A CT study of tibiofemoral rotation alignment in normal knee joint of Chinese adult

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Abstract

Background : Tibial rotation in total knee arthroplasty remains controversial. The aim was to investigate which anatomical reference was closer to SEA in 10 tibial markers in Chinese adult.

Methods : The study included 122 normal lower extremities. 10 axes were drawn on the axial sections: transverse axis of tibia(TAT), axis of medial edge of patellar tendon (MEPT), axis of medial $\frac{1}{3}$ of patellar tendon attachment (M1/3), Akagi line, Insall line, axis of medial border of tibial tubercle(MBTT) axis of anterior border of the tibia 1-4(ATC1-4). The angles between TAT and SEA as well as the angles between other axes and the perpendicular to SEA were measured. Pairwise differences among the 10 tibial axes were examined using one-way ANOVA and paired t-test.

Results : In all the knees, the mean angles of M1/3, Akagi line, Insall line, MBTT, ATC1, ATC2, ATC3, and ATC4 axes compared to perpendicular of projected SEA were $10.2\pm5.1^\circ$, $1.4\pm5.0^\circ$, $11.9\pm5.4^\circ$, $3.6\pm4.8^\circ$, $12.0\pm6.9^\circ$, $7.2\pm8.6^\circ$, $7.1\pm10.4^\circ$, and $6.6\pm13.5^\circ$ external rotation, respectively, and the MEPT axis was $1.6\pm4.5^\circ$ internal rotation. The TAT was $4.1\pm5.3^\circ$ external rotation compared to SEA. The M $\frac{1}{3}$ and Insall line were significantly externally rotated than Akagi line, MEPT, MBTT, TAT, ATC2, ATC3, and ATC4 axes. There was no significant difference between the TAT axis and the MBTT axis, as well as no significant difference between the ATC2, ATC3, and ATC4 axes.

Conclusion : Akagi line, MBTT and TAT show good consistency with SEA in axial femorotibial alignment with knee in extension. The middle segment of the anterior tibial crest also has good alignment consistency with SEA in axial femorotibial alignment, it can be reliable reference mark for rotational alignment of the tibial component in TKA.

Background

Rotation alignment between femoral and tibial components is very important in total knee arthroplasty(TKA). Rotation malalignment will lead to some symptoms, including anterior knee pain[1], poor patellar tracking[1, 2], instability of knee flexion[1, 3] and premature wear of polyethylene liner[1, 4].

The surgical epicondylar axis (SEA), the line connecting the tip of the lateral epicondyle to the medial epicondylar sulcus, has been shown to be not only a useful anatomic reference axis but also a functional flexion–extension axis of the knee [5, 6, 7, 8, 9]. Therefore, SEA has been recognized as the reliable and stable anatomical reference marker for femoral rotation positioning in TKA. Theoretically, the perpendicular to the projected SEA on the tibia can be used as an effective reference for the rotation alignment of tibial prosthesis in extended knee[10, 11, 12, 13]. However, it cannot be directly marked intraoperatively and some anatomical markers need to be selected for reference. Some known examples of tibial markers are as follows: the tibial posterior condylar line[14], the tibial transcondylar line[15] the line connecting the middle of the PCL insertion to the medial third of the tibial tubercle (Insall line)[16], the medial edge of the tubercle[17], the axis connecting the middle of the PCL insertion to the medial edge of the patellar tendon attachment (Akagi line)[11], medial sixth of the patellar tendon at the tibial attachment[18], the axis going from 1 mm medial of the tibial tubercle medial edge to between the midsulcus of the tibial spines as defined by Dalury[28], the ankle transmalleolar axis[10], and 2nd metatarsal[10]. However, these references of rotational alignment of tibial component have been controversial, and no consensus has been reached.

In our institution, the anterior tibial crest was often used as the reference for tibial rotational orientation in TKA. So far, few studies have investigated the accuracy and reliability of the anterior tibial crest as a rotational alignment reference for tibial component.

