RESEARCH ARTICLE

Analysis of the Geometry of the Distal Femur and Proximal Tibia in the Osteoarthritic Knee: A 3D Reconstruction CT Scan Based Study of 449 Cases

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Received: 5 January 2016 *Accepted: 7 February 2015*

Abstract

Background: The aim of this study is to evaluate the geometry of the distal femur and the proximal tibia in the osteoarthritic knee using 3D reconstructive CT scan imaging.

Methods: 449 patients with knee osteoarthritis were treated surgically in our center with patient-specific technology total knee arthroplasty. Preoperatively, all the patients underwent a CT scan according to a standard protocol. Using this database, the Hip-Knee-Angle (HKA), the Femur Valgus Angle (FVA), the Tibia Varus Angle (TVA), the Posterior Tibia Slope (PTS), and the angle between the posterior condylar axis and the anatomical transepicondylar axis (PCA) for each patient were recorded and statistically evaluated.

Results: In overall, the mean HKA angle was 177.3±5.55, the mean FVA angle was 3.19±2.08, the mean TVA was 3.28±2.35, the PTS angle was 9.02±3.46, and the PCA angle was 2.86±0.78. Evaluation of the correlations between HKA and PCA (r=0.035), HKA and PTS (r=-0.047), and PCA and PTS (r=0.05) showed non-significant relationships (*P*=0.46, *P*=0.32, and *P*=0.29 respectively). No significant differences were revealed from the comparison of male patients with female patients, regarding the mean HKA, FVA, TVA, PTS, and PCA.

Conclusion: The posterior condylar axis is a well-defined but not a reliable axis, while the transepicondylar and the anteroposterior are reliable, but not easily defined axes. Given the large ranges and standard deviations of the location of posterior condylar axis, and the important inter- and intraobserver variability in the intraoperative location of the transepicondylar and the anteroposterior axes, the use of a preoperative 3D CT scan is recommended.

Keywords: 3D CT scan, Knee Geometry, Patient Specific Instruments, Posterior Condylar Axis, Total Knee Arthroplasty

Introduction

The use of a measured resection technique for determination of femoral component rotation relies on accurate intraoperative identification of numerous bone landmarks. Advocates of this technique recommend placement of the femoral component either parallel to the transepicondylar axis, perpendicular to the anteroposterior axis, or 3^0 externally rotated relative to the posterior condylar axis (1- 5). Total knee arthroplasty (TKA) malalignment is related to an unsatisfactory outcome, including patella maltracking, anterior knee pain, flexion instability and early loosening (6). Furthermore, inadequate positioning, particularly of the femoral component, is a common indication for revision (7, 8). For this reason, it is important to understand the anatomical features of the knee that are involved in the surgical treatment of osteoarthritis.

The aim of this study is to evaluate the geometry of the distal femur and the proximal tibia in the osteoarthritic knee using 3D reconstructive CT scan imaging.

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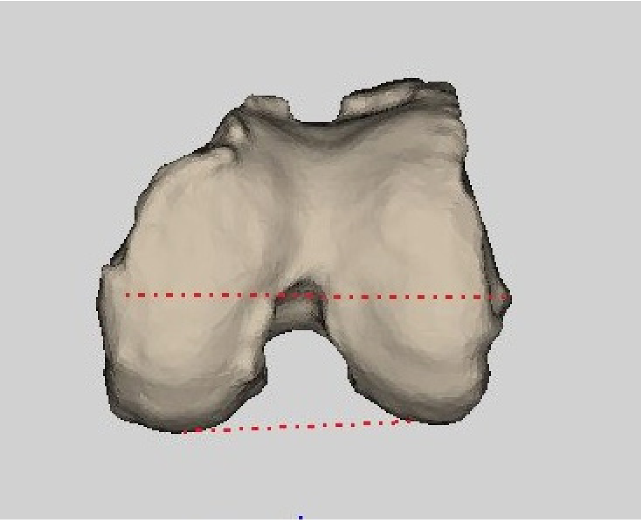

Figure 1. Example of a 3D reconstruction of the distal femur. The posterior condylar and the transepicondylar axis are shown with dotted lines.

