Anatomic Rotational Relationship of Distal Femur in Indian Population and its Implication in Total Knee Arthroplasty: A Magnetic Resonance Imaging Based Study

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Abstract

Background

Bony landmarks for referencing distal femoral rotation may differ with ethnic populations. The study aims to find out the relationship of the bony landmarks of distal femur for rotational alignment of femoral component in total knee arthroplasty in Indian population and compare it with other ethnic groups.

Methods

Rotational relationship of distal femoral bony landmarks was studied using magnetic resonance images of 141 knees. The condylar twist angle (CTA), Whiteside's-posterior condylar axis angle (WL/PCL), Whiteside's-anatomical epicondylar angle (WL/A-EA) and difference between the two epicondylar axes (S-EA/A-EA) were measured. The effect of gender, side and age of these relationships was analyzed.

Results

The mean CTA, WL/A-EA/WL/PCL and A-EA/S-EA was found to be 5.59 ± 2°, 89.38 ± 2.66°, 5.44 ± 2.88°, 3.11 ± 0.54° respectively. A-EA/S-EA was found to be lower in younger population as compared to the older population. Rest none of the variables showed any significant difference when compared against age, sex or side.

Conclusion

The posterior condylar axis was 5.59˚ externally rotated in relation to clinical epicondylar axis. About 2.5° of added external rotation is required in jigs using the conventional 3° of inbuilt external rotation, if clinical epicondylar axis is taken as reference for apt placement of the femoral component.

Introduction

Total knee arthroplasty is a surgery of precision. Technically demanding, it needs appropriate size matching between the component and the resected surface of the knee in achieving long-term success and reduction in complications [1]. The biomechanics of both tibiofemoral and patellofemoral joints is interlinked with distal femoral and proximal tibial geometry [2]. Just as one can find a mismatch between the implant and the resected bone in TKA, malrotation of the femoral and tibial components remains a matter of concern [3]. Patellofemoral complications [4], lack of adequate soft tissue gap balancing in flexion [5], and increased posteromedial polyethylene wear [6] are seen associated with TKAs where there is femoral component malrotation.

TKA aims to keep the femoral implant parallel to the epicondylar axis in the axial plane. Correct femoral rotational judgment is done using bony landmarks. The placement of the femoral component intra-operatively can be done referenced to three axes; mainly the surgical [7] or anatomical epicondylar axis [8], posterior condylar axis [9], and anteroposterior axis (Whiteside's line) [10, 11]. These are assessed during the surgery by palpation and visualization. Though there are several lines to assess the rotation of the distal femur for the posterior cut, the significance and variations in angular relationships between these lines remain hazy in the Indian population. The surgical epicondylar axis connecting the tip of the lateral epicondyle to the medial epicondylar sulcus is considered reliable and imperative [7]. Victor J et al in his review article revealed the consensus that the anteroposterior axis is perpendicular to the transepicondylar axis and the transepicondylar axis is 3 degrees externally rotated to the posterior condylar line [12].

Racial differences exist in the geometry of the femur between the Indian population and the Caucasian population [1]. The relationship between the axes in the Indian population is currently unclear. Studies pertaining to the rotational axes limit themselves by using either surgical [13] or clinical epicondylar axes [14, 15] and their relation with posterior condylar axis and Whiteside's line and in including a limited sample size. This study aims to (1) evaluate the relationship between the anatomic landmarks in the Indian population for distal femoral rotation using MRI (Magnetic resonance imaging) and (2) assess if any of these were influenced by age, side, or gender.

Materials And Methods

The study included MRIs of 189 patients with a suspected knee injury after approval from the institutional ethics committee (No. 253/IEC/PGM/2018). A total of 48 subjects with a history of fractures, infections, with surgery on the knee, and those with chondral damage were excluded giving a total of 141 MRIs that were studied. The study period was August 2017 to July 2019. MR imaging was performed employing a 1.5 T scanner with proton density fat suppression and coronal plane – 4mm slice thickness and sagittal and axial images - thickness of 3.5mm with the knees in near-normal extension. The T2 axial image wherein the epicondyles were best viewed was used for identifying the rotational axis.