This study tried to determine 1) among the ten reference marks including Insall line, Akagi line, anterior tibial crest 1-4, medial edge of patellar tendon, the transverse axis of tibial resected bone surface, medial $\frac{1}{3}$ of patellar tendon attachment and medial border of tibial tubercle, which were closer to SEA or the perpendicular of SEA? 2) whether the anterior tibial crest can be used as a reliable anatomical reference for rotational alignment of tibial component in TKA.

Materials And Methods

We selected patients who performed CTA examination of both lower limbs because of trauma or tumor of unilateral lower extremity in Xi'an honghui hospital from July 2017 to June 2018. All CT data were available on the digital image archive system PACS (Picture Archiving and Communications Systems, Synapse, Fujifilm Inc., Tokyo Japan). The study protocol was approved by the Hospital Ethics Committee. Inclusion criteria were as follows: 1. CT scan with a direction perpendicular to lower limbs; 2. at least one side of lower limb without fracture or tumor; 3. no obvious flexion, varus and valgus deformity in bilateral knees; 4. no obvious degeneration in bilateral knees. Exclusion criteria were as follows: 1. both lower limbs have fracture, residual internal fixation, tumor and other pathological changes; 2. 3D reconstruction showed incomplete extension of both knee joints or hip joints; 3. obvious deformity of external tibial arch.

Transverse CT scans (SOMATOM Definition, Siemens Inc, Munich, Germany) were made with 1-mm thickness and 1 mm interval ranging from lumbar 4/5 intervertebral space to sole of foot, including the entire lower extremity. The patient was in supine position with both lower limbs straight.

All measurement was done with PACS:

Three-dimensional reconstruction of CT data were performed and the following marks were made: 1. medial edge of patellar tendon 8 mm distal to lateral tibial plateau, 2. the medial and lateral border of the patellar tendon at the tibial attachment, connecting the two points. 3. the medial and lateral border of the widest part of the tibial tubercle, connecting two points. 4. The proximal and distal ends of the sharp margin of the anterior tibial crest were marked, two points between them were also marked on the anterior tibial crest, making the distance trisection (Fig. 1).

Finally, 122 patients with 122 lower extremities were included in this study, There were 89 males and 33 females with a mean age of 51.4 years (18–81 years), including 67 left lower extremities and 55 right lower extremities.

The following marks and measurement were made on CT axis scans:

1. the angle between PACS transverse axis and the surgical epicondylar axis (SEA), which was determined for connecting the most prominent points of the lateral epicondyle and the deepest point of the sulcus on the medial epicondyle of the femur (Fig. 2). 2. the angle between PACS longitudinal axis and the line connecting the middle of the PCL and medial border of the patellar tendon (MEPT) at the level 8 mm distal of the lateral tibial joint surface (Fig. 3). 3. the angle between PACS transverse axis and the transverse axis of the tibia (TAT) at the level 8 mm distal of the lateral tibial joint surface (Fig. 4). 4. the angle between PACS longitudinal axis and the line connecting the projected middle of the PCL and medial border of the patellar tendon at the tibial attachment (Akagi line), and the angle between PACS longitudinal axis and a line connecting the projected middle of the PCL and the medial $\frac{1}{3}$ of the patellar tendon (M1/3) at the patellar tendon attachment level (Fig. 5). 5. the angle between PACS longitudinal axis and the line connecting the projected middle of the PCL and medial border of tibial tubercle (MBTT), and the angle between PACS longitudinal axis and a line connecting the projected middle of the PCL and the medial $\frac{1}{3}$ of tibial tubercle (Insall line) (Fig. 6). 6. the angles between PACS longitudinal axis and the line connecting the four points on the anterior tibial crest (ATC1-4) and projected middle of the PCL respectively (Fig. 7–10).

The measurement data were divided into 10 groups according to 10 axes of tibia, which were Akagi line group, Insall line group, MEPT axis group, M $\frac{1}{3}$ axis group, TAT axis group, MBTT axis group, ATC1 axis group, ATC2 axis group, ATC3 axis group and ATC4 axis group. According to the principle that the longitudinal and transverse axes of PACS in each scanning plane of CT is identical, the angle between SEA and TAT as well as the angles between the perpendicular to SEA and the other nine axes was calculated. Compared with SEA or the perpendicular to SEA, the external rotation was positive and the internal rotation was negative.

