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Original Research

Orientation of Transverse Acetabular Ligament With Reference to Anterior Pelvic Plane

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ABSTRACT

Background: Transverse acetabular ligament (TAL) is a 3-dimensional structure which cannot be defined by a single plane. Therefore, we aimed at describing the orientation of different parts of TAL with respect to anterior pelvic plane (APP) and correlate it with gender, body mass index (BMI), and Lewinnek's safe zone.

Methods: A total of 109 consecutive patients undergoing imageless navigated THA were prospectively studied. Computer navigation was used as the measurement tool. APP was registered for navigation. After excision of osteophytes, a trial component matching the size of unreamed acetabular cavity was aligned with acetabular rim, outer and inner margins, and middle of TAL to record cup orientation with computer tracker.

Results: Ninety-nine patients (41 males and 58 females, mean BMI of 28.8kg/m^2) were studied after applying exclusion criteria. Mean acetabular inclination was 55.15°, 53.00°, 47.70°, and 42.60° respectively, for acetabular rim, outer, middle, and inner margins of the TAL. Corresponding mean acetabular anteversion was 6.63°, 7.41°, 11.23° and 14.90°respectively. Overall, 17.17%, 28.28%, 47.47% and 71.71% of cup orientation corresponding to acetabular rim, outer, middle, and inner margin of TAL respectively, were within Lewinnek's safe zone. No association was established between BMI and acetabular orientation. Males had overall lesser anteversion than females.

Conclusion: We describe orientation of outer, middle, and inner margins of TAL, as reference planes for TAL, in relation to APP. The anteversion differs significantly with gender. A knowledge about these will assist surgeon in component placement during THA, with inner margin of TAL providing the best chance of orientation out of the studied landmarks.

Introduction

Acetabular cup orientation has a major role in deciding the success of a total hip arthroplasty (THA). Complications such as prosthetic impingement [1-3], dislocation [4], accelerated wear [5,6], loosening, and cup failure [7-9] are attributed to malalignment of the acetabular prosthesis. The safe zone for cup orientation is debatable considering the various anatomic, functional, and dynamic factors. However, Lewinnek's safe zone [4] (40° ± 10° of abduction and 15° ± 10° of anteversion) is the most widely used tool for assessing acceptability of cup position. Various bony and soft tissue landmarks can be used intraoperatively to place the cup in the desired position during a THA. These guides include the anatomy of the native acetabulum per se [10,11], bony acetabular rim or fixed reference points on it [12], the transverse acetabular ligament (TAL) [13], and so on. However, it is not clear as to which is the most reliable intraoperative guide to place the cup in the desired orientation. Therefore, an insight into the inherent anatomy and direction of the acetabulum and TAL is of great relevance. The aim was to

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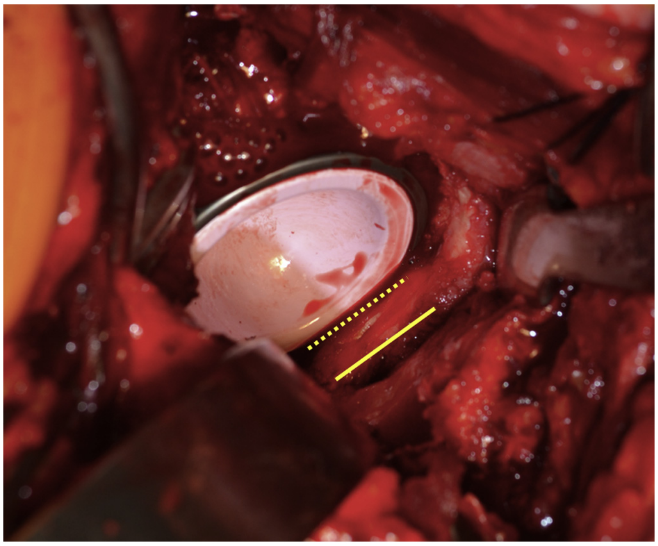

Figure 1. Acetabular cup placed along the inner border of TAL. The 2 lines (dotted and continuous) mark the different borders (inner and outer, respectively) of the TAL.

a) study the orientation of different parts of TAL and acetabular rim with respect to anterior pelvic plane (APP),
b) study its variations with gender and BMI, and
c) correlate the orientation with Lewinnek's safe zone.