Materials and Methods

Between June 2010 and March 2014, 449 patients (202 males and 247 females) with knee osteoarthritis were treated surgically in our center with patient specific technology total knee arthroplasty (MyKnee, Medacta International S.A., Castel San Pietro, Switzerland). Preoperatively, all the patients underwent a CT scan according to a standard protocol. Image acquisition consisted of three separate short spiral axial scans: 1) ipsilateral hip, 2) affected knee and 3) ipsilateral ankle. These images were sent to the company (Medacta International S.A.). The anatomical cutting blocks that can fit a patient's knee morphology and a 3D model of the patient's distal femoral and proximal tibial bone were created using a specific computer program, [Figures 1, 2].

Using this database, the Hip-Knee-Angle (HKA), the Femur Valgus Angle (FVA), the Tibia Varus Angle

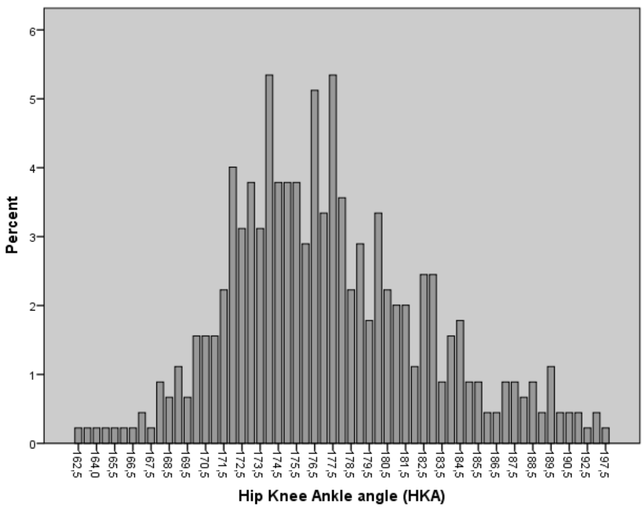

Figure 3. Graphical distribution of HKA angle.

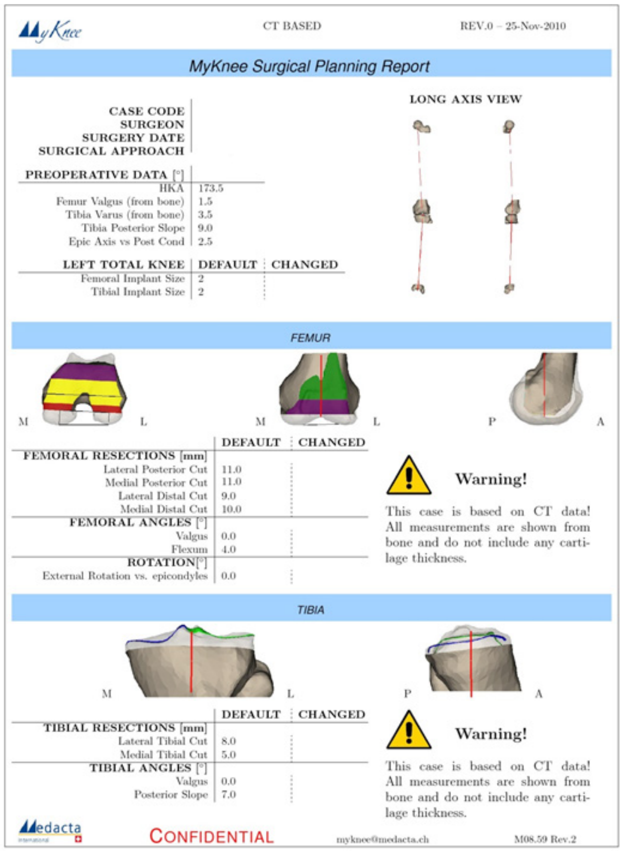

Figure 2. Presentation of the preoperative planning of a varus knee.

(TVA), the Posterior Tibia Slope (PTS), and the angle between the posterior condylar axis and the anatomical transepicondylar axis (PCA) for each patient were recorded and statistically evaluated.

The One-Way ANOVA test was used in order to compare the means of PCA and PTS angles among the three groups (varus, valgus, and neutral aligned group), whereas the Pearson correlation coefficient test was used to determine any relationship between HKA and PCA, HKA and PTS, and PCA and PTS. T-test was used for the comparison of HKA, FVA, TVA, PTS, and PCA between males and females. For statistical analysis, IBM SPSS 20.0 was used and the level of significance was set as 0.05.

