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ORIGINAL ARTICLE

Is the Akagi Line a Reliable Landmark for Adjusting the Rotational Axis of the Tibial Component in Patients with Patellofemoral Instability?

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Abstract

Purpose This study aimed to investigate whether the Akagi line is a reliable anatomic landmark for adjusting the rotational axis of the tibial component in patients with patellofemoral (PF) malalignment.

Materials and methods This retrospective case–control study included 86 patients with PF instability and 129 controls. On the superimposed axial CT images, TT-TG, TT-PCL, nTT-TG, nTT-PCL, knee joint rotation, and the angle between the Akagi line and surgical transepicondylar axis (Akagi/sTEA angle) were measured. In addition, a modified Akagi line, drawn 1 cm medial to the patellar tendon attachment, was defined, and the angle between the new Akagi line and sTEA (mAkagi/sTEA angle) was also measured and compared between groups.

Results There were 86 patients (47 females, 39 males) in the case group and 129 patients (56 females, 73 males) in the control group with a mean age of 35.7 ± 17.9 years and 41.1 ± 18.8 years, respectively ($p < 0.001$). Radiologic variables of PF alignment (TT-TG, TT-PCL, nTT-TG, nTT-PCL, and knee joint rotation) were significantly abnormal in the case group ($p < 0.001$ for all variables). The Akagi/sTEA angle was significantly higher in the case group, resulting in 89.5% external malrotation of the tibial component (> 10°). However, the tibial component was 96.5% aligned correctly (between 10° external and 3° internal rotation) in the control group. Using the modified Akagi line significantly improved the rotational alignment, and normal tibial rotation increased to 93.3% of the case group. The Akagi/sTEA angle strongly correlated with the knee rotation (rho: 0.735, p: 0.001), TT-TG (rho: 0.715, p: 0.001) and nTT-TG (rho: 0.783, p: 0.001). But the TT-PCL (rho: 0.459, p: 0.001) and nTT-PCL (rho: 0.589, p: 0.001) had a medium correlation.

Conclusions The Akagi line might cause unacceptable external rotation of the tibial component in patients with PF malalignment. The use of the modified Akagi line described in this study may be a solution for the rotational mismatch between femoral and tibial components in TKA.

Level of evidence Level III, retrospective case–control study.

Keywords Total knee arthroplasty · Total knee replacement · Tibial component rotation · Akagi line · Patellofemoral malalignment

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Abbreviations

TKA	Total knee arthroplasty
OA	Osteoarthritis
TT	Tibial tubercle
sTEA	Surgical transepicondylar axis
CT	Computerized tomography
PF	Patellofemoral
PACS	Picture archiving and communication systems
TT-TG	Tibial tubercle-Trochlear groove
nTT-TG	Normalized Tibial tubercle-Trochlear groove
TT-PCL	Tibial tubercle-Posterior cruciate ligament
nTT-PCL	Normalized Tibial tubercle-Posterior cruciate ligament
TMMA	Tibial maximal mediolateral axis
ICC	Interclass correlation coefficient
IRB	Institutional review board

Introduction

Total knee arthroplasty (TKA) is an effective treatment method with excellent long-term results in advanced knee osteoarthritis (OA) [1]. Most previous studies report more than 80% of patient satisfaction following TKA [2]. Persistent pain is the most important reason for dissatisfaction. Although the etiology of persistent pain following TKA is multifactorial, infection, aseptic loosening, joint stiffness, instability, and component malposition, particularly patellofemoral (PF) maltracking, are the most common reasons [3].

Proper rotational alignment of the tibial component is critical to a successful outcome in TKA. In an optimal TKA, the tibial component should be placed parallel to the surgical transepicondylar axis (sTEA). A maximum of 10° of external rotation and 3° of internal rotation are acceptable [4]. PF maltracking and anterior knee pain are usually related to the tibial component malrotation that exceeds the limits mentioned above.

It is challenging to project the sTEA onto the cut tibial plateau during the surgery. Thus, the patellar tendon (PT) attachment on the tibial tubercle (TT) is generally used as a reliable marker while adjusting the rotation of the tibial component. Previously Akagi et al. [5] have shown that the line drawn between the midpoint of the tibial attachment of the posterior cruciate ligament (PCL) and the medial border of the PT attachment, also known as the Akagi Line, is perpendicular to the sTEA. The Akagi Line is a widely accepted reference when determining the rotation of the tibial component [6].