Material and methods

Between March 2012 and July 2013, 109 consecutive patients (109 hips) undergoing THA using imageless computer-assisted navigation at our center were studied. Exclusion criteria of dysplastic hips, slipped capital femoral epiphysis, rheumatoid arthritis, past history of infection in the hip, fractures around the hip, pelvic deformity, and ossified TAL were applied, leaving 99 patients to be included in the analysis. The sample size of 99 would have adequate (80%) power to detect a difference of 20% in the proportion classified as outside the zone with type 1 error of 0.05.

Patient demographics and side of surgery were recorded. Institutional ethical clearance from the clinical governance team was taken. When we planned the study to look at the orientation of TAL, we found that it is a broad structure which is not in a single plane and hence one could not really define which part of TAL is being referred to by saying "oriented to TAL." Hence, it was decided to look at 3 parts of TAL. The outer (lateral) margin, the inner (medial) margin (Fig. 1), and a plane in the middle of the 2. This gave clearly defined planes of TAL, which could be measured relative to the APP.

A commercially available imageless computer navigation system (Orthopilot; B. Braun Aesculap, Tuttlingen, Germany) was used as a measurement tool in these prospectively collected data. This method has been validated and previously published to record the orientation of acetabulum with respect to APP [14]. All the surgeries and measurements were recorded by a senior orthopedic surgeon (KD) who was experienced in navigated THA. A pelvic tracker was attached to the pelvis superior to the acetabulum, and the APP was registered with orientations recorded in the radiological frame of reference using anterior superior iliac spines and pubic symphysis. All hips were exposed by a posterior approach with patients in the lateral position. Upon dislocation of femoral head, meticulous dissection of fat and soft tissue was carried out to expose acetabular floor along with TAL. The condition of the TAL was noted, and cases with ossified TAL were excluded. Any osteophytes along the margin of the acetabulum were excised to represent native acetabular rim. The inside of the empty acetabulum was sized with fitting acetabular trials. The trial component of appropriate size, that approximated with the acetabular cavity, was connected to a computer tracker and aligned with the native acetabular rim. A computer software program recorded the inclination and anteversion corresponding to this position. The tracker mounted trial component was then successively placed in the orientation that matched the outer, middle, and inner margins of TAL. While aligning to these landmarks, the inferior border of the trial cup was placed parallel to outer, middle, and inner margins of TAL as shown in Figure 2. While doing so, the insertion handle bisected the outer, middle, or inner margin of TAL. Orientations with respect to these planes were also recorded. The data on inclination and anteversion were calculated and stored by the computer software as radiographic inclination and anteversion in relation to the APP as defined by Murray [15]. To account for reliability of recordings, the orientation of the cup corresponding to all the landmarks was checked for interobserver and intraobserver errors by alternating between senior surgeon and his fellow in first 10 cases with each measuring twice. They did not look at the computer screen readings while positioning the trial cup for orientation. The Intraobserver and interobserver reliability were calculated and found to be excellent (Table 1). All of this was done before any reaming of acetabulum was attempted. Surgery then progressed as per usual THA with guidance of computer navigation system. The first reading by the consultant was taken for statistical analysis.

Statistical analysis was carried out using R version 3.5.2 (2018-12-20) "Eggshell Igloo" (R foundation, Vienna, Austria). Welch T-tests were used to test differences between gender and different BMI categories ($<30 kg/m^2$ and $\geq 30 kg/m^2$) for the measured orientations. Test of proportions was used to compare Lewinnek's