After three weeks, 20 randomly selected CT scans were measured again by the same author (Observer I) and another author (Observer II) who conducted an independent evaluation to determine intra- and interobserver variability. A conclusion was made: an intraclass correlation coefficient (ICC) > 0.8 was considered excellent agreement, ICC 0.6–0.8 was fair to good agreement, and ICC < 0.6 was poor agreement.

Quantitative data was expressed as means $\pm$ standard deviation (SD). Statistical analyses were performed with PASW statistics 18 (SPSS Inc., Chicago, IL, USA). The normality assumption of our data was checked by the Kolmogorov-Smirnov test. Single factor ANOVA and paired t-test were used to compare data between 10 axes. Values of $P < 0.05$ were considered significant.

Results

Kolmogorov-Smirnov test showed that all data were in normal distribution. Intra- and interclass correlation coefficients for the reproducibility of all parameters were greater than 80% (Table 1).

Table 1
The intraclass correlation coefficient analysis of the 11 angles of different axes relative to the longitudinal or transverse axes of PACS.

	SEA	MEPT	M1/3	AL	TAT	IL	MBTT	ATC1	ATC2	ATC3	ATC4
interobserver	0.904	0.866	0.812	0.828	0.847	0.820	0.902	0.802	0.839	0.828	0.841
intraobserver	0.922	0.891	0.855	0.901	0.844	0.865	0.914	0.876	0.900	0.892	0.889

All reference axes were external rotation compared to perpendicular to SEA or SEA except MPET axis, which was internal rotation compared to the perpendicular to SEA. Akagi line was the closest to the perpendicular to SEA, the mean angle between the perpendicular to SEA and Akagi line was $1.5^\circ \pm 5.0^\circ$. The mean angle between SEA and TAT was $4.1^\circ \pm 5.3^\circ$. The mean angles between the perpendicular to SEA and MEPT axis, MBTT

axis were $-1.6 \pm 4.5^\circ$, $3.6 \pm 4.8^\circ$ respectively. The mean angle between the perpendicular to SEA and $M^{1/3}$ axis was $10.2^\circ \pm 5.1^\circ$, and between the perpendicular to SEA and Insall line was 11.9 ± 5.4 (Table 2). $M^{1/3}$ axis and Insall line were significantly more externally rotated than Akagi line, MEPT axis, MBTT axis and TAT.

Table 2
Comparison of the angles between SEA and different tibial landmarks.

Tibial axis	Mean $\pm$ SD($^\circ$)	Range($^\circ$)	95% confidence interval
MEPT	-1.6 ± 4.5	-12.5~15.5	-2.4~-0.8
$M^{1/3}$	10.2 ± 5.1	12.2~23.1	9.2~11.1
Akagi line	1.4 ± 5.0	-11.3~15.6	0.5~2.3
TAT	4.1 ± 5.3	-12.4~18.3	3.1~5.0
Insall line	11.9 ± 5.4	-4.4~24.8	10.9~12.8
MBTT	3.6 ± 4.8	-11.0~15.3	2.7~4.4
ATC1	12.0 ± 6.9	-6.5~27.1	10.8~13.3
ATC2	7.2 ± 8.6	-14.6~25.8	5.6~8.7
ATC3	7.1 ± 10.4	-20.3~30.5	5.3~9.0
ATC4	6.6 ± 13.5	-22.2~35.0	4.1~9.0

The mean angle between the perpendicular to SEA and ATC1,2,3 and 4 were 12.0 ± 6.9 , 7.2 ± 8.6 , 7.1 ± 10.4 and 6.6 ± 13.5 . The ATC 2,3 and 4 axis were significantly more internally rotated than $M^{1/3}$ axis, Insall line and ATC1 (Table 3). However, ATC3 and ATC4 axes had larger standard deviation than that of other subjects. There was no significant difference between TAT and MBTT axis, as well as no significant difference between the axis of ATC 2, ATC3 and ATC4 (Table 3, Fig. 11). There were significant statistical differences between men and women in Akagi line, Insall line, MBTT axis, and ATC1 axis (Table 4).