However, the anatomic location of the TT is subject to individual variations. For instance, the TT is almost always found in a lateralized position in patients with PF malalignment. Therefore, we hypothesized that using the Akagi line might cause rotational malalignment of the tibial component in patients with PF malalignment and lateralized position of the TT (Fig. 1). This study aimed to investigate whether the Akagi line is a reliable landmark for adjusting the rotational axis of the tibial component in patients with PF malalignment.

Materials and Methods

Patients and Study Design

This study was a retrospective observational case–control study that was conducted using archival patient records between 2014 and 2020 in a university hospital. The case group consisted of patients with PF problems, including acute patellar dislocation, recurrent patellar dislocation, and PF instability. All subjects in the case group were clinically confirmed cases and selected based on clinical and surgical notes. The imaging studies of these patients were reviewed, and patients who had knee computerized tomography (CT) were selected. Skeletally immature patients, patients with distorted knee anatomy due to congenital or acquired deformities, patients who had CT examination with the knee in flexion, and finally had incomplete or inadequate clinical and radiological data were excluded from the case group.

The control group consisted of patients who were admitted to the emergency department following a traumatic incident and underwent knee CT. Patients with femoral or tibial fracture, skeletally immature patients, patients with distorted knee anatomy due to congenital or acquired deformities, had incomplete or inadequate clinical and radiological data were

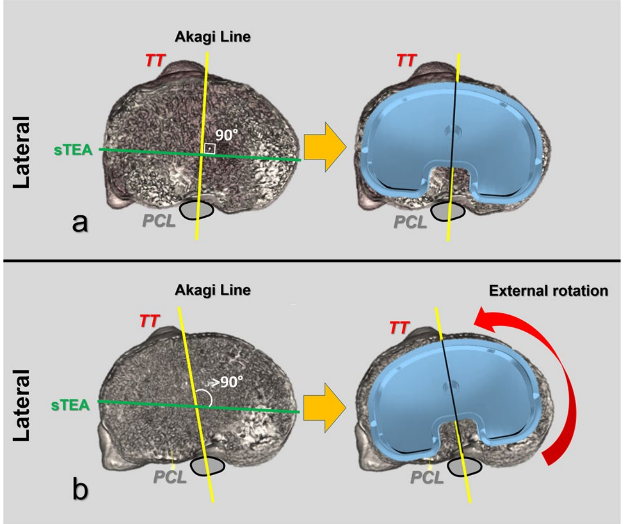

Fig. 1 **a** A patient with a normal location of TT (nTT-TG and nTT-PCL ratio are normal) and **b** a patient with an increased TT lateralization of TT

excluded from the control group. Patients with associated radiological features of PF instability (abnormal tibial tubercle-trochlear groove (TT-TG) distance) were also excluded from the control group. Thus, two groups of patients with and without clinical and radiological PF malalignment were formed. A total of 86 patients who met the inclusion criteria for the case group were identified. Among eligible patients for the control group, 129 were selected with a 1.5 allocation ratio. The demographic characteristics of patients are presented in Table 1. Since PF malalignment is frequently observed in young patients, the case group consisted of younger patients than the control group (35.7 ± 17.9 vs. 47.1 ± 18.8, $p < 0.001$).

This study was conducted following the ethical standards in the 1964 Declaration of Helsinki and its later amendments, and the institutional review board approved the study protocol (IRB approval date/issue: 2021/137).

Radiological Measurements

Radiological measurements were performed on digital CT images stored in picture archiving and communication systems (PACS) by two independent observers on two separate occasions using the software program Sectra IDS7 (Ver. 18.2., Sectra AB, Linköping, Sweden) on the digital workstation. All images were acquired with the same CT device (Philips Brilliance CT 64 Channel-DS, Koninklijke Philips Electronics N.V., Amsterdam, Holland). On the superimposed axial CT images, TT-TG distance, tibial tubercle-posterior cruciate ligament (TT-PCL) distance, and knee rotation were measured according to the previous descriptions [7, 8]. To normalize the measurements, the proximal tibial maximal mediolateral axis (TMMA) was used as a reference, and nTT-TG and nTT-PCL variables were calculated (Fig. 2) [9, 10].