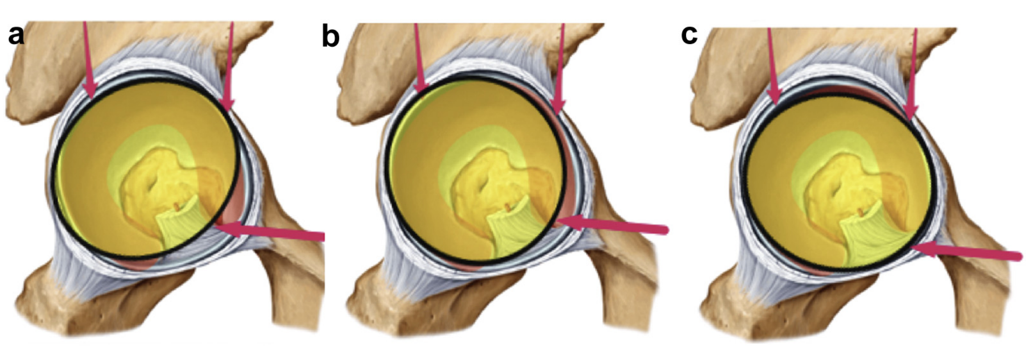

Figure 2. Orientation of the cup when aligned parallel to the inner (a), middle (b), and outer (c) margins of the TAL. Arrows show change in margin of the cup, and yellow-shaded area illustrates the spatial direction of cup opening.

Table 1
Intra observer and interobserver correlation coefficients of acetabular orientation corresponding to different landmarks (first 10 cases).

Referencing landmark	Inclination		Anteversion	
	Intraobserver correlation coefficient	Interobserver correlation coefficient	Intraobserver correlation coefficient	Interobserver correlation coefficient
Acetabular rim	0.99	0.99	0.94	0.95
Outer margin of TAL	0.93	0.94	0.95	0.99
Middle of TAL	0.97	0.90	0.96	0.98
Inner margin of TAL	0.95	0.94	0.96	0.96

“safe zone” outliers for various landmarks. Statistical significance was set at a *P* value of 0.05.

Results

Ninety-nine patients fulfilled the inclusion and exclusion criteria with 41 males (41.4%) and 58 females (58.6%). The mean age of the study population was 67.6 years (43 to 91) with a mean BMI of 28.8kg/m^2 (16 to 42). Mean inclination and anteversion of cup referenced from the acetabular rim, outer, middle, and inner margins of TAL are given in Table 2.

Reviewing inclination and anteversion of the cup referenced from acetabular rim, outer, middle, and inner margins of TAL, only 17.17%, 28.28%, 47.47%, and 71.71% were within the Lewinnek’s safe zone, respectively, (Table 2 and Fig. 3). The number of Lewinnek’s safe zone inliers referenced from various landmarks was statistically different from each other except for the acetabular rim and outer margin of TAL pair ($P = .06$).

Males had lesser anteversion than females when referenced from any of the landmarks (Table 3). Inclination and anteversion of cup referenced from various landmarks did not differ significantly between BMI groups (<30Kg/m^2 and ≥30Kg/m^2) except for anteversion using outer margin of TAL (Table 4).

Discussion

Orientation of the prosthetic cup in the desired position is a challenging task for an arthroplasty surgeon [16,17]. During conventional THA, a surgeon positions the acetabular cup by eyeballing or by the use of a cup-positioning device to align the cup in desired inclination and anteversion with respect to the plane of the patient. However, these techniques are not completely accurate because any change in pelvic position during the surgery alters cup orientation. The cup-positioning guide, used on the cup insertion handle, is a more generic practise and does not account for individual changes in hip anatomy. In a patient undergoing conventional THA in lateral position, the pelvis stabilized by a pelvic positioner may pose issues primarily involving fixation of the pelvis with discrepancies in sagittal pelvic tilt [18-20]. In addition, there is no method of determining if the pelvis remains in the same position throughout the procedure, including the time of cup implantation [21]. Meanwhile, using conventional guides, failure to address intraoperative movement of the pelvis could result in cup placement outside the desired safe-zone for anteversion [22,23]. Studies [24,25] suggest that surgeons do not rely solely on patient positioning during THA and, therefore, use anatomic landmarks, computer navigation, robotic, or other techniques to ensure accurate cup positioning.

Navigated THA is believed to offer better results with cup positioning and reduce the number of outliers [26-28]. Computer navigation, patient-specific jigs [29], and robotics have all been developed to aid accuracy but are still not commonly used. Most surgeons use conventional techniques because of the learning curve, time, and resource constraints. Therefore, techniques based on reliable patient-specific referencing need to be established.

