

## ■ HIP

# The role of the transverse acetabular ligament for acetabular component orientation in total hip replacement

## AN ANALYSIS OF ACETABULAR COMPONENT POSITION AND RANGE OF MOVEMENT USING NAVIGATION SOFTWARE

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**Orientation of the native acetabular plane as defined by the transverse acetabular ligament (TAL) and the posterior labrum was measured intra-operatively using computer-assisted navigation in 39 hips. In order to assess the influence of alignment on impingement, the range of movement was calculated for that defined by the TAL and the posterior labrum and compared with a standard acetabular component position (abduction 45°/anteversion 15°).**

**With respect to the registration of the plane defined by the TAL and the posterior labrum, there was moderate interobserver agreement ( $r = 0.64$ ,  $p < 0.001$ ) and intra-observer reproducibility ( $r = 0.73$ ,  $p < 0.001$ ). The mean acetabular component orientation achieved was abduction of 41° (32° to 51°) and anteversion of 18° (-1° to 36°). With respect to the Lewinnek safe zone (abduction 40° ± 10°, anteversion 15° ± 10°), 35 of the 39 acetabular components were within this zone. However, there was no improvement in the range of movement ( $p = 0.94$ ) and no significant difference in impingement ( $p = 0.085$ ).**

**Alignment of the acetabular component with the TAL and the posterior labrum might reduce the variability of acetabular component placement in total hip replacement. However, there is only a moderate interobserver agreement and intra-observer reliability in the alignment of the acetabular component using the TAL and the posterior labrum. No reduction in impingement was found when the acetabular component was aligned with the TAL and the posterior labrum, compared with a standard acetabular component position.**

Various orientations of the acetabular component have been proposed to improve movement, minimise contact stresses and reduce the risk of impingement and dislocation following total hip replacement (THR).<sup>1-7</sup> It seems that a universally applicable ideal orientation cannot be defined due to variations in the anatomy of the acetabulum and proximal femur.

Various techniques have been described to achieve a more individualised orientation, some of which use bony or soft-tissue landmarks for alignment.<sup>8-10</sup> Recently, Archbold et al<sup>11</sup> described and evaluated a concept of aligning the acetabular component parallel to the transverse acetabular ligament (TAL) using a posterior approach with the aim of establishing a patient-specific version. Using this method in 1000 consecutive cases, they reported a dislocation rate of 0.6% compared with a historical cohort of 3.7%. Although they focused on using the TAL to control version, they also proposed using the posterior labrum as an aid in determining abduction of the component. There have, however, been few further studies showing the

reliability of using the TAL for acetabular component orientation in THR.<sup>9,10</sup>

This study was undertaken to address this and to answer the following questions: What is the relationship of the plane defined by the TAL and the posterior labrum relative to the pelvic coordinate system defined by the anterior pelvic plane?; Is aligning the acetabular component with the TAL reliable?; and does the anatomical orientation of the acetabular component determined by the TAL and the posterior labrum improve the range of movement compared with a standardised position of 45° abduction and 15° anteversion?

## Patients and Methods

Between September 2007 and March 2008, 40 patients were prospectively enrolled into this single-centre study following approval from the ethics committee. THR was indicated in all patients because of osteoarthritis. In one patient computer-assisted surgery was abandoned because the acetabular component model could not be generated accurately. The

mean age of the remaining 39 patients was 67 years (50 to 81); 15 were male and 24 female, with 18 right THRs and 21 left. The mean body mass index (BMI) of the patients was 28 (19 to 43).

**Surgical procedure.** The THRs were performed by two senior consultants (TK, ES) with the patient in the lateral decubitus position using a minimally invasive direct anterior approach. In all patients, a cementless press-fit acetabular component (Pinnacle; DePuy, Warsaw, Indiana), a modular head with 32 mm diameter and a cementless femoral component (Corail; DePuy) were implanted. An imageless navigation system (Hip 5.0 Unlimited; Brainlab, Feldkirchen, Germany) was used for intra-operative measurement of anatomical landmarks, as well as for definitive placement of the components. Both surgeons were familiar with computer-assisted surgery for THR over the course of more than 300 navigated THRs.