Results

In overall, the mean HKA angle was 177.3±5.55, the

Table 1. Mean, Standard Deviation, Minimum, and Maximum values of HKA, FVA, TVA, PTS, and PCA angles

	Mean	Standard Deviation	Minimum	Maximum
HKA	177.3	5.54	162.5	197.5
FVA	3.19	2.08	0	11.5
TVA	3.28	2.34	0	17.5
PTS	9.02	3.46	0	19.5
PCA	2.86	0.78	1	7.5

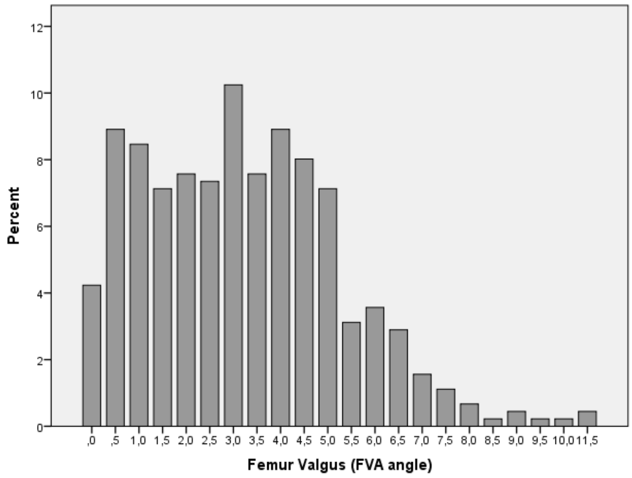

Figure 4. Graphical distribution of FVA angle.

mean FVA angle was 3.19±2.08, the mean TVA was 3.28±2.35, the PTS angle was 9.02±3.46, and the PCA angle was 2.86±0.78, [Table 1]. The distributions of the HKA, FVA, TVA, PTS, and PCA angle are shown in Figures 3-7, respectively.

There were 230 varus knees (HKA<177^0, Group 1), 156 knees with neutral alignment (HKA between 177^0 and 183^0, Group 2), and 63 valgus knees (HKA>183^0, Group 3). In the varus knees, the mean PCA angle was 2.8±0.81 and the mean PTS angle was 9.08±3.49. In the valgus knees, the mean PCA angle was 2.8±0.69 and the mean PTS angle was 8.71±3.66, and in the neutral aligned knees, the mean PCA angle was 2.96±0.77 and the mean PTS angle was 9.04±3.34. The comparison of the means of PCA angles between Groups 1 and 2 (*P*=0.12), 1 and 3 (*P*=1.0), 2 and 3 (*P*=0.34) showed no significant differences [Table 2]. Additionally, the comparison of the means of PTS angles between Groups 1 and 2 (*P*=0.99), 1 and 3 (*P*=0.73), 2 and 3 (*P*=0.81) showed no significant differences, as well [Table 3].

Evaluation of the correlations between HKA and PCA (r=0.035), HKA and PTS (r=-0.047), and PCA and PTS (r=0.05) showed non-significant relationships (*P*=0.46, *P*=0.32, and *P*=0.29 respectively) [Figures 8-10].

No significant differences were revealed from the comparison of male patients with female patients, regarding the mean HKA, FVA, TVA, PTS, and PCA [Table 4].

Discussion

Our study was based on 3D reconstructed CT images. Hirschmann et al. have studied the intra- and interobserver reliability of measurements of the position of the components after total knee replacement using a combination of radiographs, axial two-dimensional (2D) and three-dimensional (3D) reconstructed CT images, in order to identify which method is best for this purpose. The rotation of the femoral component (femoral posterior component axis) was measured in relation to the epicondylar axis. The authors recommended the use of a low-dose 3D reconstructed CT for determining the rotational, sagittal and coronal orientation of the components after total knee replacement, while 2D-CT scan was not sufficiently reliable (9).

Our results showed a wide distribution of the posterior condylar angle values. Also, it was observed that both PCA and PTS angles were not affected by the degree and the type of the deformity (varus, valgus, neutral aligned knees). The mean PCA angle in the whole sample size was 2.86±0.78°, whereas there was not any significant difference in the mean PCA angle between the varus, the valgus, and the neutral aligned knees.