The medial and lateral epicondyles are the most prominent points on either condyle. The line joining the tip of the lateral epicondyle to the deepest point on the medial sulcus is defined as the surgical epicondylar axis (S-EA) [7]. The anatomical or clinical epicondylar axis is formed by the line connecting the most prominent points on medial and lateral epicondyles (A-EA) [8]. The study mainly included the clinical epicondylar axis for the reason that the medial sulcus couldn't be appreciated in all the MRIs that were examined. In the MRIs where the medial sulcus could be identified, we calculated the angle between the two epicondylar axes as A-EA/S-EA. The posterior condylar line (PCL) is a line drawn joining the most posterior on the articular surfaces of the medial and lateral femoral condyles. The Whiteside's line (WL) or the anteroposterior axis was defined as a line running from the deepest point on the patellar groove (trochlear sulcus) to the midpoint of the intercondylar notch between the posterior-most inner surfaces [10]. The angles were then measured using RadiAnt DICOM viewer software. The angle between the anatomical epicondylar axis and the posterior condylar line is defined as the condylar twist angle (CTA) (Figure-1). The angle between the perpendicular to the Whiteside's line and the posterior condylar axis was measured as WL/PCL angle (Figure-2). Similarly, the angle between the Whiteside's line and the anatomical epicondylar axis was measured as WL/A-EA. The angles were measured by the second author.

Statistical analysis was done with Microsoft Excel software and XL-STAT software. The values were expressed as mean +/- standard deviation. The normality of the test variables was assessed with Wilk-Shapiro's test. Analysis was done with the Mann-Whitney test and a p-value of < 0.05 was considered as statistically significant. Pearson's coefficient was used to measure any relationship of the above angles with gender, age, and sides.

Results

The mean CTA was found to be 5.59 ± 2˚ with 5.76 ± 2.22˚ in females and 5.54 ± 1.84˚ in males respectively. A wide range of the angle was observed with values from 2.03 to 11.4˚. The angular difference of the WL as measured against A-EA was found to be 89.38 ± 2.66˚. The WL/A-EA angle ranged from 83.9 to 98.8˚ of external rotation. The mean angle between the PCL and the perpendicular to the WL was found to be 5.44 ± 2.88˚ with a range of -2.4 to 15.7˚. The difference between the anatomical epicondylar and surgical epicondylar axes was found to be 3.11 ± 0.57°. Table 1 enlists the mean values of the various alignment variables as well as their comparison with gender. Scatter plot analysis of the rotational variables showed very few outliers favoring the generalisability of the study results (Figure-3). While the comparison of the angles between the age and sides is listed in Table-2. No statistical difference was found between the measured variables when compared to age other than A-EA/S-EA which was lower in the younger population (< 50 years) age group.

Discussion

Understanding the bony anatomic landmarks of the knee is imperative in the primary and revision TKA. Current TKA employs a jig at 3˚ of inbuilt external rotation in general referenced to the posterior condylar axis. Being a precision surgery in itself, it is important that one comprehends the variation between the ethnic groups so as to learn the differences and hence aim to deliver long-term success. The important finding in our study was that the clinical or the anatomical epicondylar axis on average is 5.59° externally rotated compared to the posterior condylar line. Hence an added minimum of 2.5° of external rotation in the excess of the inbuilt 3 degrees in the jig would help in the optimal position of the femur component.

Re-creation of the rotational alignment of the distal femur facilitates reduction in implant failure and improving clinical outcomes [3]. In the present scenario, there exists little consensus regarding the optimal rotational axis in the distal femur. The most frequently used ones are Whiteside's line, Transepicondylar axis, and Posterior condylar axis. Cutting guides by various implant manufacturers generally rely on the bony landmarks and their relationship to each other. Berger et al [7] recommended the use of the surgical epicondylar axis as a reproducible secondary anatomical axis as a reference for rotational orientation of femoral component in TKA when posterior condylar surfaces can't be used. Yoshioka et al used the clinical epicondylar axis in determining the condylar twist angle [8]. Interobserver variability in his study was 4˚. Arima et al introduced the WL (Whiteside's line) which is considered superior in the Caucasian population [10, 11]. Victor et al in his systematic review quoted the posterior condylar axis to be on average 3˚ internally rotated relative to surgical epicondylar axis, 4˚ relative to the clinical or anatomical epicondylar axis, and 5˚ relative to the perpendicular to the Whiteside's anteroposterior axis [12]. The direct visual assessment intra-operatively is often confounded by the difficulty in identifying the medial sulcus. The distal femoral cut takes into account the cartilage thickness. Suter et al [16] noticed the anatomical epicondylar axis to be more reproducible than the surgical axis in CT scans. Studies that employ computed tomography to measure the rotational relationship do not take the cartilage into account [17, 18]. We used MRI to assess the rotational alignment of the distal femur as the cartilage thickness would exert an effect on the angles.