**Intra-operative measurement of anatomical landmarks.** The navigation system was used as an intra-operative measurement tool to determine the orientation of the TAL posterior labrum plane as defined by Archbold et al.<sup>11</sup> Kirschner wires 3.2 mm in diameter were inserted into the anterior iliac crest and the ventrolateral third of the distal femur. Dynamic reference bases were attached to the pins. The anterior superior iliac spine (ASIS) and the pubic tubercles were then registered using a reference pointer positioned on the skin surface. These locations were defined by a coordinate system, to generate the anterior pelvic and midsagittal reference planes. The anterior pelvic plane was defined by the ASIS and pubic tubercle points. The midsagittal plane refers to the symmetry plane of the ASIS points. On the femoral side, the coordinate system was defined by the mechanical axis, comprising the axis between the centre of the femoral head and the centre of the condyles, and a mediolateral reference direction. The mediolateral direction was determined according to the normal vector of a plane given by a point at the piriformis fossa, the centre of the condyles and the centre of the ankle. The ankle point was acquired while the leg was held in 90° of flexion. More precisely, the coronal plane of the femur was defined as the plane spanned by the mechanical axis and the normal vector. After resection of the femoral head, the acetabulum was exposed and TAL identified. The plane defined by the TAL and the posterior labrum was then registered by each of the two surgeons using a referenced trial acetabular component which was aligned parallel to these landmarks. The registering surgeon was blinded during this process by turning the navigation screen away from his field of view. The abduction and anteversion angles of the TAL posterior labrum plane were displayed by the navigation system and the values were verified and stored by screenshots for further evaluation. The registration step was performed three times by each of the two surgeons, to evaluate intra- and interobserver reliability. The final position and orientation of the femoral component was recorded by the navigation system relative to the obtained registration.

**Analysis of range of movement.** Post-operatively, range of movement was assessed virtually using the same navigational software, which permits a simulation of hip movement by restoring the intra-operatively acquired navigation data, including the anatomical landmarks, registration data, implant data and the verified positions of the components. For this purpose, the navigation software calculated three-dimensional (3D) models of the bony structures of the pelvis based on the acquired anatomical information. The accuracy of the 3D models was checked intra-operatively by the surgeon. In addition, the software included geometrical 3D models of the actual implants in its database, provided as computer-assisted design files by the manufacturer.

Based on the 3D models, the software checked the range of movement virtually by simulated movement of the objects, that is, the bone and the acetabular and femoral components. The software checked the maximum range of movement by determining the positions where impingement occurred. The angles of rotation were increased stepwise by 1° increments to find the maximum range of movement in each direction. The same directions of movements were analysed together (flexion/extension, abduction/adduction, internal/external rotation at 0° flexion and internal/external rotation at 90° of flexion). A perfect alignment between the pelvis and the femoral coordinate system was used to define the neutral position of the leg, at 0° flexion, 0° abduction and 0° internal rotation.

Adopting a previously reported method, we defined a minimum intended range of movement to detect impingement (Table I).<sup>12</sup> For each direction of movement the range was checked to establish whether it was within the intended range; if it was not, it was marked as impingement. The basic analysis of range of movement and impingement was performed for two different orientations of the acetabular component. One of these was the position according to the plane defined by the TAL and the posterior labrum, and for the other the software generated orientation of the acetabular component of 45° abduction and 15° anteversion.

In this way, we virtually analysed the range of movement in 24 of the 39 hips post-operatively. In the other 15 hips the quality or quantity of the anatomical landmarks and surface points registered intra-operatively were not sufficient for accurate 3D modelling.