Table 3
Comparison of different tibial axes

P/t	M1/3	AL	TAT	IL	MBTT	ATC1	ATC2	ATC3	ATC4
MEPT	0.000/-25.7	0.000/-7.7	0.000/-11.5	0.000/-26.5	0.000/-12.0	0.000/-21.0	0.000/-11.3	0.000/-9.3	0.000/-6.7
M1/3		0.000/29.6	0.000/13.4	0.000/-5.0	0.000/22.7	0.000/-3.6	0.000/4.3	0.001/3.4	0.003/3.0
AL			0.000/-5.6	0.000/-22.9	0.000/-5.8	0.000/-18.3	0.000/-7.6	0.000/-6.1	0.000/-4.1
TAT				0.000/-16.8	0.266*/1.1	0.000/-11.7	0.000/-3.6	0.004/-2.9	0.060*/-1.8
IL					0.000/32.4	0.756*/-0.3	0.000/6.5	0.000/5.1	0.000/4.3
MBTT						0.000/-16.3	0.000/-5.1	0.000/-3.9	0.013/-2.5
ATC1							0.000/10.3	0.000/6.9	0.000/5.3
ATC2								0.973*/0.03	0.423*/0.8
ATC3									0.201*/1.2
*P>0.05									

Table 4
Comparison of different tibial landmarks between male and female.

Tibial axis	Mean $\pm$ SD (M)	Mean $\pm$ SD(F)	P-value
MEPT	-1.9 $\pm$ 4.7	-0.9 $\pm$ 3.8	0.267
M ^{1/3}	9.6 $\pm$ 5.1	11.7 $\pm$ 5.0	0.051
Akagi line	0.8 $\pm$ 5.0	3.0 $\pm$ 4.5	0.026*
TAT	3.7 $\pm$ 5.3	5.2 $\pm$ 5.2	0.164
Insall line	11.1 $\pm$ 5.2	14.0 $\pm$ 5.3	0.007*
MBTT	2.9 $\pm$ 4.5	5.3 $\pm$ 5.2	0.018*
ATC1	11.1 $\pm$ 7.0	14.5 $\pm$ 5.9	0.015*
ATC2	6.8 $\pm$ 8.8	8.3 $\pm$ 8.1	0.397
ATC3	7.7 $\pm$ 10.5	5.7 $\pm$ 9.9	0.368
ATC4	7.4 $\pm$ 13.6	4.2 $\pm$ 13.2	0.241
*P<0.05			