A-TEA to PCL (CTA) averaged 5.59 ± 2˚ in our study. Yoshioka et al first used CTA as the reference for alignment [8]. In our study 97 of the subjects were found to have an angle more than 3˚ if one employs the anatomical epicondylar line as the reference axis. Furthermore, it signifies that 97% of the subjects had more than 3˚of expected internal rotation if the surgeon uses the relationship of PCL with A-EA and employs routine jig. Nagamine et al noted a condylar twist angle of 5.8 ± 2.7˚ in males and 6.2 ± 0.9˚ in females respectively [19]. Yoshioka et al reported 5˚ and 6˚ externally rotated A-TEA in relation to PCL [8]. Mullaji et al investigated the relationship using computed tomography and suggested a CTA of 5˚. The sample he used consisted of 42 men and 8 women [14]. The skewed statistical analysis is debatable and comparison of the same data with other ethnic population-based researches is not meaningful.

Arima et al described the AP axis of the distal femur in the Caucasian population.

It's found to be a reliable axis in situations where the posterior condyles are dysplastic or in arthritic knees [10]. Tables 1 and 2 describe the variation of various distal femoral rotational angles with respect to gender, sex, and side. A-EA/S-EA was found to be 3.06 ± 0.53° in the younger population (< 50 years) and 3.33 ± 0.57° which was found to be statistically significant (p-value < 0.05). Although the clinical significance of the same is debatable and requires further investigation. Tanavalee et al did a comparative study between A-EA and S-EA for rotational alignment of the femoral component. They found that perpendicular to A-EA is closer to the AP axis and provided adequate external rotation to PCL and hence is more reliable [20]. The mean WL/PCL angle was 5.44 ± 2.88˚. The angle value indicates the component to be kept at 5.44 ± 2.88˚ external rotation to PCL to match the anteroposterior axis. Table 3 shows the comparison of various variables with that of pre-existing literature based on MRI evaluation [13, 15, 21].

In the Indian scenario, most surgeons use the epicondylar prominence for the femoral component position. The 3 degrees of inbuilt external rotation in the conventional jigs will impart about 3 degrees of external rotation if one uses PCL as a reference. This would lead to an improper rotational alignment of the component which can hamper the success of TKA in the Indian population. Mullaji et al found a CTA of 5.8˚ and proposed 2˚ additional external rotation while using posterior condyles to prevent internal rotation [14].

The surgeons should maintain an apt knowledge of the bony landmarks to achieve the precise rotational alignment of the femoral component. Though the surgical epicondylar axis represents the true rotational axis of the knee, intraoperatively assessing the sulcus may be at times a bit difficult.

Our study has got some limitations to be addressed. A larger sample is required to accurately define the relationship of these axes to each other. Preoperative computed tomography is considered the best tool to analyze the bony landmarks for rotational alignment in view of low intra- and inter-observer variability [16]. Evaluation of the cartilage portion of the distal femur is not possible with CT scans. MRI score over the CT scans has been used keeping this aspect in mind. We used MRI of knees to identify the relations of the rotational axis relative to each other. Thirdly, the mechanical axis of the subjects could not be studied which would have been ideal for assessing. Lastly, the age group distribution cut off at 50 years is an arbitrary value taken at the authors' discretion for evaluating the effect of age-related changes in distal femur morphology. An evaluation by taking age as a continuous variable might yield a more robust result.

Conclusion

Our study revealed the mean CTA to be 5.59˚ in the Indian scenario. The Whiteside's line was 5.44˚ externally rotated to the PCL. The conventional jigs with 3˚ of inbuilt external rotation require a minimum of 2.5° of added external rotation if one takes the clinical or anatomical epicondylar axis as the reference point. Understanding the relation of the rotational axes to each other provides the surgeon enough knowledge to obtain correct femoral component alignment.

Declarations

1. Funding

No funding of any sort was received for the project

2. Conflicts of interest/Competing interests

There are no conflicting/competing interests of any of the authors involved

3. Ethics approval

Approval from institutional ethics committee was taken (No. 253/IEC/PGM/2018).

4. Consent to participate

Appropriate consent from the participants was obtained.

5. Consent for publication

All authors give consent for publication of the manuscript in your esteemed journal.

6. Availability of data and material

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

7. Code availability

Not applicable

8. Authors' contributions

All authors have contributed to the conceptualization, design, acquisition of data, drafting and review of this article and approve the version to be published.