Nagamine et al. studied 84 knees including normal knees and knees with tibiofemoral and patellofemoral arthritis. The CT scan-based measurements showed that the posterior condylar axis was 6±2.4° of internal rotation in relation to the transepicondylar axis. Furthermore, there were no significant differences of this angle between the three groups (5). Similar values have been showed by Park et al. In a MRI-based study, the posterior condylar axis was in 6.1° of internal rotation in 101 osteoarthritic knees with tibia vara, and 6° in 150 osteoarthritic knees with no tibia vara (10). In the study of Mantas et al. over 38 cadaveric speciments,

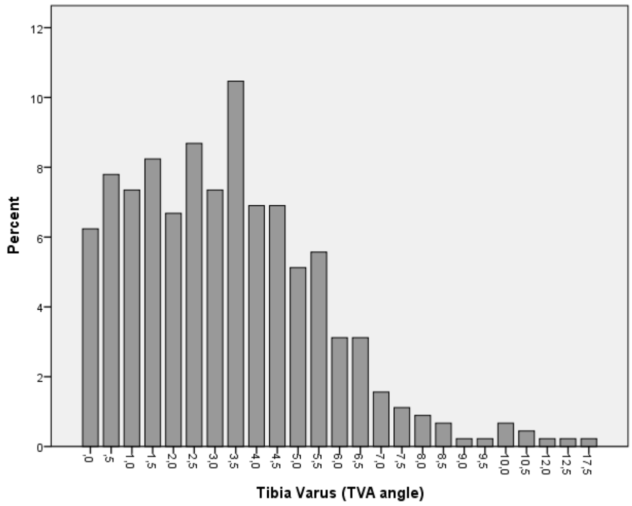

Figure 5. Graphical distribution of TVA angle.

Table 2. Mean PCA angles in the varus, the neutral aligned, and the valgus knees

	Group 1	Group 2	Group 3
PCA angle	2.80 (0.05)[a]	2.96 (0.06)[a, b]	2.8 (0.08)[a, b, c]

[a, b, c] Values are means (standard error) of the PCA angles. Means within the same column that have no common superscript letters are significantly different from each other (*P*<0.05).

Table 3. Mean PTS angles in the varus, the neutral aligned, and the valgus knees

	Group 1	Group 2	Group 3
PTS angle	9.08 (0.23)[a]	9.03 (0.27)[a, b]	8.71 (0.46)[a, b, c]

[a, b, c] Values are means (standard error) of the PCA angles. Means within the same column that have no common superscript letters are significantly different from each other (*P*<0.05).

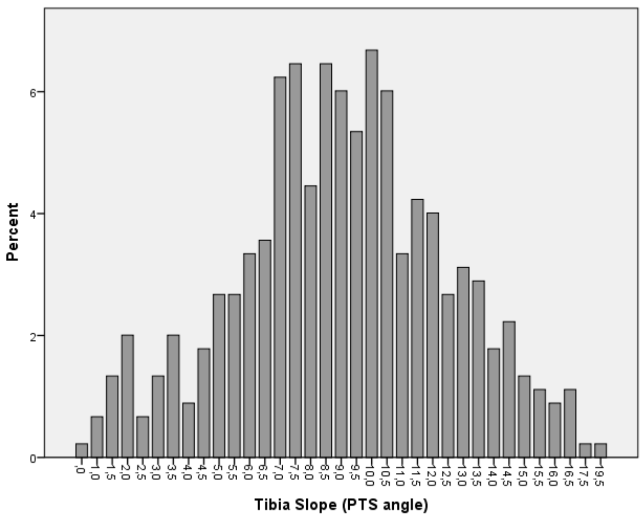

Figure 6. Graphical distribution of PTS angle.

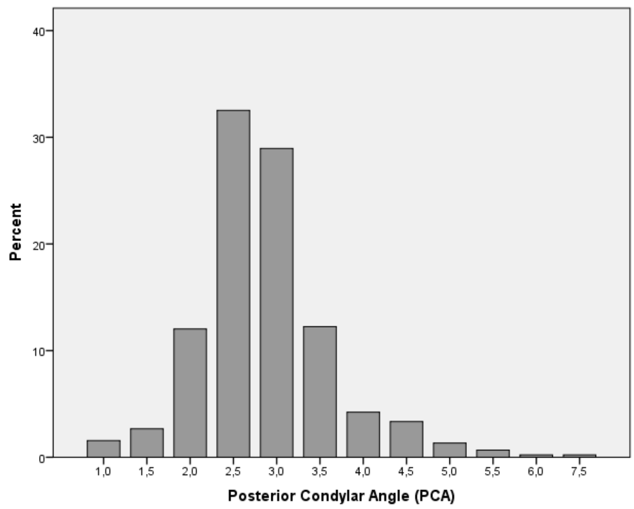

Figure 7. Graphical distribution of PCA angle.

the internal rotation of the posterior condylar axis to the transepicondylar axis was 5° (11). Another study of 55 osteoarthritic knees including 32 varus knees and 23 neutral aligned knees with CT based measurements showed that the posterior condylar axis was 5.7±1.7° internally rotated to the transepicondylar axis (12). Matsuda et al. showed in a MRI-based study of 90 knees that the PCA angles were 6.4°, 6.1°, and 11.5° for normal knees, varus knees and valgus knees, respectively (13).