Discussion

Tibial rotation in total knee arthroplasty remains controversial. In the 1990s, Insall[16] described an anteroposterior (AP) axis from the junction of the medial and middle thirds of the tibial tubercle to the posterior cruciate ligament (PCL). Wernecke et al[20]. measured MRI of 544 cases of normal knee joint, and believed that Insall's axis was a reliable landmark for rotational alignment of the tibial component and might optimize femorotibial kinematics in fixed-bearing TKA. To date, the Insall's rotational axis for the tibial component in TKA has been generally accepted. Akagi[11] measured the angle between the perpendicular to the projected SEA and a line connecting the middle of the PCL and medial border of the patellar tendon attachment (Akagi line), He found that the mean angle was $0.0^\circ \pm 2.8^\circ$ (range, -6.3° – $+5.2^\circ$), which was significantly better than the line connecting the middle of the PCL and the medial $1/3$ of the patellar tendon $10.0^\circ \pm 4.2^\circ$ (1.6° – 19.5°). After that, Akagi[10] implemented a measurement on 57 healthy adults, comparing the Akagi line with the transmalleolar axis and the second metatarsus bone axis. He found that the angle between the perpendicular to SEA and Akagi line was $-0.2^\circ \pm 2.8^\circ$ (-5.5° – 6.3°), the angle between SEA and the transmalleolar axis was $25.9^\circ \pm 9^\circ$ (8° – 49.4°), and the angle between SEA and the second metatarsus bone axis was $5.2^\circ \pm 10^\circ$ (-21.9° – 24°). This proved again that the Akagi line was more reliable for determining rotational alignment of the tibial component in total knee arthroplasty. Kawahara[18] believes that it is difficult to identify the center of the PCL attachment after tibial resection. He found the axis pass the medial $1/6$ of the patellar tendon at its tibial attachment and the geometric center of tibia was useful in the anterior referencing and alignment of the tibial component. Lyutzner[21] pointed out that referencing the tibial rotation on a line from the medial third of the tibial tubercle to the center of the tibial tray resulted in a better femoro-tibial rotational alignment. Sahin[22] found the tibial posterior condylar line were not affected by varus deformity, and can be used for guidance in determining the rotation of the tibial component. Like other authors, we found that Akagi line was closest to the perpendicular to SEA in the case of knee joint extension. Moreover, Akagi line had smaller standard deviation, relatively stable, easy identification of anatomical markers and good reproducibility. We also found that the angle between the medial border of tibial tubercle and the perpendicular to the SEA, and the angle between the transverse axis of the tibia and the SEA, were small, which, as with the Akagi line, had good repeatability, and were also good reference markers for tibial component rotation alignment. As for the Insall line, although it was more externally rotated than Akagi line, medial border of tibial tubercle and transverse axis of tibia. And the use of Insall line as a rotational reference for tibial component during TKA did not have significant adverse outcomes in many big joint centers. The reason may be that tibial component rotation alignment has a high tolerance for external rotation.

The anterior tibial crest is a bony hump that descends from the tibial tubercle to the anterior edge of the medial malleolus. The upper $2/3$ part is sharp, without muscle coverage, and it is very easy to reach. A study [23] believed that the direction of travel of the anterior tibial crest is consistent with the tibial mechanical alignment, which can be used as a reference mark for the TKA tibial osteotomy. However, to date, there have been few related anatomical and clinical studies using the anterior tibial crest as a reference for TKA tibial component rotation alignment. This study looked at 122 normal 3D reconstructed tibias and found that the anterior tibial crest is not a stable straight line but with mild internal or external rotation. Therefore, we selected 4 points during the design of the study, connecting the points with the projected middle of the PCL, as axes of ATC1, ATC2, ATC3, and ATC4, respectively. Their angles from the perpendicular to SEA were $(12.0 \pm 6.9)^\circ$, $(7.2 \pm 8.6)^\circ$, $(7.1 \pm 10.4)^\circ$, $(6.6 \pm 13.5)^\circ$. It can be seen that the external rotation of the axis gradually decreases from the proximal to the distal, but the more distal it goes, the greater the variation. The degree of external rotation of the ATC2 and ATC3 axes relative to SEA were significantly less than the Insall line and

ATC1, and the stability was better than ATC4. Study has shown that TKA tibial component rotation had good tolerance to external rotation, and its safety zone was 0–10 ° external rotation. Therefore, in TKA positioning tibial component rotation, the middle anterior tibial crest is a good choice.

There are several limitations in our study. First, The kinematics of the knee joint is very complex. It is a medial-pivot kinematic pattern in healthy knee joint. SEA is not completely consistent with the flexion and extension axis of the knee joint, which has less axis rotation and greater variability after TKA. Therefore, there are some limitations in using the fixed axis as references for tibial component rotation alignment. Second, there is a certain degree of tibial retroversion in TKA. The simulated tibial osteotomy plane in this study has no retroversion, which may lead to some deviation. Third, our sample size was small. A prospective study with a larger sample size may produce a more accurate result and allow extrapolation of the results. Finally, the study included only Chinese subjects in Northwest China. This may be typical east Asian knee data and may differ from Caucasian or other populations. Therefore, the results of this study should be interpreted cautiously.