As existing literature [30,31] encourages arthroplasty surgeons to use landmarks such as TAL or acetabular rim as referencing guides, we looked at orientation of these landmarks with respect to APP. TAL is a structure continuous peripherally with the acetabular labrum. It's strong flat fibers cross the acetabular notch anterior to posterior (length), also bridging the gap mediolaterally (breadth) with a slope (third dimension) forming a foramen along its medial (inner) border. Therefore, TAL is a 3-dimensional structure having length, breadth, and slope. TAL connects the anteroinferior and posteroinferior horns of the semilunar surface of the acetabulum. The posterior aspect of the ligament attaches to the bone beneath the lunate surface, and the anterior aspect attaches to the labrum [32]. Being an integral part of the acetabulum-labral complex, TAL moves with any pelvic tilt. TAL can be found in over 90% cases [10]; hence, evaluation of its orientation as a guiding landmark is important. As the TAL is a 3-dimensional band-like structure and not a single line in a single plane, it is possible to assume several planes from the same TAL if we do not exactly define which part of TAL is being referred to. Hence, the present study addressed this concern and defined TAL by its outer (lateral) margin, inner (medial) margin, and a plane in the middle of the 2 margins. As we are referring to 3-dimensional orientation with respect to APP, which is not in the same plane as TAL, any deviations may lead to change in angles, hence the need for referring to different margins of TAL. It was clearly evident in our study that when the cup corresponded to different margins of the TAL, it led to different orientations of the cup. We found excellent interobserver and

Table 2
Inclination and anteversion of cup (mean, standard deviation [SD], and range) when referenced from acetabular rim, outer, middle, and inner margins of TAL.

Referencing landmark	Inclination	Anteversion	Lewinnek’s safe zone—inliers (with percentage)	*P* value for Lewinnek’s safe zone—inliers
Acetabular rim	55.15° ± 7.20 (37 to 69)	6.63° ± 7.46 (−17 to 23)	17 (17.17%)	-
Outer margin of TAL	53.00° ± 6.51 (38 to 69)	7.41° ± 8.43 (−16 to 27)	28 (28.28%)	vs Acetabular rim = 0.06 vs Middle of TAL = 0.006 vs Inner margin of TAL < 0.001
Middle of TAL	47.70° ± 6.26 (30 to 63)	11.23° ± 8.28 (−7 to 30)	47 (47.47%)	vs Acetabular rim < 0.001 vs Inner margin of TAL < 0.001
Inner margin of TAL	42.60° ± 6.19 (24 to 56)	14.90° ± 8.22 (−4 to 34)	71 (71.71%)	vs Acetabular rim < 0.001