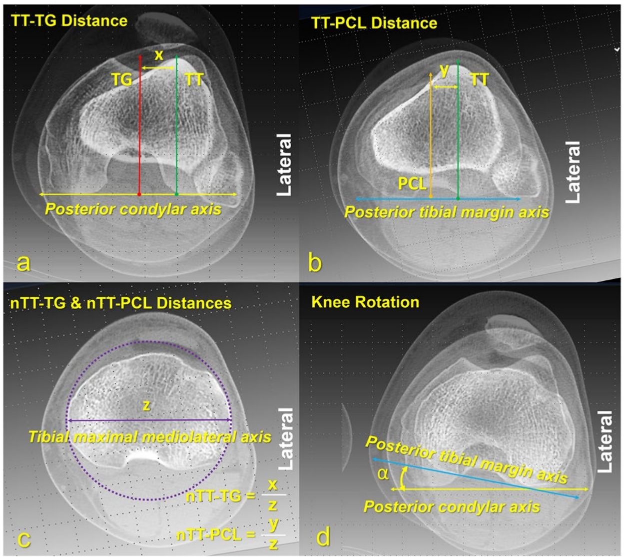

Fig. 2 Radiological measurement of **a** TT-TG distance, **b** TT-PCL distance, **c** Normalization and TT-TG and TT-PCL distances according to TMMA distance, and **d** Knee joint rotation

The angle between Akagi Line and the sTEA was measured on three superimposed axial CT images of the knee. The first axial image was used to draw the sTEA on the femur between the center of the sulcus of the medial epicondyle and the most prominent point of the lateral epicondyle. The second axial image was used to locate the PCL attachment on the proximal tibia, and the last axial image was used to locate the PT attachment on the TT. The Akagi line was drawn between the center of PCL tibial attachment and the medial border of the PT attachment on TT. The angle between the sTEA and Akagi line was measured on the lateral side. Deviation from the perpendicular axis was calculated by subtracting from 90°. Positive values were accepted as external rotation of the tibial component and negative values as internal rotation. Since the TT is lateralized in the case group, a modified Akagi line was also drawn between the center of PCL and 1 cm medial to the medial border of PT attachment (Fig. 3). Up to 10° of external rotation and 3° of internal rotation of the tibial component were accepted as normal in accordance with the current literature [4]. According to these rotational limits, patients were categorized into

Table 1 Demographic characteristics of patients

Variables	Total (*n*: 215)	Case group (*n*: 86)	Control group (*n*: 129)	*p* value
Age (mean ± SD, years)	42.5 ± 19.2	35.7 ± 17.9	47.1 ± 18.8	$<0.001^a$
Sex				0.106^b
Female	103 (47.9%)	47(54.7%)	56 (43.4%)	
Male	112 (52.1%)	39(45.3%)	73 (56.6%)	
Side				0.540^b
Left	112 (52.1%)	47 (54.7%)	65 (50.4%)	
Right	103 (47.9%)	39 (45.3%)	64 (49.6%)	