**Statistical analysis.** Statistical analysis was performed using SPSS version 16 (SPSS Inc., Chicago, Illinois). The intraclass correlation coefficient (ICC) was used to assess intra-observer reliability. The concordance correlation coefficient (CCC) proposed by Lin<sup>13</sup> was used to evaluate the interobserver agreement of TAL-posterior labrum registration measurements between two independent surgeons. In this term the bias correction factor (BCF) was reported, which measures how far the pairwise measurements deviate from the perfect agreement (difference zero). If there is no deviation of any pair of measurements, BCF = 1 (possible range of values, > 0 to 1). By definition, Lin's<sup>13</sup> CCC is determined by the product of Pearson's correlation

**Table I.** Virtual range of movement (ROM) with the acetabular component aligned in orientation defined by the transverse acetabular ligament and the posterior labrum ( $n = 24$ ) or in a standardised position (abduction  $45^\circ$ /anteversion  $15^\circ$ ). Minimal intended ROM was defined as the threshold for mechanical impingement

	Flexion	Extension	Abduction	Adduction	Internal rotation	External rotation	Internal rotation/ 90° flexion	External rotation/ 90° flexion
Minimal ROM (°)	110	30	40	50	70	30	70	30
<b>Individual position (°) of acetabular component related to native acetabulum</b>								
Mean	112	66	69	55	133	81	36	107
SD	13	22	6	14	28	29	25	28
Range	88 to 140	12 to 93	52 to 80	20 to 75	84 to 180	16 to 129	10 to 103	63 to 147
<b>Standard position (°) of the acetabular component (45° abduction/15° anteversion)</b>								
Mean	111	72	74	53	128	83	36	103
SD	12	19	7	10	26	23	22	26
Range	81 to 127	33 to 95	46 to 81	33 to 63	84 to 180	43 to 121	10 to 87	56 to 142

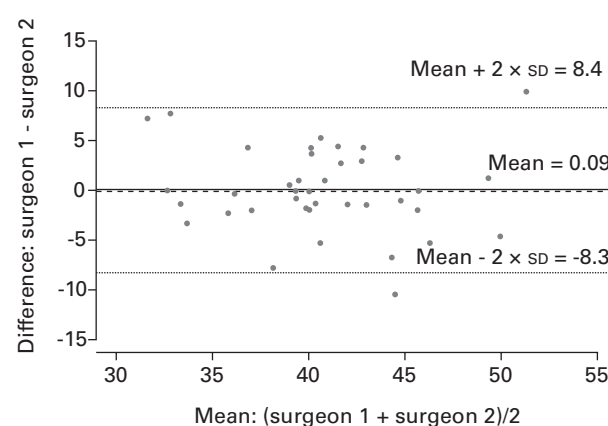


Fig. 1a

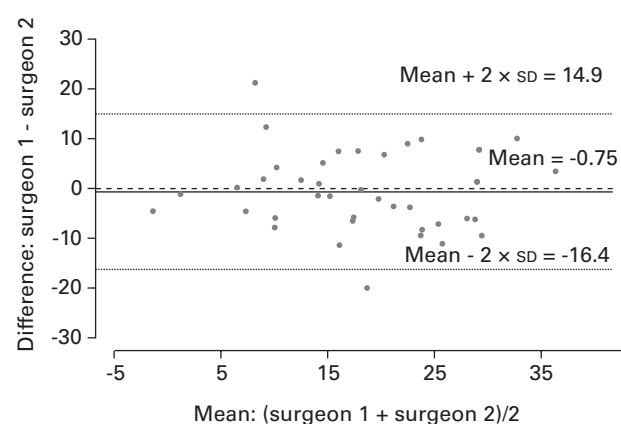


Fig. 1b

Figure 1a – Bland–Altman graph: interobserver agreement (mean values of repeated measurements per patient from surgeons 1 and 2;  $n = 39$ ) on the registration of acetabular abduction according to the transverse acetabular ligament and posterior labrum. Figure 1b – Bland–Altman graph: interobserver agreement (mean values of repeated measurements per patient from surgeons 1 and 2;  $n = 39$ ) on the registration of acetabular anteversion according to the transverse acetabular ligament and posterior labrum.

