Original article

Reference axes for optimal femoral rotational alignment in varus osteoarthritic Indian knees – A CT based study[☆] A.V. Gurava Reddy^a, Rajat Kumar Mathur^a, Aakash Mugalur^{b,*}, Krishna Kiran Eachempati^c, Anil Reddy^a^a Sunshine Hospitals, Secunderabad, Telangana State, India^b Narayani Hospital and Research Centre, Tirumalaikodi, Sripuram, Vellore, Tamil Nadu, India^c Maxcure Hospitals, Madhapur, Hyderabad, Telangana State, India

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ABSTRACT

Background: Optimal rotational alignment of femoral component is important for longevity and success of total knee replacement. Whiteside line (WL), posterior condylar axis (PCA) and femoral transepicondylar axis are various intra-operative landmarks to guide femoral rotation. Each of these has its pros and cons. The aims of our study were to assess the relationship of posterior condylar axis and the antero-posterior axis of femur with the surgical epicondylar axis and evaluate whether degree of deformity or severity of osteoarthritis alters the rotational alignment of the femur when posterior condylar axis is taken as a reference. Are we justified in using a 3° external rotation with respect to posterior condylar axis in each knee?

Methods: The study is a single-centre, CT-based, cross-sectional, radiological study in 56 bilateral osteoarthritic varus Indian knees. The following were deduced using a uniform standardised method: Whiteside-surgical transepicondylar angle and posterior condylar angle. The study population was subdivided based on age, sex, deformity and grade of osteoarthritis.

Results: The mean posterior condylar angle ($N = 112$) was $3.25 \pm 1.379^\circ$ (95% CI). The posterior condylar angle ranged from '0' degrees to '6' degrees with only 27.7% having an angle of 3°. The mean Whiteside-transepicondylar angle ($N = 112$) is $89.72 \pm 3.537^\circ$ (95% CI).

Conclusions: PCA and the WL are comparable in establishing the rotational alignment of the femoral component with respect to the surgical transepicondylar axis. A fixed, 3° external rotation with respect to the PCA is an oversimplification and rotational alignment of the knees should be individualised.

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1. Introduction

Optimal rotational alignment of femoral component in the axial plane is important for longevity and success of total knee replacement. Proper rotation of the femoral component dictates the flexion gap symmetry and stability of the prosthetic joint throughout the range of flexion. Increased internal rotation of the femoral component is associated with patellar maltracking, flexion instability, knee pain, accelerated wear of the polyethylene insert and increased revision rates.^{1–6}

Intra-operatively, femoral transepicondylar axis (TEA),^{7–12} Whiteside line¹³ and posterior condylar axis^{14–16} guide the surgeon to place the femoral component in optimal rotation along the axis. Each of these have their own pros and cons and need to be used with caution.^{17,18} Femoral transepicondylar axis is considered by various studies the most reasonable reference for alignment of femoral component. It is also considered the best representation of the axis at which flexion and extension of the knee occurs.^{7–12} Of the transepicondylar axes, surgical epicondylar axis (SEA) is accepted as a more accurate reference in comparison with the anatomical epicondylar axis to determine proper rotation of the femoral component.^{10,11} However, with soft tissue envelope, it is difficult to accurately locate the epicondyles intra-operatively in up to 50% of the cases, and surgical epicondylar axis is not a consistent landmark clinically with a wide inter- and intra-observer variability.^{11,13,19–22} The present day knee replacement systems use a fixed 3° external rotation with respect to the

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posterior condylar axis. Despite the simplicity and reproducibility of the system, it might lead to rotational malalignment especially in knees with coexistent distortion of the posterior condylar anatomy.^{23,24} Moreover, a fixed 3° external rotation with respect to the posterior condylar axis might be an oversimplification, especially in the wake of racial and geographical variations in the distal femoral anatomy.^{1,25–30}

1.1. Aims and objectives

Our study was a single-centre, CT scan based, cross-sectional, radiological study in the Indian Osteoarthritic knees with the following aims. (1) To assess the relationship of posterior condylar axis and the antero-posterior axis of femur with the surgical epicondylar axis to guide femoral component rotation in varus osteoarthritic knees. (2) To assess the changes in rotational alignment related to asymmetric cartilage erosion or hypertrophy of posterior condylar surfaces when posterior condylar axis (PCA) is used as a rotational reference in varus knees. (3) To assess whether a fixed, 3° external rotation off the posterior condylar axis is applicable in varus arthritic knees.