SD standard deviation

^{a}Mann–Whitney *U* test, ^{b}Chi-square test

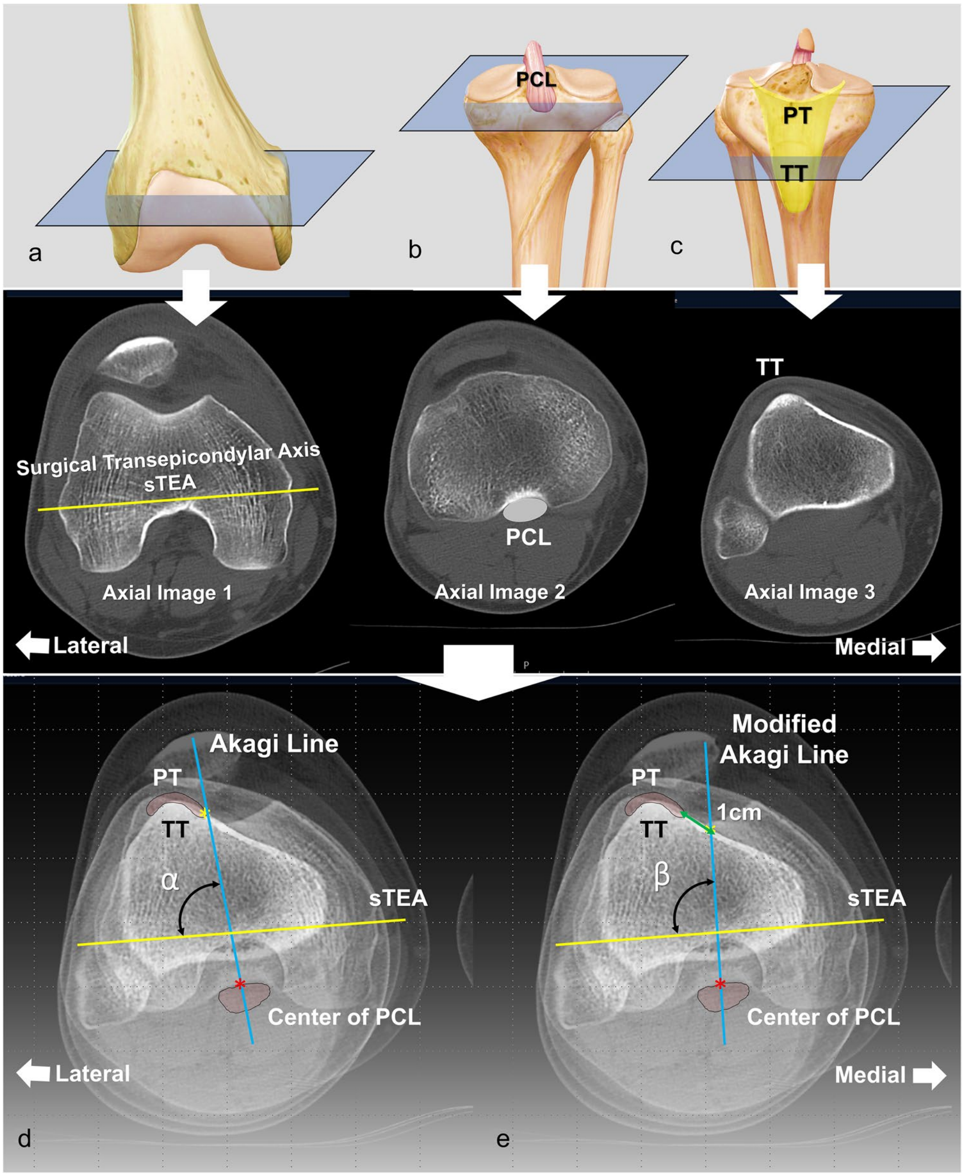

Fig. 3 Schematic illustration of three axial CT images from the femur and tibia. **a** The first axial CT image was used to draw the sTEA on the femur between the center of the sulcus of the medial epicondyle and the most prominent point of the lateral epicondyle. **b** The second axial CT image was used to locate the PCL attachment on the proximal tibia. **c** The third axial CT image was used to locate the PT attachment on the TT. **d** The Akagi line was drawn between the center of PCL and the medial border of the PT attachment. The angle (α) between the sTEA and Akagi line was measured on the lateral side. **e** The modified Akagi line was also drawn between the center of PCL and 1 cm medial to the medial border of PT attachment

three groups: normal rotation, externally malrotated, and internally malrotated.

After completing the measurements, inter- and intra-observer reliability was evaluated using the interclass correlation coefficient (ICC) and 95% confidence interval. ICCs of 0.81–1.00, 0.61–0.80, 0.41–0.60, 0.21–0.40, and 0.00–0.20 were interpreted as excellent, good, moderate, fair, and poor, respectively [11]. All measurements showed excellent inter and intra-observer reliability (ICC > 0.900 for all parameters) (Table 2). The average of four measurements was used for the final analysis.

Statistical Analysis

Statistical analysis was performed using SPSS Statistics Base v.23 for Windows. Descriptive statistics were presented with frequency, percentage, mean, and standard deviation. The Kolmogorov–Smirnov test was used in the analysis of the assumption of normality. The Chi-square test was used for the comparison of categorical variables. Either the Mann–Whitney *U* test or Student's *t* test was used to compare continuous variables according to the normality testing. Pearson's correlation analysis was performed to analyze the correlation between variables.

