar in its profile, but is in fact asymmetrical. These findings of acetabular asymmetry are well supported in the literature [41–43].

In this study there was a significant inter-individual difference in version measurements of the acetabular rim, particularly at the superior acetabular margin. While the inclination of the acetabulum (tilt relative to the sagittal plane) is consistently reported to be approximately 40°, reports of the degree of acetabular version is more variable [6,41,42]. The variation in version at the different acetabular levels found in this study may explain why other groups have reported such variable measurements. Our results showed the greatest degree of variation both within and between patients at the superior acetabulum (11.0° ± 12.9°), and the least variation at the inferior acetabulum (25.1° ± 6.2°). The variable version of the acetabular rim is clinically relevant because with respect to ‘Lewinnek’s safe zone’, the superior acetabular rim was retroverted in 30.7% of scans, while the inferior rim was excessively antverted in 53.7% of scans. Cups aligned outside Lewinnek’s ‘safe zone’ have been associated with an increased dislocation rate [17].

Techniques for alignment of the acetabular cup remain controversial [44]. The ideal inclination and anteverision in THA are different for every patient [19]. Although Lewinnek’s ‘safe zone’ is the most well known, others have suggested alternative and tighter limits [7,32,45]. Freehand positioning of the acetabular cup has been shown to be inaccurate [3,7,26,46,47] while it is suggested that navigation

---

**Table 1**

**Patient Characteristics.**

| Number of Patients (Hips Viewed) | 160 (218) |
| Mean Age (range) | 58.7 (20–96) |
| Gender (male/female) | 79/81 |
| Gender of Hips measured (male/female) | 107/111 |

**Table 2**

**Summary of Anteverision Measurements by Structure and Gender (Comparison With TAL and Gender).**

<table>
<thead>
<tr>
<th></th>
<th>Average Anteverision (Degrees)</th>
<th>Standard Deviation (Degrees)</th>
<th>P Values Comparison With TAL</th>
<th>Male Average Anteverision (Degrees)</th>
<th>Female Average Anteverision (Degrees)</th>
<th>P Values Between Genders</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAL</td>
<td>20.5</td>
<td>7.0</td>
<td></td>
<td>19.0</td>
<td>22.0</td>
<td>0.001</td>
</tr>
<tr>
<td>Superior Acetabulum</td>
<td>11.0</td>
<td>12.9</td>
<td>&lt;0.001</td>
<td>8.8</td>
<td>13.1</td>
<td>0.016</td>
</tr>
<tr>
<td>10 mm Inferior</td>
<td>19.9</td>
<td>8.8</td>
<td>0.293</td>
<td>18.3</td>
<td>21.5</td>
<td>0.007</td>
</tr>
<tr>
<td>20 mm Inferior</td>
<td>20.9</td>
<td>6.2</td>
<td>0.311</td>
<td>19.6</td>
<td>22.3</td>
<td>0.001</td>
</tr>
<tr>
<td>Most Inferior</td>
<td>25.1</td>
<td>6.2</td>
<td>&lt;0.001</td>
<td>23.3</td>
<td>26.9</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
technology is limited by cost and prolonged procedure duration \([23,27,30,48]\). Our results indicate that in some patients the use of the superior and inferior acetabular rim to align the acetabular component intra-operatively would lead to positioning it outside all reported ‘safe zones’. Using the TAL for alignment however, would be more reliable because it is aligned most closely with the predominant orientation of the acetabulum.

There are a number of advantages associated with using the TAL for alignment of the cup during THA. The cup version is patient specific and independent of the APP, rim angles or specified safe zones \([5,49]\). It is also independent of patient positioning thereby minimizing error in version estimation \([4,8]\).

In this study there was a significant gender difference for acetabular rim and TAL version. Previous studies including those by Lewinnek \[32\] and Archbold \[4\] do not describe differences between males and females or patient side in relation to TAL orientation, cup alignment or dislocation rates. However, three of four studies of acetabular morphology have reported between 2.7° and 5° greater anteversion of the acetabular rim in females compared to males and no difference between left and right sides which are comparable with our data \([41,50–52]\).

This study is unique in that it, for the first time, provides a non-invasive method for measuring the orientation of the TAL in vivo. However, the study has some limitations. Because the study was retrospective we used scans that had been taken for various reasons and therefore not all accurately imaged the TAL. For this reason not all scans could be included in the study. However, by using a pool of preexisting scans the number of patients measured far exceeds that of any previous study. Lack of numbers in previous studies has been recognized as a limitation in the literature \([2]\). A second limitation was that the acetabulum was measured at standard heights from superior to inferior rather than individually dividing the acetabulum proportionately for each patient. The height of the femoral head has been reported to have a standard deviation of 13 mm \([53]\) and this size variation could be extrapolated to the acetabulum. However, this is unlikely to have altered the overall results because the measurements represented the superior and inferior margins as well as the central rim section for all patients. Because we included only hips with normal anatomy these data represent normal hip anatomy. Further investigation of pathological hip anatomy is therefore required but these data provide a useful baseline for future comparison.

This in vivo study has found that the TAL faithfully represents the predominant orientation of the acetabulum and not the relatively retroverted and anteverted superior and inferior margins. Further, these results suggest that utilizing the superior or inferior margins of the acetabulum to orientate the acetabular component in THA could result in an excessively retroverted or anteverted cup, thereby increasing the risk of dislocation and excessive prosthetic wear. These results support the use of the TAL for alignment of the acetabular cup in total hip arthroplasty.

Acknowledgments

We acknowledge the significant contribution of the following people with thanks and gratitude: Dr J. Scarvell for assistance in the initial planning of the study concept. Dr A. Garg for identification and familiarization of the CT imaging program used in the study. Dr T. Neeman for statistical advice. Dr M. Irani for assistance with assessment of methodological reliability.

References

39. Ho KWK, Whitwell GS, Young SK. Reducing the rate of early primary hip dislocation by combining a change in surgical technique and an increase in femoral head diameter to 36 mm. Arch Orthop Trauma Surg 2012;132(7):1031.