2. Materials and methods

The study was a single-centre, computed tomography (CT) based, cross-sectional, radiological study carried out between March and May 2015. Prior clearance was obtained from the Institutional ethics committee. Informed consent was obtained from the patients before enrolling them for the study. Only patients with bilateral osteoarthritis of the knees requiring total knee replacement were enrolled into the study. Patients with inflammatory arthritis, post-traumatic or septic arthritis and trochlear dysplasia were excluded from the study. The knees where the median sulcus of the medial epicondyle was not identified were primarily excluded from the study. 56 patients (22 men and 34 women) participated in the study. A total of 112 knees were studied. All patients were graded radiographically according to Kellgren and Lawrence osteoarthritis classification³¹. Tibio-femoral angle was also calculated from the preoperative standing scanogram. Standardised CT scans of the distal femur were obtained to determine the rotational alignment of distal femur using the Siemens somatom perspective, 64-slice, CT scan system. The patients were placed supine with knees in maximum extension on the CT scanner. Using the lateral scout view, the scans were taken vertical to the long axis of the femur. This was achieved by tilting the gantry. 2 mm continuous axial images were taken starting from the knee joint to a level just proximal to the trochlea of the femur. Three reference lines were drawn on the axial section of distal femur at the level of femoral epicondyles where the median sulcus was best identifiable. Line 1 joins the posterior surfaces of the medial and lateral condyles representing the posterior condylar axis, line 2 joins the lowermost point of trochlea to the centre of the inter-condylar notch (antero-posterior axis of femur or Whiteside line) and line 3 joining the

most prominent part of the lateral epicondyle to the median sulcus of the medial epicondyle (surgical transepicondylar axis). Angle subtended by posterior condylar line and Whiteside line with the surgical transepicondylar axis was noted. Two observers [Fellows in arthroplasty with at least two years of experience in orthopaedics after completion of their post-graduation in Orthopaedics] measured the aforementioned parameters independently and a mean of the measurements was taken to minimise inter- and intra-observer variability. The observers underwent special training under the in-house, consultant radiologist before starting with the project. The study population was subdivided based on age (<60 and >60 years), sex (male and female), deformity (varus <15° and >15°) and grade of osteoarthritis (grades 3 and 4). The collected data were tabulated and were statistically analysed using SPSS 13.0 software. The mean posterior condylar angle and the Whiteside-surgical epicondylar axis angle were calculated. The same angles were calculated in each of the sub-groups. 2-tailed test was used to establish any statistical difference between the subgroups. 'p' value less than .05 was considered as significant.

3. Results

A total of 112 knees were evaluated. The mean age of the study population was 65.036 years. The mean angle ($N = 112$) between the transepicondylar axis and the posterior condylar axis was $3.25 \pm 1.379^\circ$ (95% CI). The mean angle ($N = 112$) between the Whiteside line and the transepicondylar axis is $89.72 \pm 3.537^\circ$ (95% CI). The study population was subdivided into two groups each based on the age, deformity, osteoarthritis grade and sex. A total of 78 knees were evaluated in the age group of 40–60 years and 34 knees in the age group more than 60 years [Table 1]. 55 knees comprised the Osteoarthritis grade 3 group and 57 knees in the Osteoarthritis grade 4 group [Table 2]. 60 knees had deformity less than 15° and 52 knees had deformity more than 15° [Table 3]. 44 knees of males were evaluated and 68 knees of females were evaluated [Table 4]. The aforementioned angles were calculated in each of the subgroups and were compared. However, there was no statistically significant difference between each of the subgroups except for posterior condylar angle in males and females ($p = .049$). But it is important to note that the angle between the transepicondylar axis and the posterior condylar axis ranged from '0' degrees to '6' degrees in our study population with only 27.7% of the knees having an angle of 3°. 42.8% of the cases had an angle more than 3° and the rest, 29.5%, had an angle less than 3° [Table 5].

4. Discussion

Posterior condylar axis and the Whiteside line are comparable in establishing the rotational alignment of the femoral component with respect to the surgical transepicondylar axis. The degree of the deformity or the severity of osteoarthritis did not alter the posterior condylar angle in a statistically significant manner. Though the mean posterior condylar angle was 3.25°, only

Table 1
showing the comparison of posterior condylar angle and Whiteside line-epicondylar angle in different sub-groups on the basis of age.

	Age group	N	Mean	Std. deviation	Std. error mean	Sigma (2-tailed)
Angle between TEA and PCA	<60 years	78	3.13	1.427	.162	.158
	>60 years	34	3.53	1.237	.212	
Angle between WL and TEA	<60 years	78	89.82	3.772	.427	.661
	>60 years	34	89.50	2.967	.509	
Corrected angle	<60 years	78	90.10	3.775	.427	.059
	>60 years	34	88.74	2.723	.467	

TEA, transepicondylar axis; PCA, posterior condylar axis; WL, Whiteside line.
Note that there is no statistically significant difference between the groups.