Results

All radiologic measurements of patellar alignment were abnormal in the case group compared to the control group, as expected (Table 3). The deviation between the Akagi Line and sTEA was significantly higher in the case group, resulting in 89.5% external malrotation of the tibial component. However, the tibial component was 96.1% aligned correctly in the control group. Using the Modified Akagi line in the case group significantly improved the rotational alignment, and normal tibial rotation increased to 93% of the case group (Table 4), (Fig. 4). The angle between the Akagi and STEA strongly correlated with the knee rotation TT-TG, nTT-TG. But the TT-PCL and nTT-PCL had a medium correlation (Table 5).

Post hoc power analysis was conducted to avoid type I error and eliminate insufficient sample size using G*Power (Ver. 3.1.9.6, Dusseldorf, Germany). The deviation between the Akagi Line and sTEA was used to calculate effect size since it was the study's primary outcome measure. The power of the study was 100%. (α: 0.05, *n*: 215, effect size d:2.58) [12].

Table 2 Results of inter and intra-observer reliability analysis

Variables	Intra-observer reliability (ICC. 95% CI)		Inter-observer reliability (ICC. 95% CI)	
	Observer A t_1 vs. t_2	Observer B t_1 vs. t_2	Observer A t_1 vs. B t_1	Observer A t_2 vs. B t_2
PTMM distance	0.985 (0.981–0.989)	0.995 (0.994–0.996)	0.994 (0.992–0.995)	0.986 (0.982–0.989)
nTT-TG	0.970 (0.961–0.977)	0.994 (0.992–0.996)	0.986 (0.982–0.989)	0.987 (0.983–0.990)
TT-TG distance	0.972 (0.964–0.979)	0.996 (0.994–0.997)	0.988 (0.984–0.990)	0.989 (0.986–0.992)
nTT-PCL	0.938 (0.919–0.952)	0.992 0.989–0.994)	0.994 (0.992–0.995)	0.932 (0.912–0.948)
TT-PCL distance	0.947 (0.932–0.959)	0.997 (0.995–0.997)	0.996 (0.995–0.997)	0.944 (0.927–0.957)
Knee rotation	0.968 (0.958–0.975)	0.997 (0.996–0.998)	0.994 (0.992–0.995)	0.962 (0.950–0.971)
Akagi line/sTEA angle	0.949 (0.933–0.960)	0.974 (0.966–0.980)	0.925 (0.904–0.942)	0.971 (0.963–0.978)
Modified Akagi line/sTEA angle	0.995 (0.993–0.996)	0.998 (0.998–0.999)	0.994 (0.992–0.995)	0.998 (0.997–0.998)

ICC Interclass correlation coefficient, *CI* Confidence interval, $t_{1:}$ First time, t_2 Second time

Table 3 Comparison of radiologic measurements between groups

Variables	Case group (n: 86)	Control group (*n*: 129)	*p* value
TT-TG (mm ± SD)	21.6 ± 4.1	13.5 ± 3.7	< 0.001[a]
nTT-TG (ratio ± SD)	0.29 ± 0.05	0.18 ± 0.04	< 0.001[a]
TT-PCL (mm ± SD)	25.2 ± 3.4	20.8 ± 3.7	< 0.001[a]
nTT-PCL (ratio ± SD)	0.34 ± 0.03	0.27 ± 0.04	< 0.001[a]
Knee rotation (° ± SD)	7.9 ± 4.7	2.5 ± 4.1	< 0.001[b]

[a] Student's *t* test, [b] Mann–Whitney *U* test

Table 4 Comparison of tibial component rotational mismatch between groups

Variables	Case group (*n*: 86)	Control group (*n*: 129)	*p* value
The deviation between Akagi Line and sTEA (° ± SD)	15.2 ± 4.8	3.5 ± 3.4	< 0.001[a]
Range	6.7–29.0	− 8.6–9.5	
Rotational alignment using Akagi Line			< 0.001[b]
Normal	9 (%10.5)	124 (%96.1)	
Internal rotation	0	5 (%3.9)	
External rotation	77 (%89.5)	0	
The deviation between the modified Akagi Line and sTEA (° ± SD)	3.3 ± 4.4		
Range	− 3.8—18.4		
Rotational alignment using modified Akagi Line			
Normal	80 (%93)		
Internal rotation	2 (%2.3)		
External rotation	4 (%4.7)		