Furthermore, Pagnano et al. showed that the intraoperatively measured PCA angle in 60 varus and neutral aligned knees was 3.98°, ranging from 0° to 9° (14). Finally, in the CT-based study of Anglietti et al. which included 100 knees, the angle between the mean value of the posterior condylar axis and the surgical transepicondylar axis was greater (*P*=0.001) in the valgus (4.1±1.9°) compared to the varus knees (1.9±1.4°), whereas the angle between the mean value of the posterior condylar axis and the anatomical transepicondylar axis was also greater (*P*=0.001) in valgus (8.4±1.3°) compared to varus knees (5.6±1.7°) (15).

Closer to our results is the study of Poilvache et al., who reported that the posterior condylar axis is 3.51±2.03° internally rotated to transepicondylar axis in the varus and the neutral aligned knee, and 4.41±1.83° in the valgus knees. The study included 100 knees and the measurements were performed intraoperatively (3). Similarly, Berger et al. showed that the posterior condylar axis was 3.5±1.2° internally rotated to the transepicondylar axis in 75 cadaveric specimens (1). In another study, which included 104 knees and MRI based measurements, the PCA angle was 3.11° (2).

There are also studies in the literature that reported a strong correlation between the HKA and the PCA angles. Anglietti et al. observed a linear relationship between the PCA angle and the anteroposterior mechanical

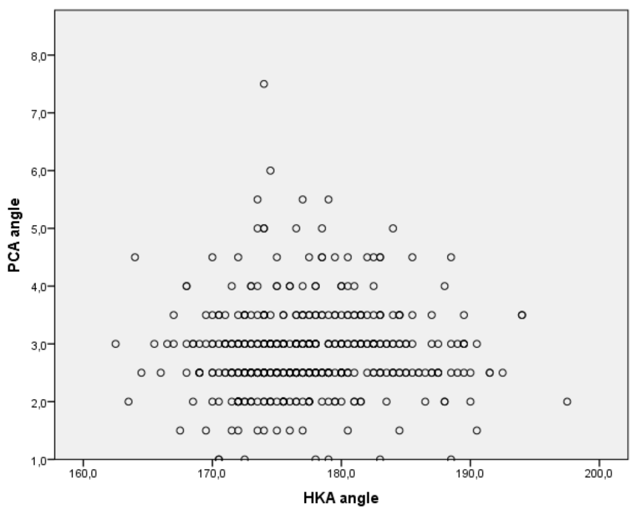

Figure 8. Scatter plot of the correlation between PCA and HKA angles.

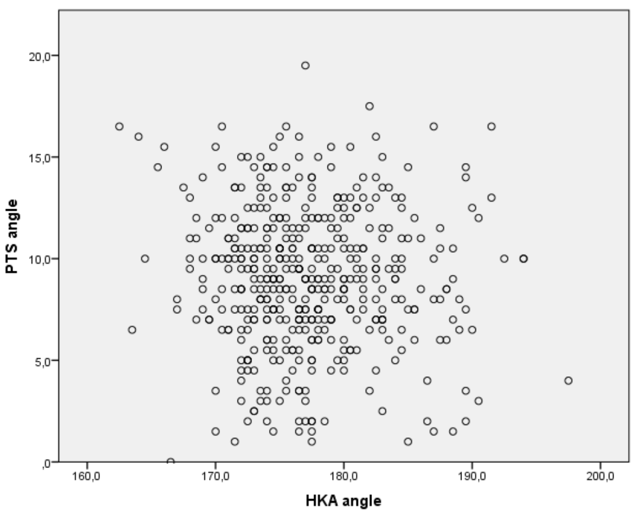

Figure 9. Scatter plot of the correlation between PTS and HKA angles.