coefficient ( $r$ ) and the BCF ( $CCC = r \times BCF$ ). In this way, information on systematic deviation and the correlation of two measurements is combined in one index, which takes values from  $-1$  to  $1$ . Agreement of repeated measurements were illustrated using scatter plots proposed by Bland and Altman.<sup>14</sup> Differences in means between standard and individual positions were statistically assessed by paired samples  $t$ -tests. Quantitative measurements were reported as mean, SD and range. Where appropriate, 95% confidence intervals (CI) were provided. The McNemar–Bowker<sup>15</sup> test was used to compare the distribution of frequencies between related samples. A two-sided  $p$ -value of  $< 0.05$  was considered statistically significant.

## Results

With respect to the registration of the plane defined by the TAL and posterior labrum, there was moderate interobserver agreement ( $r = 0.64$ ,  $p < 0.001$ ) and intra-observer reproducibility ( $r = 0.73$ ,  $p < 0.001$ ) in our study. The intra-observer reliability for acetabular abduction was substantial,

with ICC values of  $0.75$  and  $0.80$ , respectively (95% CI  $0.62$  to  $0.88$ ). Similar values were achieved for acetabular anteversion ( $0.71$  and  $0.76$ , 95% CI  $0.56$  to  $0.95$ ). With a BCF of  $0.99$ , there was almost no deviation between observers for abduction or anteversion. However, CCC values were only  $0.66$  (abduction) and  $0.65$  (anteversion), respectively (95% CI  $0.42$  to  $0.80$ ), indicating only a modest interobserver agreement with regard to individual measurements (Fig. 1).

In order to eliminate inter- and intra-observer inaccuracies in measuring the TAL-posterior labrum plane, the mean value of all six measurements was used to determine the orientation of this plane in each patient. According to the definition described by Murray,<sup>16</sup> the mean operative abduction was  $41^\circ$  ( $32^\circ$  to  $51^\circ$ ) and the mean anteversion was  $18^\circ$  ( $-1^\circ$  to  $36^\circ$ ).

In order to plot the orientation of the TAL-posterior labrum plane against the safe zone described by Lewinnek et al.,<sup>1</sup> we converted the values to the radiological definition described by Murray.<sup>16</sup> In relation to the Lewinnek safe

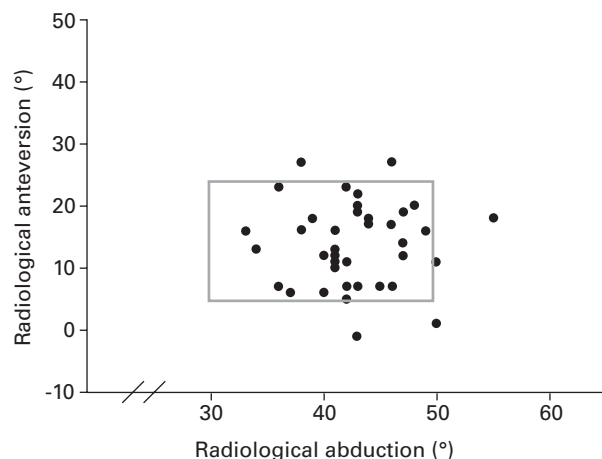


Fig. 2

Graph showing orientation of the native acetabular plane ( $n = 39$ ) defined by the transverse acetabular ligament and the posterior labrum relative to Lewinnek's safe zone (grey frame).