[a] Mann–Whitney *U* test, [b] Chi-square test

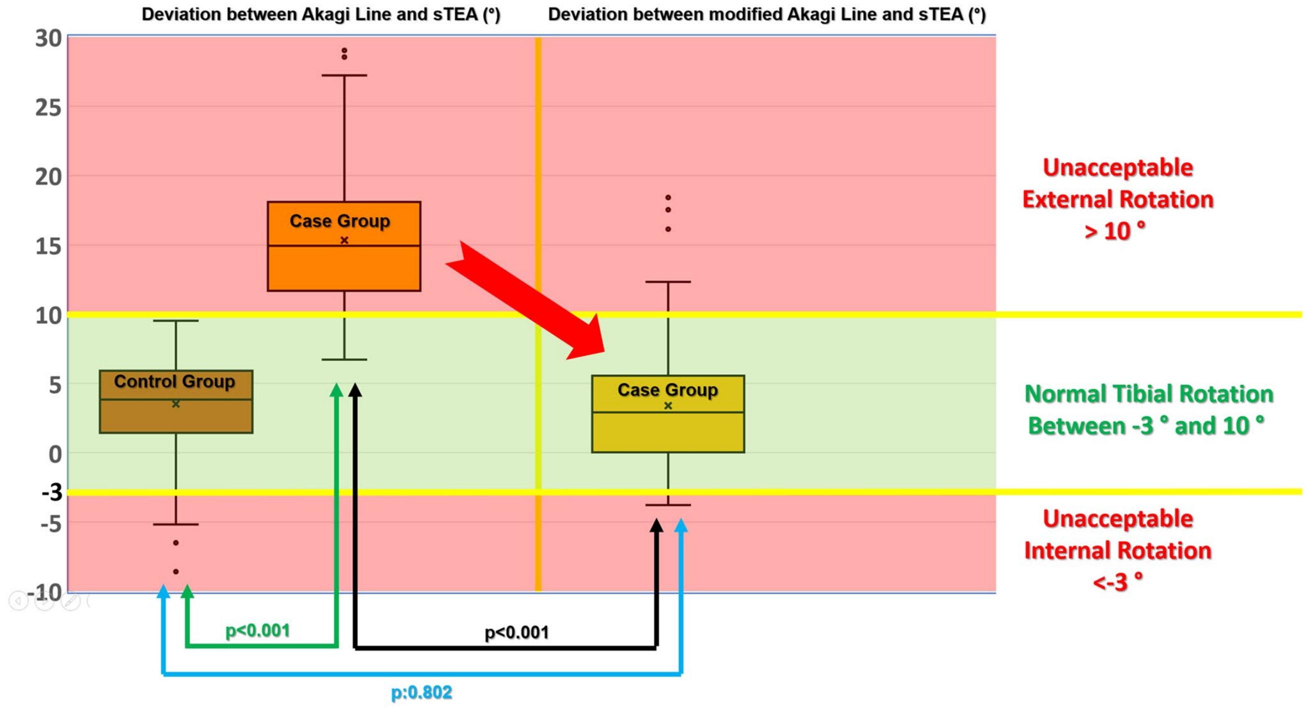

Fig. 4 Boxplot showing the angle between the original Akagi line and sTEA in case and control groups. The use of the modified Akagi line provided significant normal rotational alignment in the case group