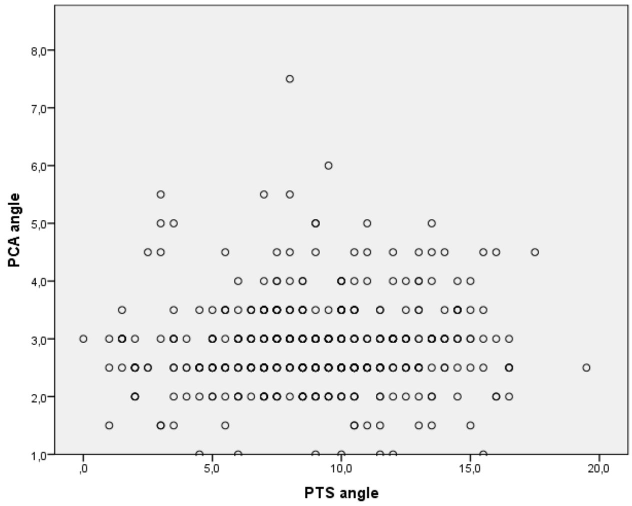

Figure 10. Scatter plot of the correlation between PCA and PTS angles.

axis. From varus to valgus for approximately every 10° increment of coronal deformity, a 1° PCA increment was observed (15). Similarly, Akagi et al. showed that the angle between the posterior condylar axis and the anatomical transepicondylar axis was almost constant and averaged 6 degrees when the femoral valgus angle was 9 degrees or less, but increased gradually when the angle was greater than 9 degrees. For this reason, the authors recommended the use of the posterior condylar axis in common varus or neutral knees, and the use of the anteroposterior axis in cases with a larger femoral valgus angle (16). Furthermore, Pagnano et al. reported that the tibial plateau-tibial shaft angle values were significantly correlated with the value of the posterior condylar angle. As the tibial varus joint line obliquity increased, there was a distinct tendency for the transepicondylar axis to be rotated more externally relative to the posterior condylar axis. This variance suggests that the use of the posterior condylar axis as a rotational reference is inappropriate in many knees with arthritis with varus or neutral tibiofemoral alignment. In conclusion, varus tibial joint line obliquity of more than 4 degrees increases the likelihood of femoral component malrotation when the posterior femoral condyles are used to reference femoral component rotation (14). In contrast to the previous studies, our study did not find any correlation between PCA and HKA angles.

It is obvious that the available literature is not able to define clearly the relationship between the posterior condylar axis and the transepicondylar axis, and the correlation between the PCA angle and the coronal tibiofemoral alignment. Different results have been presented by many studies, which have employed various methods. MRI-based data, 2D CT-based data, intraoperatively measurements, and measurements in cadaveric specimens, all have failed to show a consensus of results.

Table 4. Comparison of HKA, FVA, TVA, PTS, PCA between male and female patients

	Males	Females	*P*
	Mean	Mean	
HKA	175.6	178.3	0.42
FVA	3.08	3.24	0.09
TVA	3.32	3.12	0.13
PTS	8.89	9.16	0.28
PCA	2.72	2.94	0.29

On the other hand, the transepicondylar and the anteroposterior axis have been recognized as reliable landmarks for the placement of the femoral component. However, recent research has showed that the identification of the transepicondylar axis is not frequently accomplished by the surgeons. Kinzel et al. reported a series of 74 total knee arthroplasties in which the femoral epicondyles were marked with pins intraoperatively, and postoperative CT scans were performed to assess the accuracy of epicondylar identification. They observed that the epicondyles were correctly identified to within 3° in only 75% of the cases, with a wide range of error from 6° of external rotation to 11° of internal rotation (17). Similarly, Yau et al. have found a wide range of error in intraoperative surgeon identification of the femoral epicondyles (28° error range, from 11° of external rotation to 17° of internal rotation) (18).

Furthermore, other researchers have demonstrated a wide range of errors when using the anteroposterior axis as a determinant of femoral component rotation. Yau et al. showed a 32° range of error using the anteroposterior axis (15° of external rotation to 17° of internal rotation) (18), whereas Nagamine et al. reported a significant external rotation error using the anteroposterior axis in varus knees with medial compartment osteoarthritis (5).

In conclusion, the posterior condylar axis is a well-defined but not a reliable axis, while the transepicondylar and the anteroposterior are reliable, but not easily-defined axes. Given the large ranges and standard deviations of the location of posterior condylar axis, and the important inter- and intraobserver variability in the intraoperative location of the transepicondylar and the anteroposterior axes, the use of a preoperative 3D CT scan is recommended.