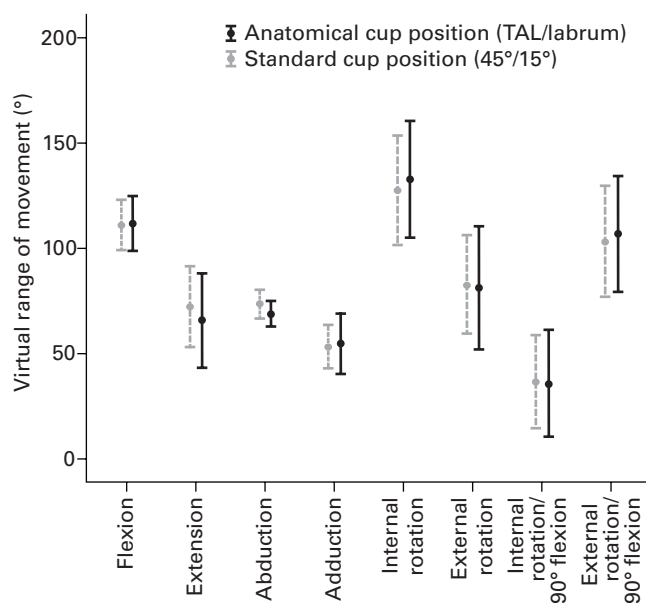


Fig. 3

Analysis of virtual range of movement for a standard acetabular component position (abduction 45°, anteversion 15°) and for an anatomical position, defined by the transverse acetabular ligament (TAL) and the posterior labrum ( $n = 24$ ) (error bars denote  $\pm 1$  SD).

zone (abduction 40° ( $\pm 10^\circ$ ) and anteversion 15° ( $\pm 10^\circ$ ), 34 of the 39 (87%; 95% CI 73 to 96) TAL-posterior labrum planes were within this zone (Fig. 2), and five (13%) were outside it.

With regard to the amount of virtual range of movement, there was no significant difference between the orientation based on the TAL posterior labrum plane and the standard acetabular orientation (abduction 45°, anteversion 15°) (paired Student's  $t$ -test,  $p = 0.94$ ) (Table I, Fig. 3).

**Table II.** Bone-prosthesis impingement with the acetabular component aligned in an orientation defined by the transverse acetabular ligament (TAL) and posterior labrum or in a standard orientation (abduction 45°/anteversion 15°). In all datasets ( $n = 24$ ) virtual mechanical impingement was detected in one, two or three directions of range of movement (ROM). The incidence of impingement for all directions within the ROM ( $8 \times 24 = 192$ ) was counted (McNemar-Bowker test,  $p = 0.085$ ).

TAL (native acetabulum)			
Number of impingements	1	10	10
	2	11	22
	3	3	9
			41/192
Standard (45°/15°)			
Number of impingements	1	15	15
	2	7	14
	3	2	6
Total			35/192

Based on the virtual calculation, impingement was detected in all 24 evaluable datasets (patients) with the acetabular component orientation relative to the TAL-posterior labrum plane (41 of 192) as well as with standard orientation (35 of 192) (McNemar-Bowker,  $p = 0.085$ ) (Table II).

## Discussion

The ideal anteversion and abduction of the acetabular component remains controversial. Harris<sup>2</sup> recommended abduction of 30° and anteversion of 20°. Harkess<sup>3</sup> suggested abduction of 45° and anteversion of 15° ( $\pm 5^\circ$ ). Lewinnek et al<sup>1</sup> defined the safe zone as being within an abduction of 40° ( $\pm 10^\circ$ ) and an anteversion of 15° ( $\pm 10^\circ$ ).