Table 2

The comparison of posterior condylar angle and Whiteside line-epicondylar angle in different sub-groups on the severity of arthritis based on Kellgren and Lawrence osteoarthritis classification.

	OA group	N	Mean	Std. deviation	Std. error mean	Sigma (2-tailed)
Angle between TEA and PCA	Grade 3	55	3.05	1.297	.175	.141
	Grade 4	57	3.44	1.439	.191	
Angle between WL and TEA	Grade 3	55	89.15	3.274	.441	.090
	Grade 4	57	90.28	3.717	.492	
Corrected angle	Grade 3	55	89.73	3.374	.455	.907
	Grade 4	57	89.65	3.710	.491	

TEA, transepicondylar axis; PCA, posterior condylar axis; WL, Whiteside line.

Note that there is no statistically significant difference between the groups.

Table 3

The comparison of posterior condylar angle and Whiteside line-epicondylar angle in different sub-groups on the severity of deformity on the basis of tibio-femoral (T-F) angle.

	Deformity group – T-F angle	N	Mean	Std. deviation	Std. error mean	Sigma (2-tailed)
Angle between TEA and PCA	<15°	60	3.28	1.391	.180	.785
	>15°	52	3.21	1.377	.191	
Angle between WL and TEA	<15°	60	89.58	3.361	.434	.655
	>15°	52	89.88	3.756	.521	
Corrected angle	<15°	60	90.12	3.385	.437	.168
	>15°	52	89.19	3.668	.509	

TEA, transepicondylar axis; PCA, posterior condylar axis; WL, Whiteside line.

Note that there is no statistically significant difference between the groups.

Table 4

The comparison of posterior condylar angle and Whiteside line-epicondylar angle in different sub-groups on the basis of sex of the patient.

	Sex	N	Mean	Std. deviation	Std. error mean	Sigma (2-tailed)
Angle between TEA and PCA	Males	44	2.93	1.453	.219	.049
	Females	68	3.46	1.298	.157	
Angle between WL and TEA	Males	44	90.11	3.617	.545	.350
	Females	68	89.47	3.488	.423	
Corrected angle	Males	44	89.80	3.613	.545	.796
	Females	68	89.62	3.507	.425	

TEA, transepicondylar axis; PCA, posterior condylar axis; WL, Whiteside line.

Note that there is no statistically significant difference between the groups.

27.7 percent of the knees had a posterior condylar angle of 3°. The values ranged from 0° to 6°.

The following were the drawbacks of our study. Ours was a CT-based radiological study. Cartilage wear is not delineated properly on the CT scans. The study population consisted of only a subgroup of Indian patients. Varus osteoarthritic knees and only bilaterally affected cases were analysed. Thus it does not represent the normal characteristics of the Indian knees. The wear patterns could be different in each arthritic knee and the wear patterns were not a part of the study.

Axial rotation of the distal femoral component is important and every effort must be made to replicate the normal anatomical axial rotation of the distal femur. Whiteside line,¹³ posterior condylar axis^{14–16} and transepicondylar axis^{7–12} are the intra-operative guides for the surgeon to assess rotational alignment of the femoral

component. Each method has its own advantages and disadvantages but they all share the common drawback of inter-observer reproducibility.^{20,32,33} Whiteside line, despite being considered by some as a reliable guide, is unreliable in destructive arthritis, trochlear dysplasia and excessive rotation in knees with significant varus or valgus deformity.^{13,23} Moreover, posterior condylar axis is considered a better reference in medial tibio-femoral arthritis knees as Whiteside line predisposes the component to more external rotation.^{23,34} Despite the ongoing debate between the superiority of clinical and surgical epicondylar axis it is recommended that surgical transepicondylar axis is more representative of the flexion extension axis of the knee.¹⁷ But the intra-operative identification of the transepicondylar axis is marred by the soft tissue cover and the wide range of inter and intra-observer variation.²⁰

Most of the present day posterior referencing TKA systems recommend a 3° external rotation with reference to the posterior condylar axis to set the rotational alignment of the femoral component.³⁵ This is generally reasonable and practical in a knee with a normal posterior condylar anatomy, where an external rotation of 3–4° can restore the flexion gap parallel to the cut tibial surface.²⁴ Severe varus and valgus knees and those associated with distortion of the lateral and the medial femoral condyles,^{36,37} demand caution with this generalisation. Distal femoral anatomy has geographic and interracial differences. The mean posterior condylar angle measured in our study was much less as compared to the Japanese population^{23,38} (mean of 3.25 vs 5.8 and 6.3°). It is also much less when compared to cadaveric Caucasian studies.^{11,36} Our mean angle between the whiteside line and the transepicondylar

Table 5

The distribution and frequency of the posterior condylar angle in the study population. Note that only 27.7% of the knees had a posterior condylar angle of 3°.