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Tables

Table 1 Relationship of the distal femoral rotational axes relative to each other and gender wise comparison

Variable	Mean	Male	Female	P value
CTA°	5.59 ± 2.0 (2.03-11.4)	5.54 ± 1.84° (2.03-10.4)	5.76 ± 2.22° (2.45-11.4)	0.517
WL/A-EA angle°	89.38 ± 2.66 (83.9-98.8)	89.5 ± 3.0 (83.9-98.8)	89.16 ± 2.00 (84.2-94.1)	0.474
WL/PCL angle°	5.44 ± 2.88 (-2.4-15.7)	5.56 ± 3.27 (-2.4-15.7)	5.25 ± 2.08 (1.3-10.1)	0.537
A-EA/S-EA angle°	3.11 ± 0.54 (0.9-4.8)	3.09 ± 0.53 (0.9-4.8)	3.12 ± 0.56 (1.9-4.2)	0.811

PCA; posterior condylar angle, CTA; condylar twist angle, WL; whiteside's line, S-EA; surgical epicondylar axis, A-EA; anatomical epicondylar axis, PCL; posterior condylar line

Values expressed as mean +/- standard deviation

P value < 0.05 is significant

Table 2 Comparison of rotational axes in relation with age and side

Variable	Right side(n=83)	Left side (n=58)	P value	Age <50(n=119)	Age > 50(n=22)	P value
CTA°	5.55 ± 1.77°	5.64 ± 2.29°	0.783	5.49 ± 1.98°	6.13 ± 2.07°	0.166
WL/A-EA angle°	89.09 ± 2.6°	89.79 ± 2.7°	0.122	89.43 ± 2.74°	89.11 ± 2.15°	0.607
WL/PCL angle°	5.19 ± 2.95°	5.79 ± 2.73°	0.218	5.46 ± 2.93°	5.31 ± 2.59°	0.828
A-EA/S-EA angle°	3.11 ± 0.57°	3.09 ± 0.51°	0.858	3.06 ± 0.53°	3.33 ± 0.57°	**0.034**

PCA; posterior condylar angle, CTA; condylar twist angle, WL; whiteside's line, S-EA; surgical epicondylar axis, A-EA; anatomical epicondylar axis, PCL; posterior condylar line

Values are expressed as mean +/- standard deviation

P value < 0.05 is significant

Table 3 Comparison of rotational variables with the previous MRI based studies. CTA Condylar twist angle; WL Whiteside line; AEA Anatomical epicondylar axis; PCL Posterior condylar line; SEA Surgical epicondylar axis; SD Standard deviation. p-

value < 0.05 taken as significant.

Study	Ethnicity	Number	CTA (mean +/- SD)	p-value	WL-AEA (mean +/- SD)	p-value	WL-PCL (mean+/- SD)	p-value	AEA-SEA (mean+/- SD)	p-value
Our study	Indian	141	5.59 ± 2.0		89.38 ± 2.66		5.44 ± 2.88		3.11 ± 0.54	
Pun et al [13]	Indian	40			92.7 ± 1.32	**<0.0001**				
Amarnath et al [15]	Australian	265	2.3 ± 1.8	**<0.0001**	92.6 ± 2.3	**<0.0001**				
Raju et al [20]	Indian	124	5.92 ± 2.32	0.215	88.99 ± 2.86	0.251				

Figures

Figure 1

Relation of posterior condylar line with epicondylar axis.

Line AB represents the posterior condylar line tangent to the posterior most points on medial and lateral condyles. The surgical epicondylar axis (Line CD) is formed by connecting the prominent point on lateral epicondyle and the medial sulcus. The clinical/anatomical epicondylar line CE connects the most prominent points on medial and lateral epicondyles. Posterior condylar angle is formed by lines AB and CD (a). Condylar twist angle is formed by lines AB and CE (b)

Figure 2

The Whiteside's line (WL- connecting the midpoint of the intercondylar notch and deepest point on the patellar groove) forms WL/S-EA angle with the surgical epicondylar line CD and WL/A-EA angle with the clinical epicondylar line CE. The A-EA/S-EA (ECD) angle represents the difference between the posterior condylar angle and condylar twist angle. The WL/PCL angle is formed by the perpendicular to the Whiteside's line (Line GH) and posterior condylar line (Line AB)

Figure 3

Scatter plot of various distal femur rotational variables. WL Whiteside line; PCL Posterior condylar line; A-EA Anatomical epicondylar axis; S-EA surgical epicondylar axis. All the charts show very few outliers in every category.

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