Independently of the target position, recent studies have shown that there is high variability and considerable inaccuracy in the freehand placement of the acetabular component during THR. For example, in a multi-centre study performed by Saxler et al,<sup>17</sup> only 27 of 105 (26%) of acetabular components were placed within the Lewinnek safe zone. Using CT scans for evaluation, these authors reported a range of radiological abduction as defined by Murray<sup>16</sup> from 23° to 71° (SD 10.1°) and a range of radiological anteversion from -23° to 59° (SD 15.0°). In a further study, 42% of the acetabular components were positioned outside the safe zone, despite the use of mechanical alignment guides.<sup>18</sup> In 74 primary THRs, Digioia et al<sup>19</sup> found a range from 35° to 59° (SD 4.0°) in abduction and from -26° retroversion to 33° anteversion (SD 10.0°). This problem is further increased by the use of less-invasive techniques.<sup>20</sup> Although navigation technology has been shown to significantly improve precision during insertion of the acetabular component, the additional cost and increased duration of surgery has prevented the widespread uptake of these techniques.<sup>19,21</sup> Furthermore, considering the variation in the patients' anatomy and their functional pelvic tilt, one might question the necessity of achieving standard acetabular

implant orientation in every patient. In our opinion therefore, in order to achieve a reliable and patient-specific alignment, there is a need for technical aids and tools based on reproducible anatomical landmarks.

Our results show that the outliers, outside Lewinnek's safe zone, can be minimised by aligning the component with the plane defined by the TAL and the posterior labrum. When technical aids are not used during the implantation process, the acetabular component is placed outside the safe zone in between 42% to 72% of THRs.<sup>17-19,21</sup> Owing to the methodological heterogeneity of surgical approaches, patient positions and post-operative analysis, a direct comparison between these studies and our own results is not possible. However, our study has shown that 87% (34 of 39) of the acetabular components aligned relative to the TAL and the posterior labrum were within Lewinnek's safe zone. We therefore conclude that these landmarks can be used to prevent serious malpositioning of the component. However, a limitation of the TAL concept is a moderate interobserver agreement and a moderate intra-observer reliability when aligning the component using these landmarks. As the TAL is a relatively short anatomical structure, small inaccuracies during alignment may lead to large inaccuracies in registration and placement.

A limitation of our study is the fact that the repeated measurements of alignment of the acetabular component parallel to the TAL for evaluation of intra-observer reliability and interobserver agreement were performed during the same operation. One could argue that this does not allow a sufficient interval for these measurements to be considered independent. An even worse intra-observer reliability and interobserver agreement might be assumed for alignment of the component parallel to the TAL and the posterior acetabular labrum outside the rigors of a dedicated investigation.

Some concerns have been raised about the restoration of pre-disease alignment, however. Archbold et al<sup>11</sup> have suggested that, except in the presence of significant acetabular structural deformity, such as in severe dysplasia, stability and the restoration of a functional range of movement are best achieved by restoring the natural biomechanics of the hip. This philosophy is also dependent on correct positioning of the femoral component and accurate restoration of the original centre of the femoral head.

In our study we could not confirm that acetabular component placement relative to the TAL-posterior labrum produced a better functional range of movement than a standard placement. There was a greater, albeit not significant, incidence of impingement with components aligned parallel to the TAL and the labrum compared to the standard position of the acetabular component. This would appear to contradict the low dislocation rate described when using the TAL technique.<sup>11</sup>

This might be explained by the fact that our study was limited by the virtual range of movement analysis being based upon the patient lying supine and on the anterior pelvic plane. Recent studies have shown a significant influence

of pelvic tilt on such models, which makes it theoretically possible that a TAL-posterior labrum-orientated acetabular component may be associated with an increased range of movement and reduced impingement during standing and walking, compared to a conventional acetabular component placement of 45° abduction and 15° anteversion.<sup>22</sup> Future studies are needed to clarify this.

In conclusion, we suggest that alignment of the acetabular component relative to the TAL and the posterior labrum as soft-tissue landmarks can reduce malpositioning of the acetabular component in THR according to the traditional safe zones. However, there is only a moderate interobserver agreement and intra-observer reliability regarding registration of the TAL and posterior labrum when using a minimally invasive direct anterior approach. Our results show no improvement in range of movement and no decrease in impingement in an anatomical orientation when the acetabular component is aligned to the TAL and the posterior labrum, compared to a standard orientation in 45° of abduction and 15° of anteversion.

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