The authors declare that they have no conflict of interest.

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References

1. Berger RA, Rubash HE, Seel MJ, Thompson WH, Crossett LS. Determining the rotational alignment of the femoral component in total knee arthroplasty using the epicondylar axis. Clin Orthop Relat Res. 1993; 286(1):40-7.
2. Griffin FM, Math K, Scuderi GR, Insall JN, Poilvache PL. Anatomy of the epicondyles of the distal femur: MRI analysis of normal knees. J Arthroplasty. 2000; 15(3):354-9.
3. Poilvache PL, Insall JN, Scuderi GR, Font-Rodriguez DE. Rotational landmarks and sizing of the distal femur in total knee arthroplasty. Clin Orthop Relat Res. 1996; 331(10):35-46.
4. Whiteside LA, Arima J. The anteroposterior axis for femoral rotational alignment in valgus total knee arthroplasty. Clin Orthop Relat Res. 1995; 321(12):168-72.
5. Nagamine R, Miura H, Inoue Y, Urabe K, Matsuda S, Okamoto Y et al. Reliability of the anteroposterior axis and the posterior condylar axis for determining rotational alignment of the femoral component in total knee arthroplasty. J Orthop Sci. 1998; 3(4):194-8.
6. Sharkey PF, Hozack WJ, Rothman RH, Shastri S, Jacoby SM. Insall Award paper. Why are total knee arthroplasties failing today. Clin Orthop Relat Res. 2002; 404(11):7-13.
7. Barrack RL, Schrader T, Bertot AJ, Wolfe MW, Myers L. Component rotation and anterior knee pain after total knee arthroplasty. Clin Orthop Relat Res. 2001; 392(11):46-55.
8. Boldt JG, Stiehl JB, Munzinger U, Beverland D, Keblish PA. Femoral component rotation in mobile-bearing total knee arthroplasty. Knee. 2006; 13(4):284-9.
9. Hirschmann MT, Konala P, Amsler F, Iranpour F, Friederich NF, Cobb JP. The position and orientation of total knee replacement components: a comparison of conventional radiographs, transverse2D-CTslices and 3D-CT reconstruction. J Bone Joint Surg Br. 2011; 93(5):629-33.
10. Park IS, Ong A, Nam CH, Ahn NK, Ahn HS, Lee SC et al. Transepicondylar axes for femoral component rotation might produce flexion asymmetry during total knee arthroplasty in knees with proximal tibia vara. Knee. 2014; 21(2):369-73.
11. Mantas JP, Bloebaum RD, Skedros JG, Hofmann AA. Implications of reference axes used for rotational alignment of the femoral component in primary and revision knee arthroplasty. J Arthroplasty. 1992; 7(4):531-5.
12. Tanavalee A, Yuktanandana P, Ngarmukos C. Surgical epicondylar axis vs anatomical epicondylar axis for rotational alignment of the femoral component in total knee arthroplasty. J Med Assoc Thai. 2001; 84(Suppl 1):S401-8.
13. Matsuda S, Miura H, Nagamine R, Urabe K, Hirata G, Iwamoto Y. Effect of femoral and tibial component position on patellar tracking following total knee arthroplasty: 10-year follow-up of Miller-Galante I knees. Am J Knee Surg. 2001; 14(3):152-6.
14. Pagnano MW, Hanssen AD. Varus tibial joint line obliquity: a potential cause of femoral component malrotation. Clin Orthop Relat Res. 2001; 392(11):68-74.
15. Aglietti P, Sensi L, Cuomo P, Ciardullo A. Rotational position of femoral and tibial components in TKA using the femoral transepicondylar axis. Clin Orthop Relat Res. 2008; 466(11):2751-5.
16. Akagi M, Yamashita E, Nakagawa T, Asano T, Nakamura T. Relationship between frontal knee alignment and reference axes in the distal femur. Clin Orthop Relat Res. 2001; 388(7):147-56.
17. Kinzel V, Ledger M, Shakespeare D. Can the epicondylar axis be defined accurately in total knee arthroplasty. Knee. 2005; 12(4):293-6.
18. Yau WP, Chiu KY, Tang WM. How precise is the determination of rotational alignment of the femoral prosthesis in total knee arthroplasty: an in vivo study. J Arthroplasty. 2007; 22(7):1042-8.