Conclusion

Akagi line, MBTT and TAT show good consistency with SEA in axial femorotibial alignment with knee in extension. They have little variation and good reproducibility. The middle segment of the anterior tibial crest also has good alignment consistency with SEA in axial femorotibial alignment, it can be reliable reference mark for rotational alignment of the tibial component in TKA.

Abbreviations

AL: Akagi line;ATC1: Anterior tibial crest1; ATC2: Anterior tibial crest2; ATC3: Anterior tibial crest3; ATC4: Anterior tibial crest4; IL: Insall line; MBTT: Medial border of tibial tubercle; MEPT: Medial edge of patellar tendon; M1/3: Medial 1/3 of patellar tendon attachment;SEA: surgical epicondylar axis; TAT: Transverse axis of tibia; TKA: total knee arthroplasty; PACS: Picture Archiving and Communications Systems.

Declarations

Ethics approval and consent to participate

The ethical approval was obtained from the Institutional Review Board (IRB) (IRB-2017-07-001) at Honghui Hospital, Xi'an Jiaotong University. The participants provided their written informed consent to undergo the study and to have their data used in the study.

Consent to publish

The participants in this study provided their written informed consent to undergo the study and to have their data used in the study.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding authors on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' Contributions

Yufeng Lu: Data management, analysis and manuscript writing

Xiaoyu Ren: Data collection

Benyin Liu: Data collection

Peng Xu: Protocol development

Yangquan Hao: Protocol and project development

All authors have read and approved the manuscript.

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Figures

Figure 1

Landmarks at 3-D reconstruction of the tibia: the point (e), 8 mm distal to lateral tibial plateau, the medial(b) and lateral border(a) at the level of patellar tendon attachment, and the medial(b) and lateral border(a) at the widest part of the tibial tubercle, Isometric marking of 4 points(f1,f2,f3,f4) along the sharpest margin of the tibial anterior border.

Figure 2

The surgical epicondylar axis (SEA) was determined by connecting the sulcus of the medial epicondyle and the lateral epicondyle of the femur. The horizontal line is the horizontal axis of PACS

Figure 3

The medial edge of patellar tendon axis was drawn as a line passing through the middle of the PCL and medial border of the patellar tendon at a level 8mm below the lowest point on the lateral plateau. The PCL was recognized clearly in the posterior condylar notch of the tibia. The vertical line is the vertical axis of PACS.

Figure 4

The transverse axis of the tibia is defined as the line connecting the midpoint of the medial and lateral tibial condyle at a level 8mm below the lowest point on the lateral plateau. The horizontal line is the horizontal axis of PACS

Figure 5

Akagi line was drawn as a line passing through O' and G and the medial 1/3 of the patellar tendon axis was drawn as a line passing through O' and F . The vertical line is the vertical axis of PACS. O' : the projected midpoint of the PCL; G : the medial edge of the patellar tendon attachment; F : the medial 1/3 of the patellar tendon at the level of the patellar tendon attachment.

Figure 6

Insall line was drawn as a line passing through O' and H and medial border of tibial tubercle axis was drawn as a line passing through O' and I . The vertical line is the vertical axis of PACS. O' : the projected midpoint of the PCL; H : the medial 1/3 of tibial tubercle, I : medial border of tibial tubercle

Figure 7

Anterior tibial crest axis was drawn as a line passing through the projected midpoint of the PCL and the most prominent anterior points on the anterior border of tibia. The vertical line is the vertical axis of PACS.

Figure 8

Anterior tibial crest axis was drawn as a line passing through the projected midpoint of the PCL and the most prominent anterior points on the anterior border of tibia. The vertical line is the vertical axis of PACS.

Figure 9

Anterior tibial crest axis was drawn as a line passing through the projected midpoint of the PCL and the most prominent anterior points on the anterior border of tibia. The vertical line is the vertical axis of PACS.

Figure 10

Anterior tibial crest axis was drawn as a line passing through the projected midpoint of the PCL and the most prominent anterior points on the anterior border of tibia. The vertical line is the vertical axis of PACS.

Figure 11

The Boxplot shows the distributions of the angles between SEA and the perpendicular to SEA or the angle between SEA and the transverse axis of the tibia.