Table 5 Correlation between radiological variables

		Deviation between Akagi Line and sTEA	TT-TG	nTT-TG	TT-PCL	nTT-PCL	Knee rotation
Deviation between Akagi Line and sTEA	rho	1	0.715****	0.783**	0.459**	0.589**	0.735**
	p value		0.001	0.001	0.001	0.001	0.001
TT-TG	rho		1	0.967**	0.704**	0.654**	0.579**
	p value			0.001	0.001	0.001	0.001
nTT-TG	rho			1	0.627**	0.693**	0.628**
	p value				0.001	0.001	0.001
TT-PCL	rho				1	.892**	.104
	p value					0.001	0.127
nTT-PCL	rho					1	0.190**
	p value						0.005
Knee Rotation	rho						1
	p value						

rho correlation coefficient

**Correlation is significant at the 0.001 level (2-tailed)

Discussion

The current study was designed to investigate whether the Akagi line is an accurate method for proper rotational positioning of the tibial component in patients with PF malalignment. The use of the Akagi line has resulted in unacceptable external malrotation (> 10°) in almost 90% of the patients in the case group. At the same time, it provided 96.1% correct rotational positioning of the tibial component in the control group. On the other hand, a significant improvement was obtained using the modified Akagi line in the case group. Modified Akagi line might prevent tibial component malrotation in patients with PF malalignment. Deviation of the angle between the Akagi line and sTEA was strongly correlated with increased TT-TG distance and knee rotation.

Numerous methods have previously been described for the correct determination of the tibial component rotation up to date [5, 13–23]. These methods have some advantages and disadvantages, such as difficulties in detecting anatomical guide points, insufficient accuracy, and low repeatability. In a recent systematic review, the Akagi line and anterior tibial border were shown as the most accurate and repeatable methods [24]. In his original study published in 2004, Akagi et al. reported the angle between the Akagi line and sTEA as 0.0° ± 2.8° (range, − 6.3°– + 5.2°) [5]. The exact perpendicular placement of the Akagi line with projected sTEA with a small standard deviation is a significant benefit. However, Akagi conducted this study on 39 healthy volunteers and excluded one patient in whom they detected lateral patellar subluxation. The current study supports these findings. In the healthy control group, the angle between projected sTEA and the Akagi line was 3.5° ± 3.4° (range, − 8.6°–9.5°). However, when the PF alignment is impaired, especially when the TT-TG distance and knee rotation increase, the deviation increases to an average of 15.2 ± 4.8 degrees, and the position of the tibial component results in external rotation with the guidance of the Akagi line.

Increased tibiofemoral rotation is a newly recognized pathology in patients with PF instability. It has been suggested that excessive external knee joint rotation plays a significant role in the pathophysiology of PF instability. Bernholt et al. [25] examined 30 patients with recurrent patellar dislocation, and 30 controls matched for age and gender without patellar instability. In patients with patellar instability, tibial rotation was increased with a mean of 6.9° of external tibial rotation compared to 0.8° of internal tibial rotation in controls, even when TT-PCL was normal. Lin et al. [26] evaluated knee rotation on MRI in 100 patellar instability patients and 40 controls and found a strong positive correlation between knee rotation and TT-TG distance. Similarly, in the current study, knee rotation strongly correlated with TT-TG distance, while it was moderately correlated with TT-PCL distance. Increased external knee rotation and increased TT-TG distance are prevalent pathologies in patellofemoral malalignment, leading to a rotational mismatch between the femur and the tibia. These findings support that anatomic landmarks may be misleading while adjusting the tibial component rotation in this patient group.

There are other studies in the literature that support our findings. Kawaguchi et al. [27] measured tibiofemoral rotation on preoperative CT images of 79 patients who underwent TKA and examined the relationship between postoperative tibial component malrotation and preoperative knee rotation. They showed that postoperative tibial component malrotation is significantly related to preoperative tibiofemoral rotation. They defined abnormal preoperative tibiofemoral rotational alignment as a risk factor for postoperative component rotational mismatch in TKA. Lee et al. [28] suggested that in the case of tibiofemoral rotational mismatch, postoperative mismatching continues when the rotation of the femur and tibia is adjusted separately using the anatomical landmarks. They developed a device (Linker) to prevent this problem. The tibial component rotational adjustment was made according to the femoral component alignment by extending the knee after making the femoral preparation with the help of this device. However, this device is not available in standard knee prosthesis instrument sets. We have proposed a new modified Akagi line, which is 1 cm medial to the medial border of patellar tendon attachment at the tibial tuberosity. Tibial component rotation reached acceptable limits in 93% of patients with TT-TG distance above 15 mm. The preoperative TT-TG distance must be measured and confirmed to be over 15 mm to use this method.