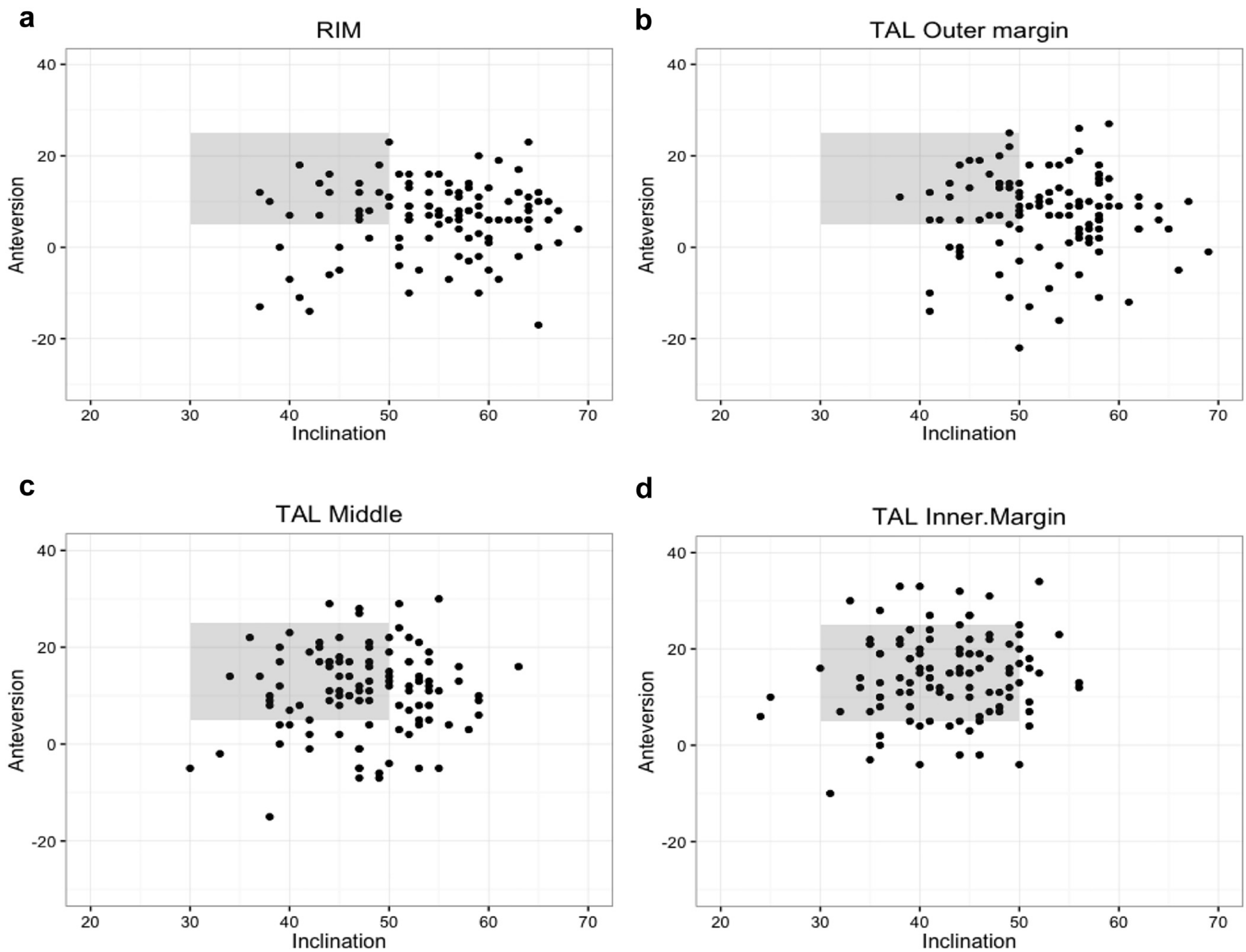

Figure 3. Scatter graph showing the acetabular inclination and anteversion data with respect to Lewinnek's safe zone (shaded area) referenced from (a) acetabular rim; (b) outer margin of TAL; (c) middle of TAL; and (d) inner margin of TAL.

intraobserver repeatability (correlation-coefficient > 0.9). Kalteis et al. used different landmarks (TAL and posterior labrum) to record the acetabular plane [30]. However, they only had moderate interobserver and intraobserver repeatability. The mean acetabular inclination in their study was 41° (32 to 51), and anteversion was 18° (−1 to 36) with 87% of hips within conventional safe zone. Inclination and anteversion corresponding to inner margin of TAL in our study were 42.60° (24 to 56) and 14.90° (−4 to 34), respectively, with 71.71% of recordings being within the Lewinnek's safe zone.

A cadaveric study in 14 hips by Pearce et al. [31] found that all cups placed using TAL as the landmark were within the safe zone for anteversion. The cups were aligned parallel to the superficial (outer) margin of TAL. The mean acetabular cup anteversion was 15.4° (10.9 to 24) which was very close to our mean anteversion (14.90°) corresponding to inner margin of TAL. However, their study had a small sample size (1 male and 6 female cadavers), and only anteversion was considered (anteversion differs as with gender) on cadaveric (nonarthritic) hips with a trial component placed and radiographs taken in lateral position and not with respect to APP.

In present study, males had lesser anteversion when referenced from all referenced landmarks. A significant variation in mean acetabular anteversion between genders was also noted in previous studies with women having greater anteversion [11,33-35]. As the presence of osteophytes might alter the measurement of native

Table 3
Gender and acetabular cup orientation (mean, SD, and range).

Referencing landmark	Inclination			Anteversion		
	Male	Female	*P* value	Male	Female	*P* value
Acetabular rim	55.00° ± 6.18 (40 to 69)	55.24° ± 7.83 (37 to 67)	.866	4.10° ± 7.03 (−10 to 14)	8.41° ± 7.24 (−17 to 23)	.004
Outer margin of TAL	53.78° ± 6.28 (41 to 67)	52.43° ± 6.61 (38 to 69)	.311	4.20° ± 7.89 (−16 to 16)	9.69° ± 8.05 (−12 to 27)	.001
Middle of TAL	48.39° ± 6.41 (30 to 63)	47.19° ± 6.10 (33 to 59)	.357	8.34° ± 7.71 (−7 to 22)	13.28° ± 8.05 (−6 to 30)	.003
Inner margin of TAL	42.82° ± 6.15 (24 to 56)	42.34° ± 6.20 (25 to 56)	.705	12.04° ± 8.07 (−4 to 30)	16.89° ± 7.71 (0 to 34)	.004

Table 4
BMI and acetabular cup orientation (mean, SD, and range).