Posterior condylar angle	Frequency	Percent (%)
0	1	.9
1	11	9.8
2	21	18.8
3	31	27.7
4	31	27.7
5	8	7.1
6	9	8.0
Total	112	100.0

axis is $89.72 \pm 3.537^\circ$ is more than that of Nagamine et al. but less when compared to Mullaji et al.^{23,28} In a CT based study by Mullaji et al.²⁸ the posterior condylar was 5° with Whiteside-epicondylar angle of 90.8° but they utilised most prominent point of the medial epicondyle to calculate the angles. In one magnetic resonance imaging study of 40 knees in Indian population by Pun et al.²⁷ the mean posterior condylar angle in the Indian knee was 4.67° and the mean whiteside-epicondylar angle was 92.7° which was greater than the respective angles calculated in our study. They concluded that angles differed across various races and using a fixed angle to determine rotational alignment could lead to rotational malalignment of the femoral component. This could be due to the utilisation of the MRI in their study which provides better delineation of the cartilage. In yet another study of Iranian knees by Moghtadaei et al.²⁹ the posterior condylar angle was $2.35^\circ (\pm 1.34)$. In an Indian cadaveric study by Bhanu et al.³⁰ the mean posterior condylar angle on the right side was $6.84 \pm 2.71^\circ$ and that on the left side was $3.19 \pm .99^\circ$. The Whiteside line-transsepicondylar angle on the right and the left side were $94.84 \pm 3.43^\circ$ and $92.36 \pm 4.06^\circ$ respectively. But they analysed normal cadaveric femora and they considered most prominent point of the epicondyle for determination of the epicondylar axis. Our study population involved the arthritic knees in comparison to the aforementioned studies which evaluated the normal knees. This may be responsible for the wide variation in the results.

The grade of the osteoarthritis or the deformity of the knees did not alter the posterior condylar angle or Whiteside-transsepicondylar angle in a statistically significant manner in our study population. Nor there were statistically significant differences when age was taken into consideration. There existed a statistically significant difference ($p = .049$) in the posterior condylar angle between the sexes. The mean posterior condylar angle in males was 2.93 ± 1.453 and was 3.46 ± 1.298 in females. In a cadaveric study by Berger et al.,¹¹ considering the anatomical axis the mean posterior condylar angle in males and females was 4.7° and 5.2° respectively. But in their study, 40 knees out of the total study size were of unknown gender and were assumed to be equally divided among the sexes. In yet another cadaveric study of 32 femora by Yoshioka et al.¹⁰ a small difference of 1° was seen between the sexes. No significant difference was reported between the sexes in other studies.^{28,29} There was no statistically significant difference between the sexes when whiteside line-transsepicondylar angle was taken into consideration in our study.

Though the mean posterior condylar angle was 3.25° , only 27.7 percent of the knees had a posterior condylar angle of 3° . In the rest of the knees the posterior condylar angle ranges from 0° to 6° . Taking a fixed 3° external rotation with respect to the posterior condylar axis in these knees might lead to malrotation of the femoral component. Thus caution has to be exercised and rotational alignment should be individualised to the each knee.

However, it is interesting to note that the posterior condylar angle in arthritic knees is less in comparison to angles measured by Mullaji et al.²⁸ and Pun et al.²⁷ in normal knees of Indian population. The change in angle could partly be attributed to the degenerative changes in the cartilage and distortion of the posterior condylar anatomy, as our study population consisted of arthritic knees. The normal posterior condylar angle in a population should be tailored to that of the arthritic knee to dictate optimal rotation. Other intra-operative reference lines should be used to maximise the optimisation.

5. Conclusion

Posterior condylar axis and the Whiteside line are comparable in establishing the rotational alignment of the femoral component with respect to the surgical transepicondylar axis. In varus knees, the degree of deformity or the severity of the deformity does not

have a statistically significant effect on the alteration of the posterior condylar angle. For optimal rotational alignment, the fixed, 3° external rotation with reference to the posterior condylar axis should be used with caution and has to be combined with other intraoperative reference lines for a better rotational alignment. The rotational alignment of the knees should be individualised and has to be decided on a case-to-case basis.

Conflicts of interest

The authors have none to declare.

Ethical review committee statement

Prior clearance was obtained from the institutional ethics committee before the commencement of the study.

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