There is only one study in the literature that contradicts our findings. Yike et al. [29] measured TT-TG distance in 133 patients with knee OA and categorized these patients into three groups; TT-TG < 10 mm, 10 mm ≤ TTTG < 15 mm, and TTTG > 15 mm. A comparison of four different rotational measurement methods (Akagi line, the medial third of the tibial tuberosity, the medial third of the patellar tendon, and the medial border of the tibial tuberosity) was made between groups. They reported that the Akagi line was the best indicator in the group with TT-TG of more than 15 mm, and showed an average deviation of 2.5° ± 6.9° with the sTEA projection. However, the Akagi line was erroneously drawn on a single MRI section that passes through the PCL attachment and the medial border of the patellar tendon at the same level of the tibial plateau. But the original Akagi line [5] should be drawn using the medial border of the patellar tendon attachment at the level of the tibial tubercle, which is located inferiorly. Since the patellar tendon follows an oblique course that extends from distal lateral to proximal medial, the medial border of the patellar tendon is displaced medially at the tibial plateau. Therefore, the incorrectly drawn Akagi line correctly aligned the tibial component in patients with a large TT-TG distance. In our study, the modified Akagi line was taken medially, and the tibial component rotation was improved in the case group whose TT-TG distance was above 15 mm. Furthermore, in the original study of Akagi et al. [5], it was shown that the AP axis of the tibia and the patellar tendon varies depending on the cutting level of the tibia, but the medial border of the patellar tendon attachment at the level of tibial tuberosity was constantly accurate.

It is not precisely known how many patients who underwent TKA have a PF malalignment. However, PF osteoarthritis (OA) accompanies tibiofemoral OA in a significant proportion of patients who underwent TKA. Heekin et al.

[30] reviewed 269 TKA patients and reported that the incidence of tricompartmental OA was 59%. PF malalignment, patellar maltracking, and abnormal trochlear morphology have been shown to be the most important risk factors for PF OA [31]. Sanders et al. [32] followed 609 patients with patellar dislocation and reported a 49.5% cumulative incidence of PF OA 25 years after the first patellar dislocation. Furthermore, it has been suggested that PF OA is a precursor for tricompartmental knee OA [33]. In light of these previous findings, it would not be wrong to say that PF malalignment accompanies some of the total knee replacement candidates. Therefore, PF malalignment should always be kept in mind in patients with TKA, especially if PF complaints are dominant. Furthermore, the presence of PF maltracking, advanced PF OA, and abnormal trochlear morphology during the operation should alert the surgeons, and care should be taken when adjusting tibial component rotation.

There are some strengths and limitations of this study. First, this study focused on the Akagi line, and other methods used to adjust tibial component rotation were not evaluated. All patients were Caucasian patients; thus, conclusions may not reflect ethnic morphological differences in different populations. Finally, the lower extremity alignment was not available, which might be another dependent variable for knee joint rotation. There are also strengths of the study. All radiological measurements were performed twice by two observers and were shown to be highly concordant. The selection of patients was carefully made, and clinical and radiological PF malalignment was excluded from the control group. The sample size was sufficient, and the power of the study was calculated as 100%.

Conclusions

In conclusion, this study has shown that the Akagi line might cause unacceptable external rotation of the tibial component in patients with PF malalignment. A thorough radiological evaluation, including a knee CT, should be performed during preoperative planning on these patients. The use of the modified Akagi line described in this study may be a solution for the rotational mismatch between femoral and tibial components. However, further studies are needed to examine the effect of this new method on postoperative tibiofemoral rotation, more importantly, on clinical outcomes.

Authors Contribution Study conception and design: MBE, OK, ET, Acquisition of data: MBE, OK, ET, MMA, Analysis and interpretation of data: OK, AC, ID, MMA, Drafting of the manuscript: MBE, OK, AC, ID, MMA, ET, Critical revision: OK, AC, ET, ID, MMA, MBE (Initials of authors' names).

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Data Availability The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Declarations

Conflict of İnterest Authors have no conflict of interest to declare.

Ethical Approval Institutional Review Board approved the study protocol (Date/Issue: 2021/137).

Informed consent Written informed consent was provided by the participants.

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