Referencing landmark	Inclination			Anteversion		
	BMI < 30 kg/m^2	BMI ≥ 30 kg/m^2	*P* value	BMI < 30 kg/m^2	BMI ≥ 30 kg/m^2	*P* value
Acetabular rim	54.63° ± 7.27 (38 to 63)	55.83° ± 7.04 (37 to 65)	.230	7.02° ± 6.31 (−6 to 20)	6.09° ± 8.76 (−17 to 23)	.564
Outer margin of TAL	52.10° ± 5.70 (41 to 67)	54.19° ± 7.31 (38 to 69)	.072	8.89° ± 7.78 (−14 to 26)	5.40° ± 8.85 (−16 to 27)	.046
Middle of TAL	46.91° ± 5.82 (30 to 63)	48.73° ± 6.67 (33 to 59)	.089	12.52° ± 7.83 (−5 to 29)	9.48° ± 8.54 (−7 to 30)	.081
Inner margin of TAL	41.20° ± 5.94 (24 to 56)	43.52° ± 6.38 (25 to 56)	.104	16.12° ± 7.81 (−3 to 33)	13.21° ± 8.47 (−4 to 34)	.103

acetabular orientation, arthritic acetabula were excluded from the study by Murtha and Hafez [35]. Therefore, their study reveals a physiological difference in acetabular orientation between men and women. Our findings match these studies with gender-based difference in acetabular anteversion.

Merle et al. [36] converted the Lewinnek's to their anatomical definition and found that 80% of hips were out of the safe zone. Our study found similar numbers (82.83%) to be outside of the safe zone when the cup orientation was referenced from the acetabular rim. However, 71.71% of coordinates were within the Lewinnek's safe zone when referenced from the inner margin of TAL.

To our knowledge, there are no studies till date which assess a direct relationship of BMI with orientation of native acetabular rim and TAL. However, the association of high BMI with variation in cup placement during THA has been attributed to issues pertaining to stable patient positioning, intraoperative challenges such as excessive traction/retraction and poor visualisation of landmarks [37,38]. Pirard et al. [39] in a retrospective analysis found no significant relationship between BMI and version of the acetabular cup. We could not establish any statistical relationship between BMI and difference in the cup orientations referenced from various landmarks when considering BMI of 30 kg/m^2 as the cutoff. Only using the outer margin of TAL showed a statistically significant, mean difference of 3.5° (P = .046) for anteversion alone, with higher BMI being lesser anteverted. However, a larger study with bigger difference in BMI might detect differences between the 2 groups.

We would like to bring out the following drawbacks of our study. Imageless navigation system was used as a measuring tool for acetabular orientation wherein the accuracy would depend on registration of bony landmarks through the skin. This may cause errors in the computer measurement of acetabular orientation [40] in obese patients with excess subcutaneous fat around the bony landmarks. However, no problems were reported while registering the anatomical landmarks in our study, and the surgeon was experienced having performed over 500 navigated surgeries. Evidence suggests that accuracy of acetabular component placement in navigated THA is not affected by BMI [41]. This method of measurement has also been used in previously published studies [11,30]. We included only primary osteoarthritis cases in a Caucasians population. Therefore, due caution is to be exercised while extrapolating the results to a wider range of population from varied ethnicity with multiple hip conditions. Caution should also be taken as our study only determined the orientation of “native” TAL with respect to APP in an unreamed cup. Medializing the cup center during reaming may have an effect on the orientation as the cup is medialized.

Conclusions

For the first time in English literature, we describe the orientation of outer margin, inner margin, and a plane in the middle of these 2 margins as reference planes for TAL, in relation to APP. The anteversion differs significantly with gender and is greater in females. A knowledge about these would assist the surgeon in component placement during THA with inner margin of TAL providing the best chance of orientation, out of the studied landmarks.

Conflict of interests

The authors declare there are no conflicts of interest.

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